OPTIMAL SITING AND SIZING OF DISTRIBUTED GENERATION RESOURCES IN RADIAL DISTRIBUTION SYSTEMS

A DISSERTATION

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Submitted By

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CANDIDATE'S DECLARATION

I, **Varsha Aggarwal**, Roll No. **2K16/PSY/19** student of M. Tech. Electrical Engineering (**Power System**), hereby declare that the dissertation titled "**OPTIMAL SITING AND SIZING OF DISTRIBUTED GENERATION RESOURCES IN RADIAL DISTRIBUTION SYSTEMS**" under the supervision of Prof. Suman Bhowmick, Professor, Department of Electrical Engineering, Delhi Technological University, in partial fulfillment of the requirement for the award of the degree of Master of Technology is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Fellowship or other similar title anywhere.

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CERTIFICATE

I hereby certify that the Project Dissertation titled **"OPTIMAL SITING AND SIZING OF DISTRIBUTED GENERATION RESOURCES IN RADIAL DISTRIBUTION SYSTEMS"** which is submitted by **VARSHA AGGARWAL**, Roll No. **2K16/PSY/19** student of M.Tech (**Power System**) to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

This thesis proposes an approach for the optimal sizing and placement of various types of Distributed Generation (DG) resources with the objective of minimizing the active power losses and improving the voltage profile improvement. Load flow studies have been carried out using BIBC and BCBV matrices. Teaching Learning Based Optimization (TLBO) and Artificial Bee Colony (ABC) algorithms have been implemented for optimal allocation of Type-1,Type-2 and Type-3 DG.

To check the effectiveness, these two algorithms have been tested on the IEEE-33 bus, 69 bus and 119 bus radial distribution systems and compared with different existing techniques like Bacterial Foraging Optimization (BFO) and particle swarm optimization (PSO) algorithms. 24-hour load variation has been considered for some cases. The simulation results show that maximum reduction of losses take place when Type-3 DGs are used.

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LIST OF ABBREVIATIONS

DG	Distributed Generation
FACTS	Flexible Alternating Current Transmission Systems
STATCOM	Static Synchronous Compensator
SVC	Static VAR Compensator
TCR	Thyristor Controlled Reactor
UPFC	Unified Power Flow Controller
TCSC	Thyristor Controlled Series Capacitor
RDS	Radial Distribution Systems
GA	Genetic Algorithm
TLBO	Teaching Learning Based Optimization
ABC	Artificial Bee Colony
PSO	Particle Swarm Optimization
DSTATCOM	Distribution Static Compensator
BIBC	Bus Injection to Branch Current
BCBV	Branch-Current to Bus-Voltage

CHAPTER-1

INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

The main objective of power systems is to supply reliable and economical electric power to the consumers. But generally, the generating stations are situated far away from the loads. In the process of supplying electric power to these widely spread users, a power system experiences a huge amount of transmission losses and costs. About 13% of the total generated power is wasted as real power losses [1]. Real power losses are higher in the distribution systems as compared to the transmission systems as the R/X ratio is higher in distribution systems [2]. These losses have a considerable effect on the overall performance of the power system. For reducing the losses, the following methods can be adopted-:

- DG placement
- Reactive power compensation
- Feeder reconfiguration
- High voltage distribution system

1.1.1 Distributed Generation

DG stands for distributed generation or dispersed generation which involves renewable and non-renewable sources of energy scattered throughout the power system or energy sources that are being installed near the load centers [3]. They are either used for fulfilling load requirements or to minimize losses and their size may vary from few KW to about 10 MW. Installation of DGs may offer a helpful alternative to a traditional system for different applications. It provides cleaner energy with more efficiency. Integration of DGs in the distribution system adds several operational complexities like power quality issues, voltage fluctuations, protection co-ordinations etc[4].

1.1.2 Types of DGs

On the basis of the type of energy supplied DGs can be classified into four types:-

Type 1 This type of DG delivers active power only e.g. photovoltaic arrays, fuel cells etc. They are integrated into the system with the help of converters.

Type 2 This type of DG delivers reactive power only e.g. capacitors, SVCs, STATCOMs.

Type 3 This type of DG delivers both active and reactive power e.g. synchronous generators.

Type 4 This type of DG delivers active power but consumes reactive power e.g. induction generators.

1.1.3 Benefits of DG integration in distribution systems

- Power Loss Minimization

The reduction in active power losses remains a major concern for the utility because it reflects the efficiency of the system. This can be achieved with the help of DGs. The DG units are generally installed near the load points. This reduces real power losses.

- Improvement In Voltage Profile

As the system operator is required to maintain the system voltage profile within a specified range, by injecting active and reactive power into the system this can be improved. Voltage profile gets significantly affected by number and size of DGs.

- Environmental benefits

Most of the conventional energy generation methods release greenhouse gases like sulphur dioxide, carbon dioxide and nitrogen oxide. By increasing the use of renewable energy based DGs, this emission can be reduced.

The main reason for the escalating uses of DGs can be summarized as given below [5]-:

1. DG units are generally installed near loads. This reduces transmission and distribution losses and operational costs.
2. It is easier to find locations for installation of generators of small ratings as compared to those with larger ratings.
3. Due to a reduction in transmission and distribution losses, efficiency is improved.
4. Setting up time for DG is very small.

5. It offers various other benefits like improving voltage fluctuations, improving power quality etc.
6. It presents a flexible combination of various resources (like solar power) that are available locally.
7. DG technology is more environment-friendly as compared to the traditional system.

To improve system performance, FACTS devices are also installed along with DGs supplying active power. This is because node voltage decreases if the load is at a distant location from the supply point. So, to maintain this voltage, sufficient reactive power is needed. For this reactive compensation is required [6]. Some FACTS devices that are used for this purpose are STATCOM,SVC,TCR,UPFC etc. These FACTS devices have the ability to increase the reliability of the system. Some of its advantages are lower harmonic distortion, better voltage profile, immune to resonance etc. However, these should be placed optimally or else instead of improving the performance, they may deteriorate it. A lot of research work is going on for siting and sizing of these devices.

1.2 OBJECTIVE OF THE WORK

The main focus of the work is to find out suitable size and location of the DGs for different types. This work has been carried out using two techniques. The first technique is using TLBO and the second is the ABC based optimization. The analysis is done on multi-type DGs i.e. for Type-1, Type-2 and Type-3 DGs. Optimal allocation of all three types of DGs is tested on three different radial distribution systems– the IEEE 33-bus, 69-bus, and 118 bus systems. 24-hour load variation has also been considered for some cases.

1.3 LITERATURE REVIEW

1.3.1 Load flow Technique

Load flow analysis is a study of the flow of power in a system. It is an important area to be focussed as it provides an absolute link between the distribution system and consumers. Load flow analysis is different for distribution systems as compared to transmission systems. Various researchers have proposed several methods for this.

In [7], Newton-based power flow method was proposed but this method requires large memory requirement. In [8], a fast decoupled load flow method was proposed for unbalanced radial distribution networks. This method takes less memory as compared to Newton's method but its convergence is slow for distribution systems. In [9], a modification over fast decoupled load flow method was proposed. In [10], a compensation based power flow solution was developed for radial and weakly meshed networks. This method proved to be more efficient and robust as compared to Newton Raphson method. But this method takes more computational time as compared to the Newton's and the Fast Decoupled methods.

In [11], a new method for load flow was reported that uses the topological structure of the system. Since this method does not involve matrix inversion, it takes very less computational time as compared to other methods. This method is also free from initial assumptions so there is no chance of divergence that may happen with the Newton Raphson algorithm if initial assumptions are wrong. This method is valid for radial distribution networks as well as weakly meshed networks.

1.3.2 DG placement

Various researchers have implemented different algorithms for optimal placement of DGs. Both analytical and heuristic methods have been used for this. In [12], an analytical method was developed for optimal siting and sizing of DGs for a different type of static load but there was no information of the load profile. In [13], another analytical method was proposed for finding out the optimal sites and size of DGs in both radial and meshed type networks involving the use of admittance matrix due to which it takes more computational time. In [14], an analytical method using the theory of loss sensitivity factor based on equivalent current injection was developed that proved to be a more robust technique. This method works without computing the admittance matrix and provided the comparable result to classical grid search algorithms in less time.

Several techniques other than analytical ones have been suggested for optimal placement of DGs. In [15], genetic algorithm was implemented for optimal siting and sizing of DGs in RDS for active power loss reduction by placing DGs strategically. This algorithm was tested on the IEEE 33-bus system. In [16], a new method named Hereford Ranch Algorithm was developed for further improvement in GA by means of selective breeding in choosing parents for the genetic string. This improved the convergence time and prevented premature convergence. In [17], PSO based planning of distributed generation was done for which a multi-objective function was formulated for power loss minimization for curtailing the cost of power loss and improving the annual energy savings. The concept of 'weight factors' was used for obtaining the best proportion of this cost. In [18], Cuckoo algorithm was implemented for voltage profile improvement and reduction in power losses. The main criterion used was voltage indices to minimize deviations in voltage from the target value. In [19], a new meta-heuristic technique named ABC algorithm was implemented in radial distribution systems for determining the DG size, power factor and location of DG in order to minimize the power losses. In [20], TLBO based method was implemented for finding the optimal site, size and number of DGs in order to minimize power losses and improve the voltage profile. The results were compared with three techniques - GA, PSO and Cuckoo Search Algorithm and proved to be more effective in terms of percentage power loss reduction. In [21], a hybrid method of Fuzzy and ABC algorithm was proposed for the placement of DGs with the objective of minimizing power losses and operational costs. This method was also used to find out the suitable number, size and location of DGs, keeping voltage deviation as constraints.

In [22], Tabu Search algorithm was implemented for optimal siting and sizing of shunt capacitors in RDS to minimize investment cost and energy losses. In this approach, sensitivity analysis concept has been used to select those nodes which have maximum impact on the real power losses. In [23], Genetic Algorithm (GA) based optimal sitting and sizing of capacitors has been suggested considering the additional constraint of harmonic distortion, when nonlinear loads are present in the network. Particle swarm optimization (PSO) has been used in [24] for the placement of capacitors considering harmonic distortion limits with varying load. In [25], modified artificial bee colony

(MABC) algorithm has been used for the placement of capacitors for maximum cost savings and loss minimization.

Advancement in power-electronics has paved the way for many FACTS devices as controllable reactive power sources. These static devices provide better transient stability, small signal stability, power loss reduction and voltage profile than a conventional capacitor.

In [26], PSO was implemented for the optimal placement of STATCOM in RDS. The results were validated on a 45-bus system considering voltage deviation constraint at each bus. In [27], DSTATCOM was allocated using Bat Algorithm (BA) on the basis of voltage stability index (VSI). In [28], Index vector method has been used for the optimal allocation of DSTATCOM for several load models and load growth.

In [29], Bacterial Foraging Algorithm (BFA) has been implemented for evaluating suitable locations and sizes of multiple DGs and DSTATCOMs taking Loss Sensitivity Factor as a predetermining factor. In [30], SVC along with DG has been implemented using differential search algorithm. In this study, two penetration levels for DG have been considered and cost analysis has been done along with power loss reduction and voltage profile improvement.

CHAPTER-2

PROBLEM FORMULATION

2.1 OBJECTIVE FUNCTION

The problem is to find out suitable size and site for DGs so that active power losses can be minimized subject to inequality constraints. So our main objective function is power loss minimizaton. The proposed method uses bus injection to branch current (BIBC) matrix and branch-current to bus-voltage (BCBV) matrix for load flow. These matrices are developed on the basis of the topological structure of the distribution system [31]. The development of these matrices is explained in chapter 3.

2.1.1 Active power loss reduction

For real power loss calculation, the current injected at each node is computed which is specified by given equation 2.1

$$\mathbf{I_i} = ((P_i + jQ_i)^* / \ \boldsymbol{V_i}^*) \tag{2.1}$$

where i varies from 1 to n, n is the no. of buses, $\mathbf{I_i}$ is the corresponding current injection, P_i and Q_i are the corresponding real and reactive powers injected at each node and $\mathbf{V_i}$ is the node voltage. Our main objective is to curtail active power losses represented by equation 2.2.

$$\text{Objective Function} \quad = \min(P_{loss}) \tag{2.2}$$

$$P_{loss} = \sum_{i,j=1}^{n} {I_i}^2 * r_j \tag{2.3}$$

In this equation 'i', 'j' and 'n' represents bus number , branch number and total number of buses.

2.1.2 Constraints

- Voltage constraints

The voltage magnitude at each node should be in the specified range

$$V_{min} \leq V_i \leq V_{max}$$

Where V_{max} and V_{min} are the maximum and minimum value of node voltage magnitude in p.u. i.e. 1.05 p.u. and 0.9 p.u respectively.

- ACTIVE AND REACTIVE POWER SOURCE CAPACITY LIMITS

The active and reactive powers injected by the sources to be installed must be within their specified rating limits i.e.

$$P_{min} \leq P_i \leq P_{max}$$

$$Q_{min} \leq Q_i \leq Q_{max}$$

Where P_{max} and P_{min} are the maximum and minimum values of active power source ratings i.e. 3 MW (5 MW for 119 bus system) and zero respectively. Similarly, Q_{max} and Q_{min} are the maximum and minimum values of reactive power source ratings i.e. 3MVAr (5 MVAr for 119 bus system) and zero respectively.

CHAPTER-3

LOAD FLOW STUDIES

3.1 LOAD FLOW TECHNIQUE

Load flow analysis is basically an study of the flow of active and reactive powers in a power system. Its solution presents knowledge about the voltage profile, phase angles, active and reactive power flows. Conventional methods used for load flow are Gauss Siedel, Newton-Raphson and fast-decoupled method etc[31]. But these methods are not suitable for distribution systems due to various reasons like large number of branches and nodes, radial and weakly meshed networks, extensive ranges of resistance and reactance values. For these methods, it would require a matrix of large dimension (according to the number of buses and branches), a long computational time and more memory requirements. To eradicate all these drawbacks a novel method has been developed based on the topology of distribution system[11]. The only input of this method is the bus-branch related data. By using this data, two matrices named bus injection to branch current (BIBC) and branch current to bus voltage (BCBV) are developed. The development of these matrices is explained later.

This load flow technique is mainly based on these two matrices BIBC and BCBV. For explaining its development a sample of the radial distribution network is shown in fig 3.1.

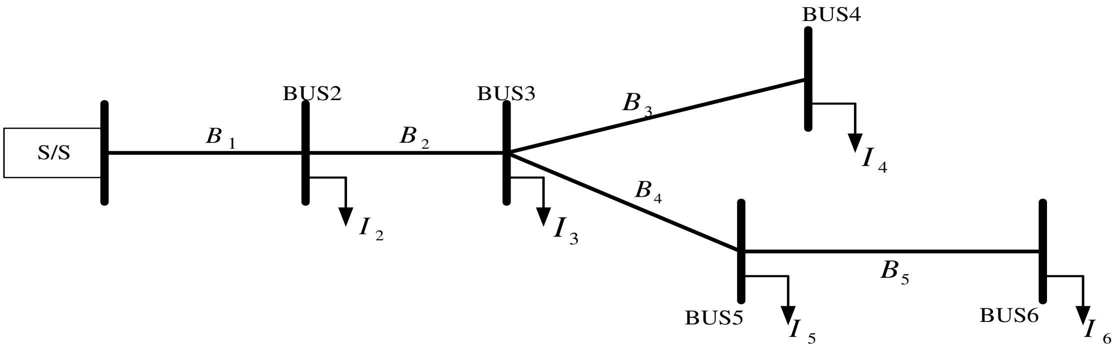

Fig. 3.1 A typical distribution network

The power injections at every bus can be converted into respective current injections which is represented in equation 3.1 and by using Kirchhoff's Current Law at each node branch current can be obtained which is shown in equations 3.2 to 3.6.

$$\mathrm{I_i} = ((\boldsymbol{P_i} + \boldsymbol{jQ_i})/\ \boldsymbol{V_i})^* \tag{3.1}$$

$$\boldsymbol{B_1} = \boldsymbol{I_2} + \boldsymbol{I_3} + \boldsymbol{I_4} + \boldsymbol{I_5} + \boldsymbol{I_6} \tag{3.2}$$

$$\boldsymbol{B_2} = \boldsymbol{I_3} + \boldsymbol{I_4} + \boldsymbol{I_5} + \boldsymbol{I_6} \tag{3.3}$$

$$\boldsymbol{B_3} = \boldsymbol{I_4} \tag{3.4}$$

$$\boldsymbol{B_4} = \boldsymbol{I_5} + \boldsymbol{I_6} \tag{3.5}$$

$$\boldsymbol{B_5} = \boldsymbol{I_6} \tag{3.6}$$

From equations 3.2 to 3.6, the relation between bus current injection and branch current can be represented in matrix form which is given by equation 3.7.

$$\begin{bmatrix} \boldsymbol{B_1} \\ \boldsymbol{B_2} \\ \boldsymbol{B_3} \\ \boldsymbol{B_4} \\ \boldsymbol{B_5} \end{bmatrix} = \begin{bmatrix} \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} \\ \mathbf{0} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} & \mathbf{1} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{1} \end{bmatrix} \begin{bmatrix} \boldsymbol{I_2} \\ \boldsymbol{I_3} \\ \boldsymbol{I_4} \\ \boldsymbol{I_5} \\ \boldsymbol{I_6} \end{bmatrix} \tag{3.7}$$

Equation 3.7 in generalised form can be represented by equation **3.8.**

$$[\boldsymbol{B}] = [\boldsymbol{BIBC}][\boldsymbol{I}] \tag{3.8}$$

The relationships between branch currents and bus voltages can be characterized by using KVL and is represented in equation 3.9-3.13.

$$\boldsymbol{V_2} = \boldsymbol{V_1} - \boldsymbol{B_1 Z_{12}} \tag{3.9}$$

$$\boldsymbol{V_3} = \boldsymbol{V_2} - \boldsymbol{B_2 Z_{23}} \tag{3.10}$$

$$\boldsymbol{V_4} = \boldsymbol{V_3} - \boldsymbol{B_3 Z_{34}} \tag{3.11}$$

$$\boldsymbol{V_5} = \boldsymbol{V_3} - \boldsymbol{B_4 Z_{35}} \tag{3.12}$$

$$\boldsymbol{V_6} = \boldsymbol{V_5} - \boldsymbol{B_5 Z_{56}} \tag{3.13}$$

From equations 3.9, 3.10 and 3.11 we can write $\mathbf{V_4}$ as per equation 3.14

$$\boldsymbol{V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34}} \tag{3.14}$$

$$\boldsymbol{V_5 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_4 Z_{35}} \tag{3.15}$$

$$\boldsymbol{V_6 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_4 Z_{35} - B_5 Z_{56}} \tag{3.16}$$

$$\begin{bmatrix} \boldsymbol{V_1} \\ \boldsymbol{V_1} \\ \boldsymbol{V_1} \\ \boldsymbol{V_1} \\ \boldsymbol{V_1} \end{bmatrix} - \begin{bmatrix} \boldsymbol{V_2} \\ \boldsymbol{V_3} \\ \boldsymbol{V_4} \\ \boldsymbol{V_5} \\ \boldsymbol{V_6} \end{bmatrix} = \begin{bmatrix} \boldsymbol{Z_{12}} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \boldsymbol{Z_{12}} & \boldsymbol{Z_{23}} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \boldsymbol{Z_{12}} & \boldsymbol{Z_{23}} & \boldsymbol{Z_{34}} & \mathbf{0} & \mathbf{0} \\ \boldsymbol{Z_{12}} & \boldsymbol{Z_{23}} & \mathbf{0} & \boldsymbol{Z_{35}} & \mathbf{0} \\ \boldsymbol{Z_{12}} & \boldsymbol{Z_{23}} & \mathbf{0} & \boldsymbol{Z_{35}} & \boldsymbol{Z_{36}} \end{bmatrix} \begin{bmatrix} \boldsymbol{B_1} \\ \boldsymbol{B_2} \\ \boldsymbol{B_3} \\ \boldsymbol{B_4} \\ \boldsymbol{B_5} \end{bmatrix} \tag{3.17}$$

Equation 3.17 in generalized form can be represented as

$$[\Delta \boldsymbol{V}] = [\boldsymbol{BCBV}][\boldsymbol{B}] \tag{3.18}$$

From 3.8,

$$[\Delta \boldsymbol{V}] = [\boldsymbol{BCBV}][\boldsymbol{BIBC}][\boldsymbol{I}] \tag{3.19}$$

$$[\boldsymbol{DLF}] = [\boldsymbol{BCBV}][\boldsymbol{BIBC}] \tag{3.20}$$

$$[\Delta \boldsymbol{V}] = [\boldsymbol{DLF}][\boldsymbol{I}] \tag{3.21}$$

The solution of load flow can be obtained by solving equations (3.22),(3.23) and (3.24) iteratively.

$$\boldsymbol{I_i^k} = \left((\mathbf{P_i} + \mathbf{jQ_i})/\ \mathbf{V_i^k}\right)^* \tag{3.22}$$

$$\left[\Delta \boldsymbol{V^{k+1}}\right] = [\boldsymbol{DLF}]\left[\boldsymbol{I^k}\right] \tag{3.23}$$

$$\left[\mathbf{V^{k+1}}\right] = [\mathbf{V^0}] + \left[\Delta \mathbf{V^{k+1}}\right] \tag{3.24}$$

3.2 MATRIX DEVELOPMENT ALGORITHM

3.2.1 BIBC Matrix Development

1. For BIBC matrix, a null matrix of size m×n is initialized, where m is the number of branches and n is number of buses. The bus-branch data is read.

2. If a branch (B_z) is connected between bus x and bus y then the data of the x^{th} bus column is copied to the y^{th} bus column in the BIBC matrix and +1 is placed in the z^{th} row and y^{th} column.
3. The same procedure for each branch section is repeated.
4. A matrix of row from 1 to m and column from 2 to n is selected. This gives the BIBC matrix of size m×(n-1).

3.2.2 BCBV Matrix Development

1. For BCBV matrix, a null matrix of size n×m is initialized, where m is the number of branches and n is number of the buses. Bus-branch data is read.
2. If a branch (B_z)is connected between bus x and bus y then the data of the x^{th} bus row is copied to the y^{th} bus row in the BIBC matrix and Z_{xy} is placed in the y^{th} row and z^{th} column.
3. The same procedure is repeated for each branch section.
4. A matrix of column from 1 to m and row from 2 to n is selected. This will give BCBV matrix of size (n-1)×m.

3.2.3 Steps of the algorithm

1. Read bus-branch data.
2. Develop BIBC matrix.
3. Develop BCBV matrix.
4. Calculate DLF matrix as per equation 3.20.
5. Find out ΔV as per equation 3.21.
6. Initialize k=1.
7. Update voltages by using equations 3.22, 3.23 and 3.24.
8. Set k=k+1.
9. If $|V^{k+1}| - |V^k| > 10^{-6}$ go to step 7 otherwise go to step 10.
10. Find other parameters like branch currents, active power losses and reactive power losses.

3.3 TEST RESULTS

The following method has been analyzed on the different bus system. The result has been summarized in table 3.1

TABLE 3.1: Load Flow Results of Different RDS

Bus-System	Active Power Loss (kW)	Min voltage (p.u.)
33 Bus-System	202.677	0.91309
69 Bus-system	224.995	0.90918
119 Bus-System	1298.092	0.86889

CHAPTER-4

OPTIMAL SITING AND SIZING OF DG USING TLBO

4.1 INTRODUCTION

TLBO optimization technique is based on the concept of the teaching and learning process. This technique was proposed by V. Rao in 2011. This algorithm reflects the effect of the teacher on the learner's output (knowledge). In this algorithm, a group of students is treated as the population and different subjects are treated as different variables [32]. The fitness value of the objective function is considered as the knowledge of the student. As the teacher is symbolized as most knowledgeable and most experienced person, that's why the best solution is taken as the teacher. The students learn from two ways. The first is through the teacher which is known as 'Teacher Phase' and the second is via interaction between different learners which is known as 'Learner Phase'.

4.2 STEPS OF THE ALGORITHM

The steps of the given algorithm can be explained as follows -:

4.2.1. Initialization Phase

Randomly generate initial population by using equation 4.1.

$$\mathrm{X0} = \mathrm{X_{LOW}} + (\mathrm{X_{UP}} - \mathrm{X_{LOW}}) * \mathrm{rand(NUMPOP, D)} \quad (4.1)$$

where X_{LOW} and X_{UP} are the minimum and maximum value of the variable used, NUMPOP is population size (number of students) and D is number of design variables(subjects).

Calculate the value of the fitness function by using the fitness function evaluation equation specific for a defined problem.

4.2.2 Teacher Phase

The best solution of the randomly initialized matrix is treated as the teacher and the mean of the learner's knowledge is shifted towards the teacher to improve their knowledge (outcome). The equation representing the teacher phase is given by equation 4.2.

$$X_{new}(i) = X0(i) + rand \times (X_{teacher} - TF * Mean) \quad (4.2)$$

where the Mean vector is the mean of the learners in the class for each variable (subject) which is computed during every iteration. $X_{teacher}$ is the best solution obtained so far and TF is the teaching factor which affects the shifting of the learner's result towards the teacher outcome or best solution. Its value is either 1 or 2 which is decided randomly in the algorithm and is given by equation 4.3.

$$TF = round(1 + rand) \tag{4.3}$$

After this, the fitness value of each X_{new} vector is calculated and compared correspondingly with the outcome of vector X0. If the result of the new vector (X_{new}) is better than the previous vector (X0), then X0 is updated**.**

4.2.3 Learner Phase

In this phase, the learners learn via each other. In the learner phase, different learners interact randomly with each other and improve their knowledge. For a given learner (i) a second learner (h) is selected randomly out of the given population or number of students such that i≠h and then the vector X_{new} is modified by using the equations.

$$X_{new}(i) = X0(i) + rand * \left(X0(i) - X0(h)\right) \tag{4.4}$$

The above equation is valid if the fitness of vector X0(i) is better than X0(h) otherwise learner follows equation 4.5.

$$X_{new}(i) = X0(i) + rand * \left(X0(h) - X0(i)\right) \tag{4.5}$$

4.2.4 Termination Phase

After termination criterion (maximum no. of iteration), the algorithm stops executing and presents the best solution.

The described algorithm has been applied on the problem described in chapter 2 and the results are summarized below.

4.2.5 Parameters Used

Population size	:	200
Maximum No. of Iterations	:	500
TF	:	[1,2]

4.3 Flow Chart of TLBO

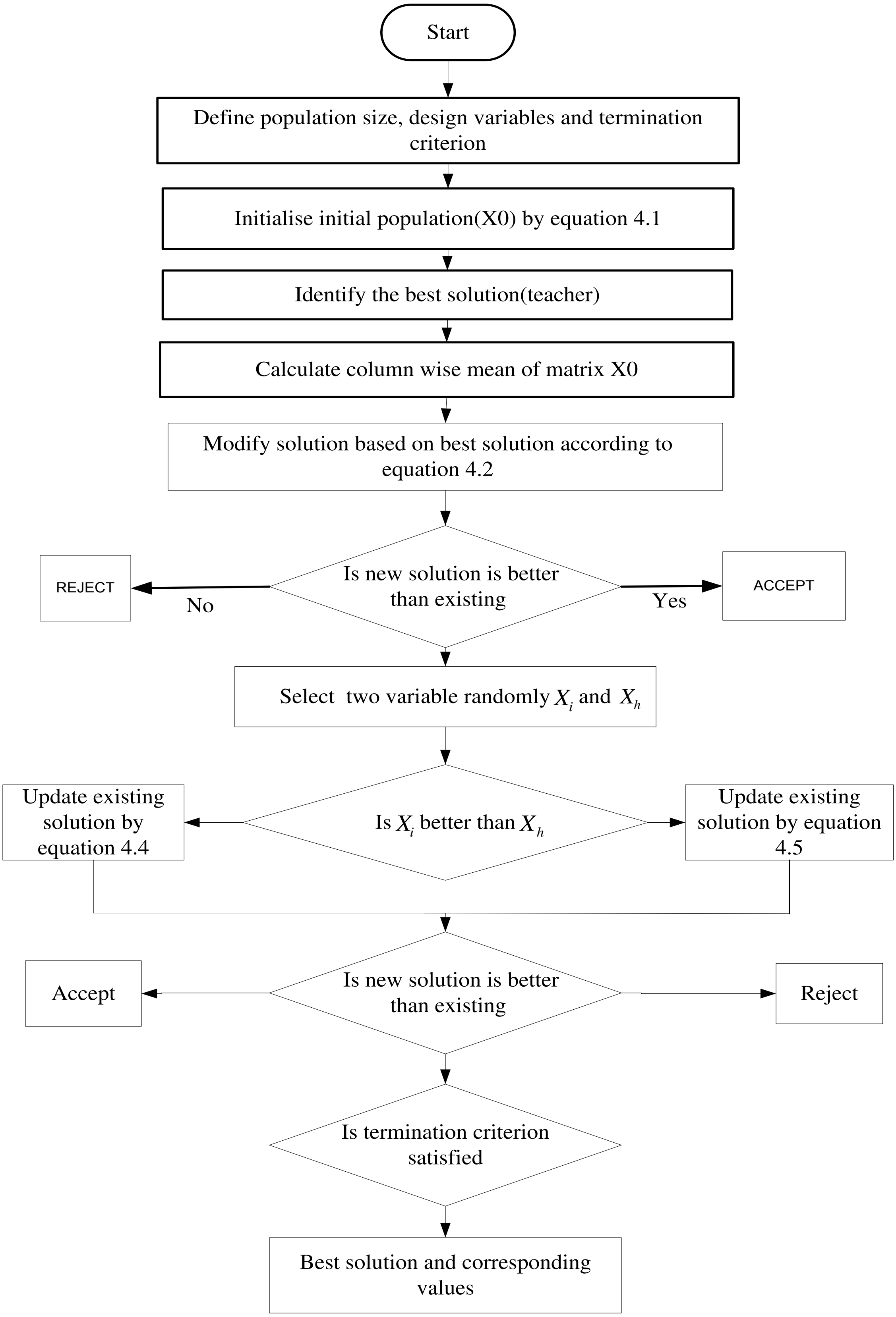

Fig. 4.1 Flow chart of TLBO method

4.4 OPTIMAL LOCATION FOR 33 BUS RADIAL DISTRIBUTION SYSTEM

IEEE 33 RDS is shown in figure [29]. It comprises of 33 buses and 32 branches. Out of the 33 buses, the first bus is the slack bus and rest 32 buses are available for installing different types of DGs. The data for this system has been taken from [33]. Selected base values are 12.66 kV and 100 MVA.

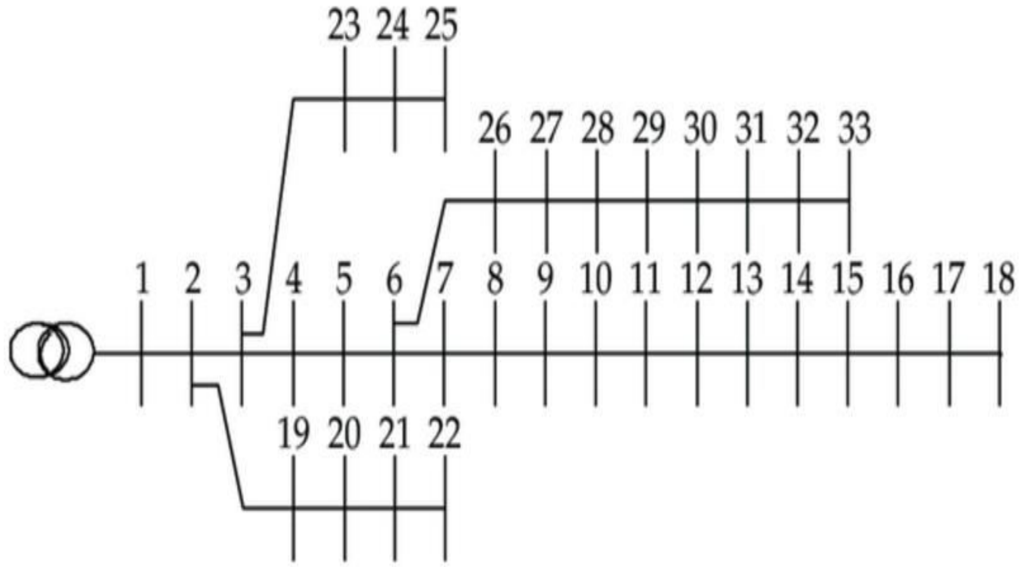

Fig. 4.2. Schematic diagram of 33 bus RDS [29]

Performance of 33 bus system without any DG (base case)

Active power load	:	3715 kW
Reactive power load	:	2300 kVAr
Total real power loss	:	202.677 kW
Minimum voltage	:	0.9131 p.u

4.4.1 Placement of Type-1 DGs in 33 bus RDS

TABLE 4.1: Allocation of Type-1 DG in 33 bus RDS by TLBO algorithm

No. of DG	Active Power Loss (kW)	Power Loss Reduction (%)	Location (Bus no)	Size (MW)
0	202.677	-	-	-
1	103.966	48.70%	6	2.575
2	85.910	57.61%	13 30	0.846 1.158
3	71.457	64.74%	14 24 30	0.753 1.099 1.071
4	65.935	67.47%	7 14 24 31	0.9162 0.585 0.980 0.708
5	64.885	67.99%	7 14 21 24 31	0.908 0.585 0.277 0.970 0.708

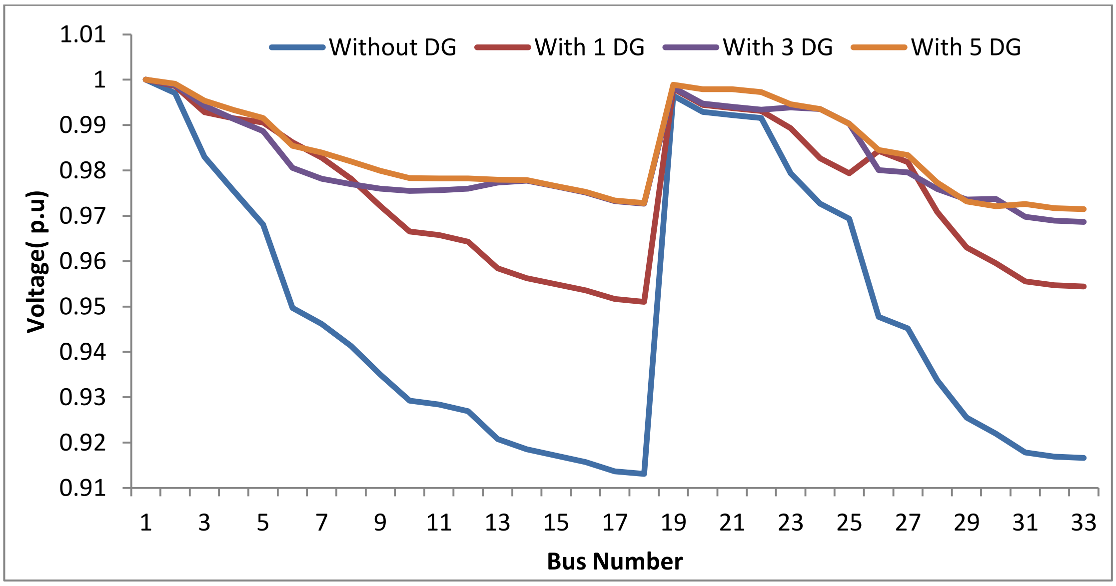

Fig. 4.3. Voltage profile with and without placing Type-1 DGs in 33 bus RDS by using TLBO algorithm

4.4.2 Placement of Type-2 DGs (DSTATCOM) in 33 bus RDS

TABLE 4.2: Allocation of Type-2 DG in 33 bus RDS by TLBO algorithm

No. of DSTATCOM	Active Power Loss (kW)	Power Loss Reduction (%)	Location (bus no.)	Size (MVAr)
0	202.677	-	-	-
1	143.602	29.15	30	1.253
2	135.753	33.02	12 30	0.469 1.058
3	132.173	34.78	13 24 30	0.379 0.544 1.037
4	130.688	35.51	7 14 24 30	0.442 0.276 0.483 0.904
5	130.315	35.70	7 14 24 30 32	0.442 0.276 0.483 0.709 0.194

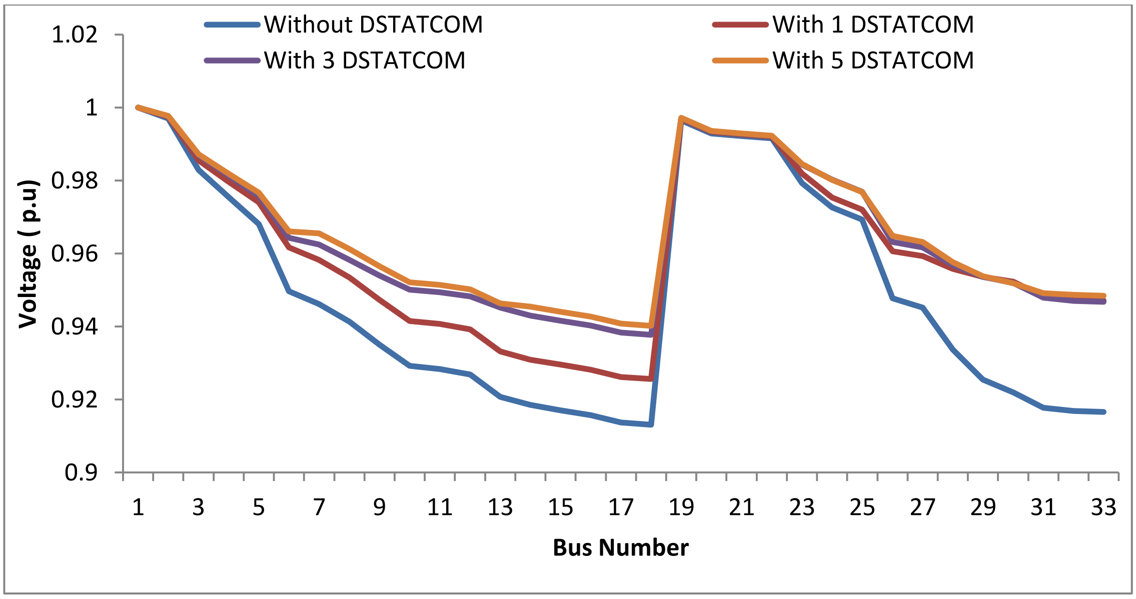

Fig. 4.4. Voltage profile with and without placing Type-2 DG in 33 bus RDS by using TLBO algorithm

4.4.3 Placement of Type-3 DGs in 33 bus RDS

TABLE 4.3: Allocation of Type-3 DG in 33 bus RDS by TLBO algorithm

No. of DG	Real Power Loss (kW)	Power Loss Reduction (%)	DG size (MW)	DG size (MVAr)	Location (Bus No.)
0	202.677	-	-	-	-
1	61.363	69.72	2.545	1.750	6
2	28.492	85.94	0.839 1.140	0.396 1.066	13 30
3	11.630	94.26	0.747 1.078 1.048	0.350 0.521 1.021	14 24 30
4	6.427	96.83	0.788 0.586 0.964 0.788	0.377 0.272 0.467 0.896	7 14 24 30
5	5.078	97.49	0.831 0.586 0.782 0.404 0.383	0.398 0.272 0.378 0.701 0.193	7 14 25 30 32

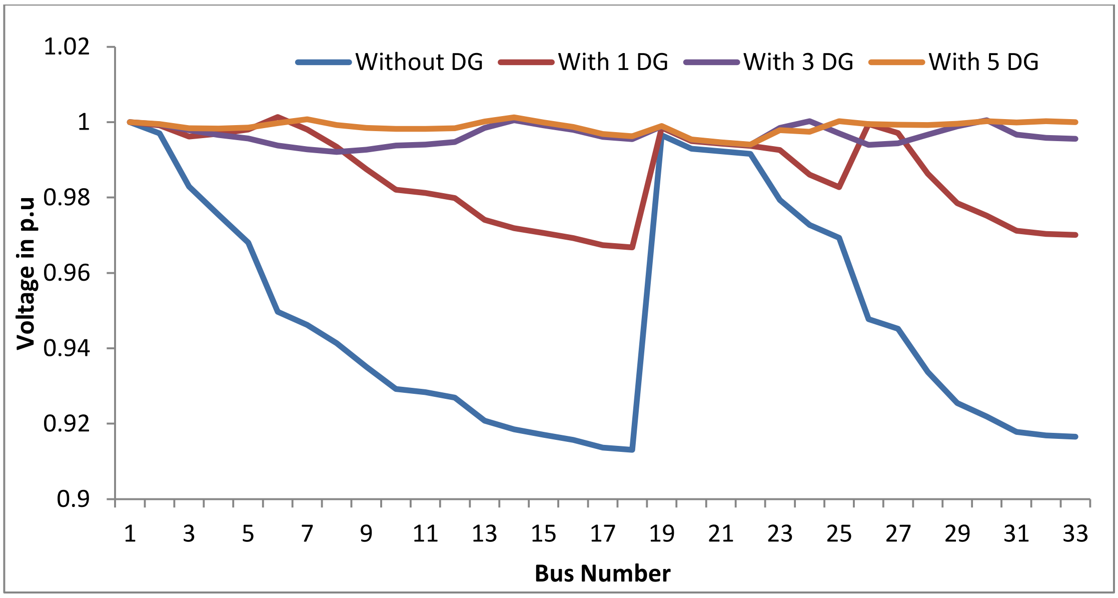

Fig. 4.5. Voltage profile with and without placing Type-3 DG in 33 bus RDS by using TLBO algorithm

4.5 OPTIMAL LOCATION FOR 69 BUS RADIAL DISTRIBUTION SYSTEM

IEEE 69 radial bus distribution system shown in figure [34]. It comprises of 69 buses and 68 branches. Out of the 69 buses, the first bus is the slack bus and rest 68 buses are available for installing different types of DGs. The data for this system has been taken from [35]. Selected base value are 12.66 kV and 100 MVA.

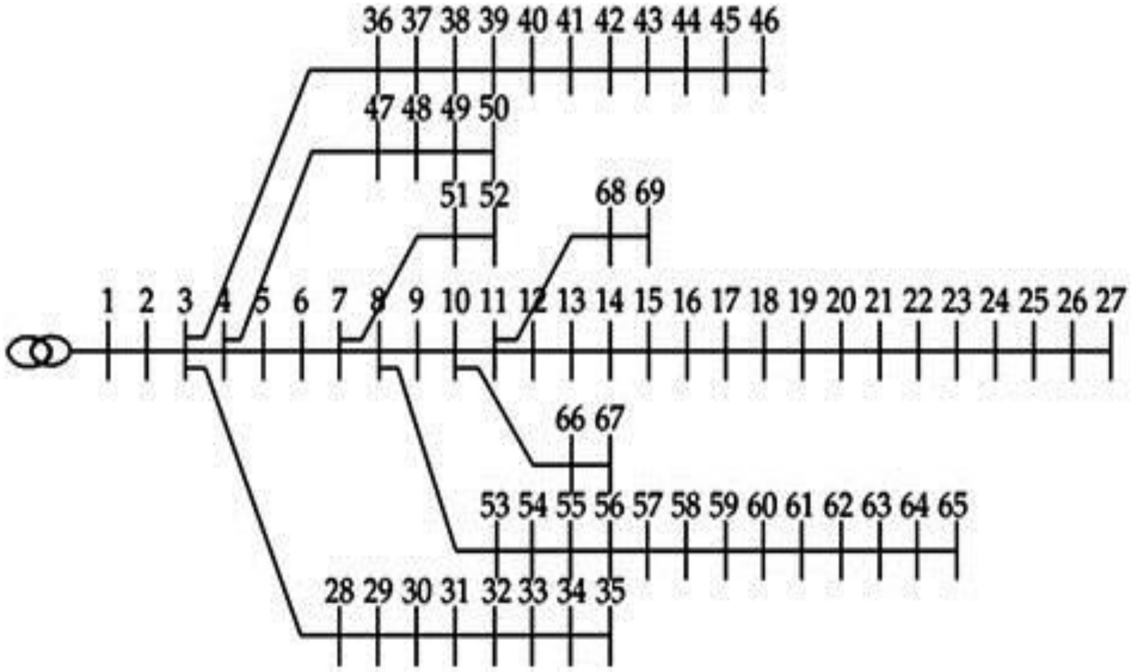

Fig.4.6. The schematic diagram of 69 radial bus distribution system

Performance of 69 bus system without placing DG

Active power load	:	3802.19 kW
Reactive power load	:	2694.6 kVAr
Total real power loss	:	224.995 kW
Minimum voltage	:	0.90919 p.u

4.5.1 Placement of Type-1 DG in 69 bus RDS

TABLE 4.4: Allocation of Type-1 DG in 69 bus RDS by TLBO algorithm

No. Of DG	Active Power Loss (kW)	Power Loss Reduction (%)	Location (bus no.)	Size (MW)
0	224.995	-	-	-
1	83.223	63.011	61	1.873
2	71.675	68.144	17 61	0.531 1.781
3	69.427	69.143	11 18 61	0.527 0.380 1.719
4	67.917	69.814	11 18 50 61	0.526 0.380 0.718 1.719
5	67.373	70.056	11 18 50 61 64	0.526 0.380 0.718 1.428 0.289

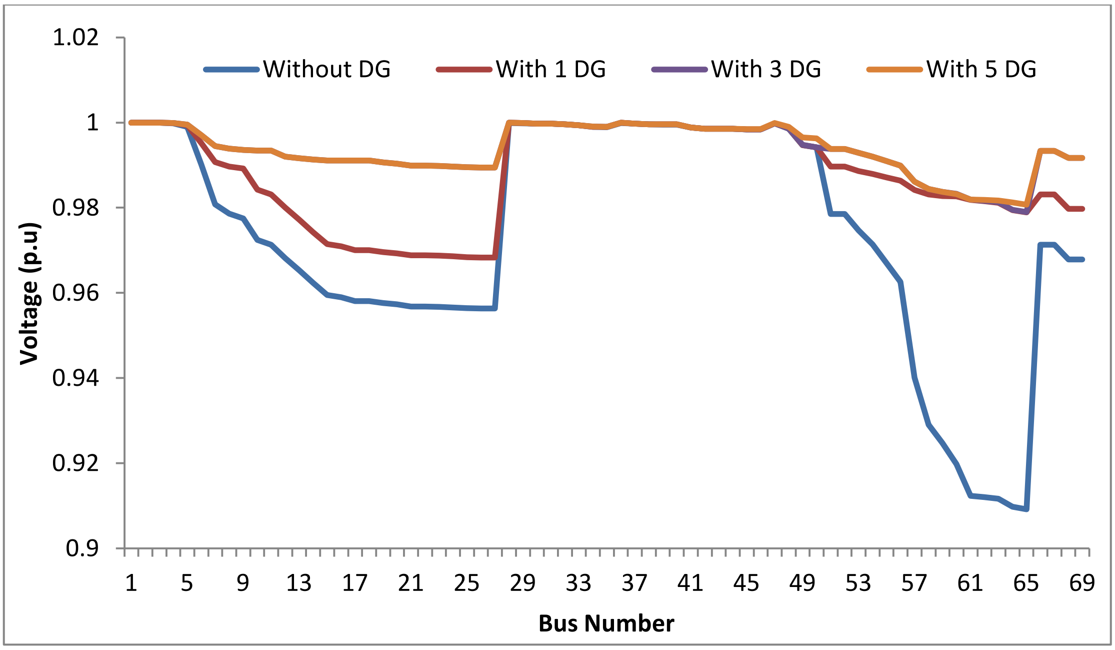

Fig. 4.7. Voltage profile with and without placing Type-1 DG in 69 bus RDS by using TLBO algorithm

4.5.2 Placement of Type-2 DG (DSTATCOM) in 69 bus RDS

TABLE 4.5: Allocation of Type-2 DG in 69 bus RDS by TLBO algorithm

No. Of DSTATCOM	Active Power Loss (kW)	Power Loss Reduction (%)	Location (bus no.)	Size (MVAr)
0	224.995	-	-	-
1	152.039	32.42	61	1.329
2	146.439	34.91	17 61	0.361 1.275
3	145.114	35.50	11 21 61	0.413 0.231 1.232
4	144.332	35.85	11 21 50 61	0.413 0.231 0.517 1.232
5	143.996	36.00	11 18 50 61 64	0.415 0.232 0.509 1.031 0.200

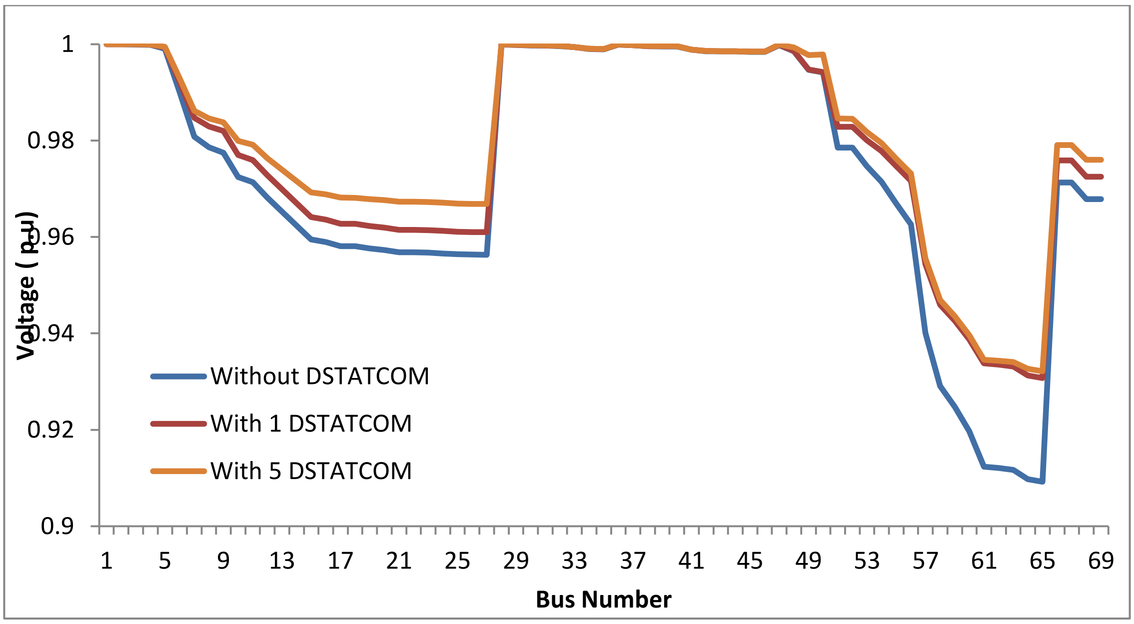

Fig. 4.8. Voltage profile with and without placing Type-2 DG in 69 bus RDS by using TLBO algorithm

4.5.3 Placement of Type-3 DG in 69 bus RDS

TABLE 4.6: Allocation of Type-3 DG in 69 bus RDS by TLBO algorithm

No. Of DG	Real Power Loss (kW)	Power Loss Reduction (%)	Optimal DG Size (MW)	(MVAr)	Location
0	224.995	-	-	-	-
1	23.171	89.702	1.828	1.301	61
2	7.204	96.798	0.522 1.735	0.353 1.238	17 61
3	4.268	98.103	0.494 0.379 1.674	0.354 0.251 1.195	11 18 61
4	1.997	99.112	0.493 0.379 0.718 1.674	0.353 0.252 0.513 1.195	11 17 50 61
5	1.633	99.274	0.388 0.312 0.718 0.279 1.647	0.273 0.207 0.512 0.201 1.175	12 21 50 53 61

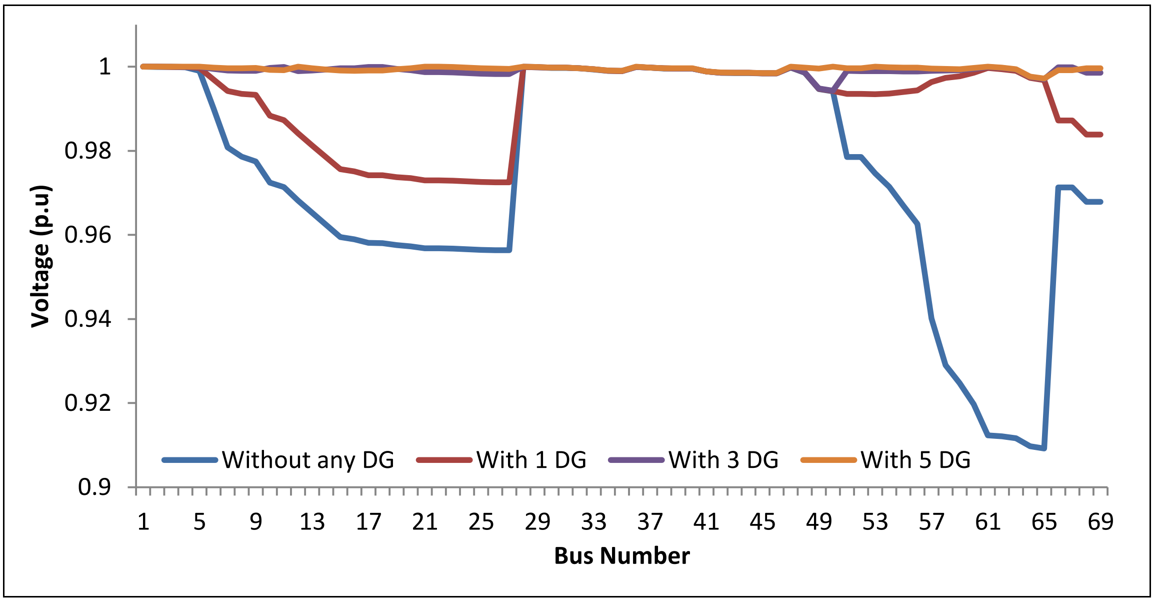

Fig. 4.9. Voltage profile with and without placing Type-3 DG in 69 bus RDS by using TLBO algorithm

4.6 OPTIMAL LOCATION FOR 119 BUS RADIAL DISTRIBUTION SYSTEM

IEEE 119 radial bus distribution system shown in figure [29]comprises 119 buses and 118 branches. Out of 119 buses first bus is slack bus and rest 118 buses are available for installing different types of DG. The data for this system has been taken from [36]. Selected base values are 11 kV and 100 MVA.

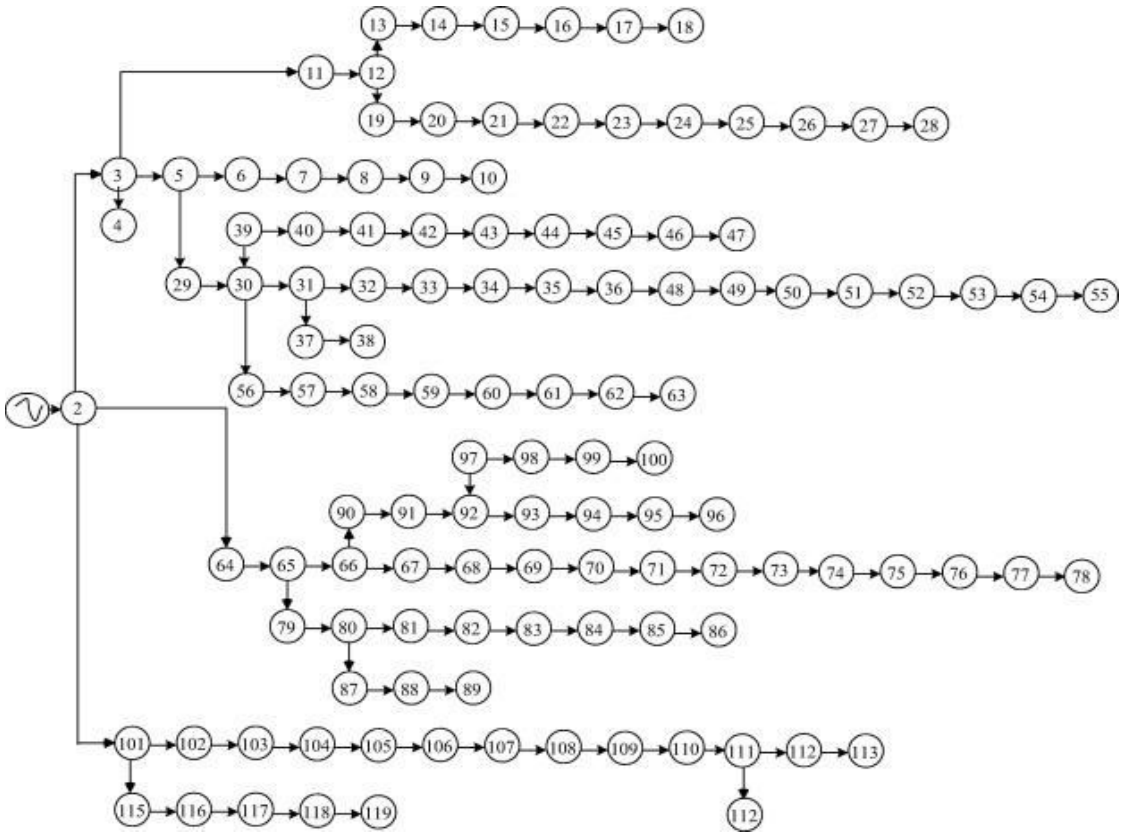

Fig. 4.10. The schematic diagram of 119 bus radial distribution system

Performance of 119 bus system without placing DG

Active power load	:	22.70972 MW
Reactive power load	:	17.0410 MVAr
Total real power loss	:	1298.092 kW
Minimum voltage	:	0.86889 p.u.

4.6.1 Placement of Type-1 DG in 119 bus RDS

TABLE 4.7: Allocation of Type-1 DG in 119 bus RDS by TLBO algorithm

No. of DG	Active Power Loss (kW)	Power Loss Reduction (%)	Location (bus no.)	Size (MW)
0	1298.092	-	-	-
1	1016.758	21.67	72	2.978
2	805.249	37.97	72 110	2.978 3.119
3	667.294	48.59	51 72 110	2.883 2.978 3.119
4	616.154	52.53	51 73 97 110	2.883 2.606 1.820 3.119
5	574.652	55.73	51 73 81 97 110	2.883 2.533 2.094 1.663 3.119

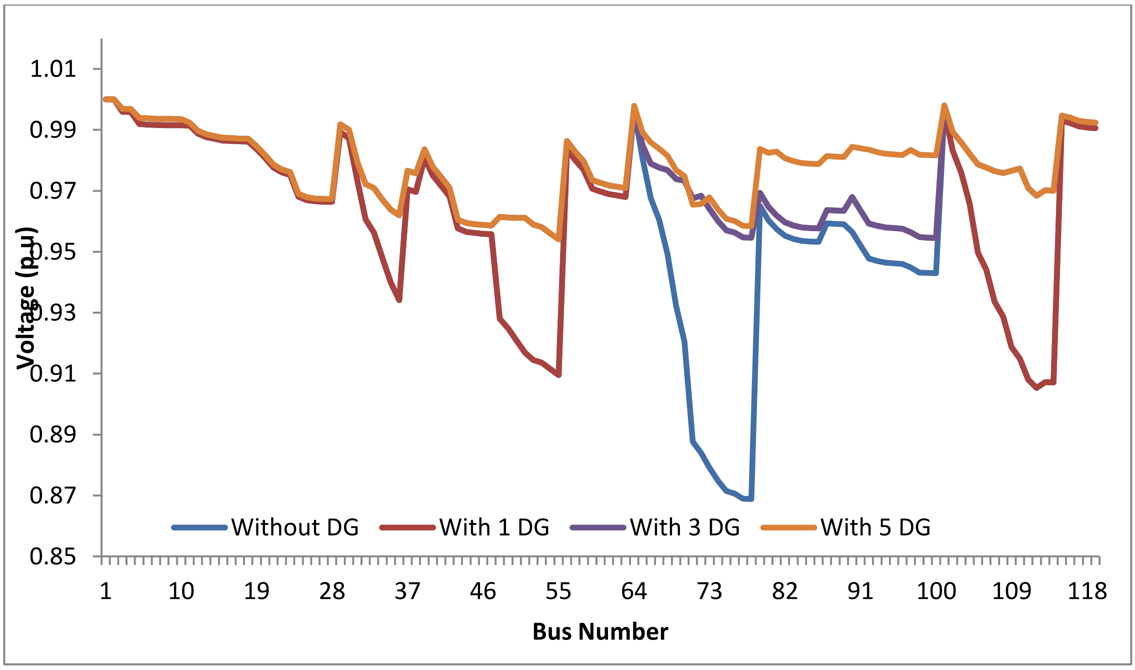

Fig. 4.11. Voltage profile with and without placing Type-1 DG in 119 bus RDS using TLBO algorithm

4.6.2 Placement of Type-2 DG (DSTATCOM) in 119 bus RDS

TABLE 4.8: Allocation of Type-2 DG (DSTATCOM) in 119 bus RDS by TLBO algorithm

No. of DG	Real Power Loss with DSTATCOM (kW)	Reduction in Power loss (%)	Location (bus no)	Size (MVAr)
0	1298.092	-	-	-
1	1153.301	11.154	111	2.333
2	1027.750	20.83	72 111	1.956 2.333
3	913.060	29.66	51 72 111	2.610 1.956 2.333
4	882.163	32.04	51 73 81 111	2.610 1.780 1.794 2.333
5	861.526	33.63	51 75 81 97 111	2.610 1.538 1.672 1.138 2.333

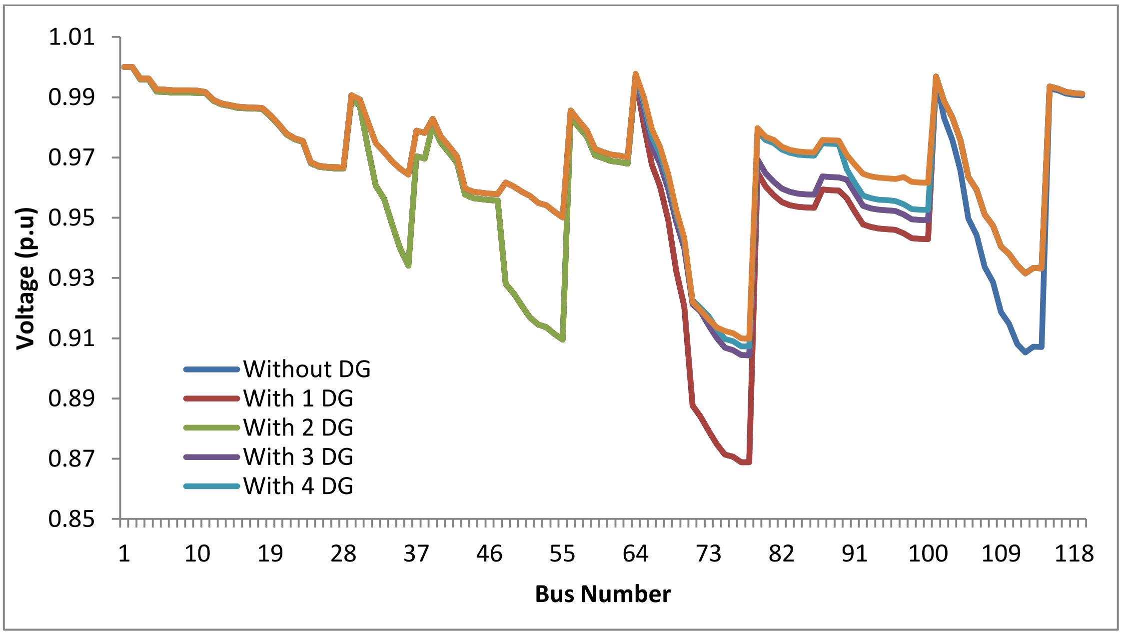

Fig. 4.12. Voltage profile with and without placing Type-2 DG in 119 bus RDS by using TLBO algorithm

4.6.3 Placement of Type-3 DG in 119 bus RDS

TABLE 4.9: Allocation of Type-3 DG in 119 bus RDS by TLBO algorithm

No. of DG	Real Power Loss(kW)	Power loss Reduction (%)	Optimal DG size MW	Optimal DG size MVAr	Location (bus no.)	Optimal Power Factor
0	1298.092	-	-	-	-	-
1	919.847	29.138	2.934	1.889	72	0.841
2	584.900	54.941	2.935 2.799	1.889 2.318	72 111	0.841 0.770
3	344.432	73.466	2.874 2.934 2.799	2.588 1.889 2.318	51 72 111	0.743 0.841 0.770
4	269.671	79.225	2.874 2.669 2.508 2.799	2.588 1.709 1.867 2.318	51 73 81 111	0.743 0.842 0.802 0.770
5	212.762	83.609	2.874 2.291 2.076 1.745 2.799	2.588 1.475 1.574 1.131 2.318	51 75 81 92 111	0.743 0.841 0.797 0.839 0.770

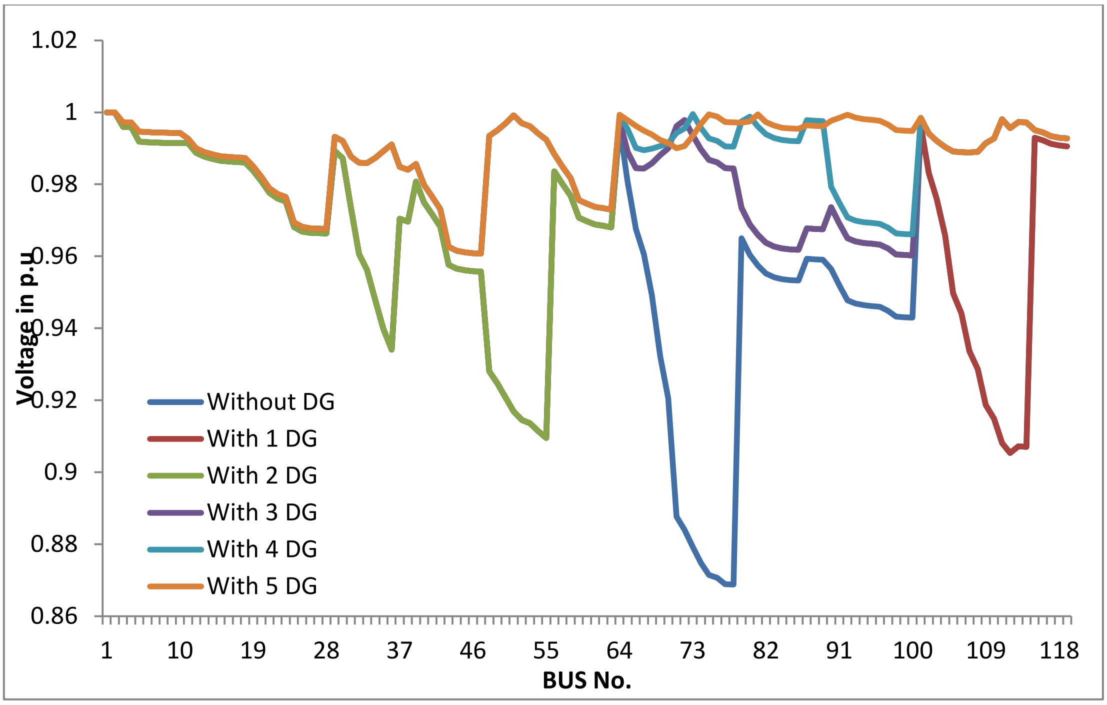

Fig. 4.13. Voltage profile with and without placing Type-3 DG in 119 bus RDS by using TLBO algorithm

CHAPTER-5

OPTIMAL PLACEMENT OF DG USING ARTIFICIAL BEE COLONY ALGORITHM

5.1 INTRODUCTION

This algorithm was introduced by Karaboga in 2005[37]. It is a nature-inspired algorithm based on the foraging behavior of bees. The strategy of this algorithm can be explained by three types of bees i.e. employed bees, onlooker bees and scout bees. Each type of bee performs different function. Every food source is searched by one employed bee. So, number of employed bees is equal to the number of food sources. Food source basically represents the amount of nectar quantity which we can relate with fitness value of the function that is to be optimized. Initially a scout bee goes for a search of nectar or food and saves the location of that food source and becomes an employed bee. The employed bees compare the different nearby available food sources and store the information of the best one. Then these employed bees share the information of the food source through waggle dance. Through their waggle dance onlooker bees judge the quality of nectar and go in search of food suggested by the employed bees. First-half bees are employed bees and second half is onlooker bees. The algorithm is constrained by two factors. The first one is the bee colony size and the second one is the limit i.e. the number of attempts after which employed bee will discard their solution and after which scout bees will generate a new solution. The functioning of these bees can be summarized as follows-:

1. **Employed Bees**-:_Employed bees basically perform exploration of food sources. It had been allocated a location of food resources. They find out food sources in the given search space (means in the neighbourhood of that location also) and share this information with the onlooker bees through waggle dance. The given information includes quantity, distance, and direction of the nectar source.

2. **Onlooker Bees**-: Onlooker bees perform exploitation by using the information given by the employed bees. They try to find out food in the region suggested by the employed bees and perform as newly employed bees related to that food source.

3. **Scout Bees**-: An employed bee, whose solution has been abandoned after a certain number (LIMIT), becomes a scout bee which randomly generates a new solution in the given range.

Control Parameters-:

LIMIT- no. of the count after which employed bees abandon solution, NUMPOP-no. of population size, CN- Number of the cycle for which the algorithm is to be iterated.

5.2 STEPS OF THE ALGORITHM

5.2.1 Initialization Phase

- Randomly generate initial population by using equation 5.1

$$X0 = X_{LOW} + (X_{UP} - X_{LOW}) * rand(NUMPOP, D) \tag{5.1}$$

  where X_{LOW} is the lower limit of the solution, X_{UP} is the upper limit of solution and D is the dimension of the problem.
- Calculate the value of the fitness function by using the fitness function evaluating equation specific for a defined problem.
- Set count equals 1.
- Set iteration to 1 and run until iteration equals CN.

5.2.2. Employed Phase

- Generate a new matrix by using X0 matrix with the equation 5.2.

$$V0_{i,j} = X0_{i,j} + (-1,1) * (X0_{i,j} - X0_{k,j}) \tag{5.2}$$

  where i varies from 1 to half of the population size, j varies from 1 to dimension and k is any value from 1 to half of the population except i.
- Again calculate fitness function for V0 vector and compare one by one with fitness value of X0 vector.
- If fitness value of the new solution is better than the fitness value of the old solution, then update the old solution with a new one and reset the count otherwise increase the count by 1.

5.2.3. Onlooker Bees

- Onlooker bees decide food source depending on the various information provided by the employed bees. They select the location of a food source and then find out its probability. If the probability is greater than a random value then it generates the new matrix with the help of the previous matrix by using equation 5.2. To find out the probability, equation 5.3 is used or roulette wheel selection method can be used.

$$p_i = \frac{fit_i}{\sum_{i=1}^{n} fit_i} \tag{5.3}$$

  where n is equal to half of the size of the population.
- Then the fitness function of the new generated matrix of onlooker bees is computed. If fitness value of the new solution is better than the fitness value with the old solution, then the old solution is updated with the new one and the count is reset otherwise it is increased by 1.

5.2.4. Scout Bees

- The count number for each solution is checked. If count number exceeds the LIMIT then a new solution is generated and the count is reset to 1.

5.2.5. Termination Phase

- If termination criterion is met then the algorithm stops executing and presents the best solution otherwise it goes to step 2 i.e. employed bee phase and iteration number is increased by 1.

5.3 Implementation of the ABC Algorithm for Optimal Siting and Sizing of DGs

The strategic location of DGs enhances power reliability and reduces the operational costs of the distribution network. For finding out the optimal location and size of the DGs, ABC algorithm has been applied. For this, several case studies are carried out. At first, the placement of Type-1 DGs is considered. Then its two sub-cases are investigated – the first one is for constant load and second one is for varying load throughout the whole day. The second case is for the placement of Type-2 DGs. The third case is for the placement of Type-3 DGs. The given case studies have been implemented in the IEEE 33-bus, 69-bus and 119-bus radial distribution system .Single line diagram of these distribution systems are shown in chapter 4.

5.4 OPTIMAL LOCATION of DGs IN IEEE 33-BUS RDS

5.4.1 Placement of Type-1 DGs in 33 RDS for constant load

TABLE 5.1: Allocation of Type-1 DG in 33 bus RDS by ABC algorithm

No. of DG	Real Power Loss (kW)	Power loss Reduction (%)	Location (bus no)	Size (MW)
0	202.677	-	-	-
1	103.966	48.70	6	2.575
2	85.910	57.61	13 30	0.846 1.158
3	71.457	64.74	14 24 30	0.754 1.099 1.071
4	65.935	67.47	7 14 24 31	0.916 0.585 0.981 0.708
5	64.885	67.99	7 14 21 24 31	0.908 0.585 0.277 0.970 0.708

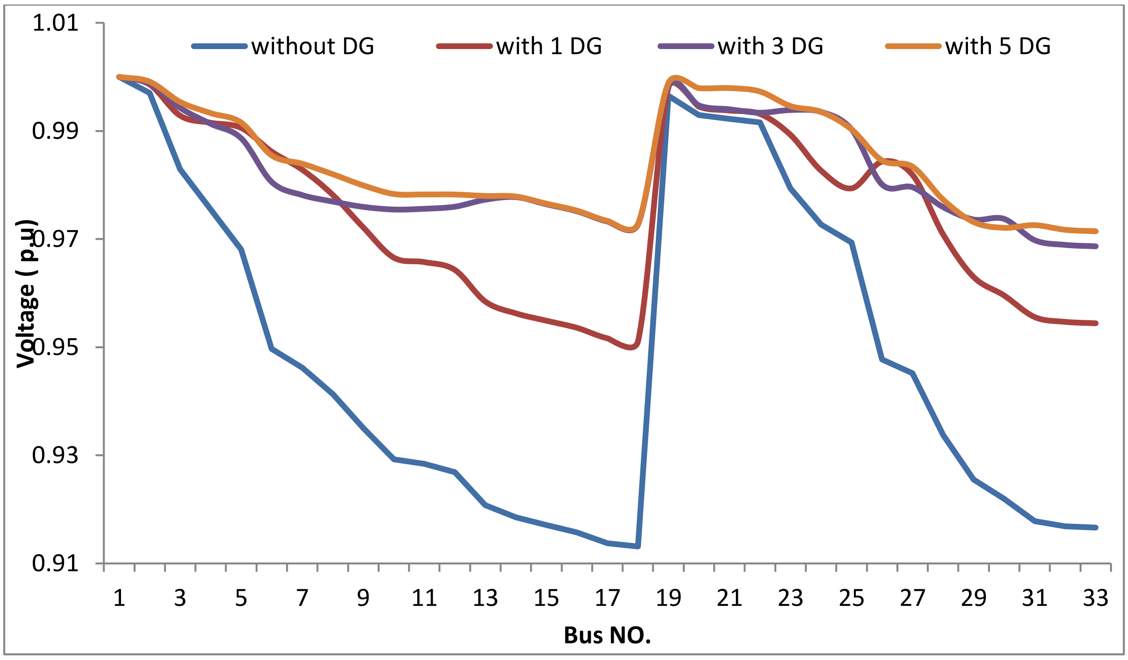

Fig. 5.1. Voltage profile with and without placing Type-1 DGs in 33 bus RDS by using ABC algorithm

5.4.2 Placement of Type1 DGs in 33 bus RDS with varying load

The algorithm has been implemented on 24 hours load data during summer seasons. The 24-hour load data has been taken from [39].

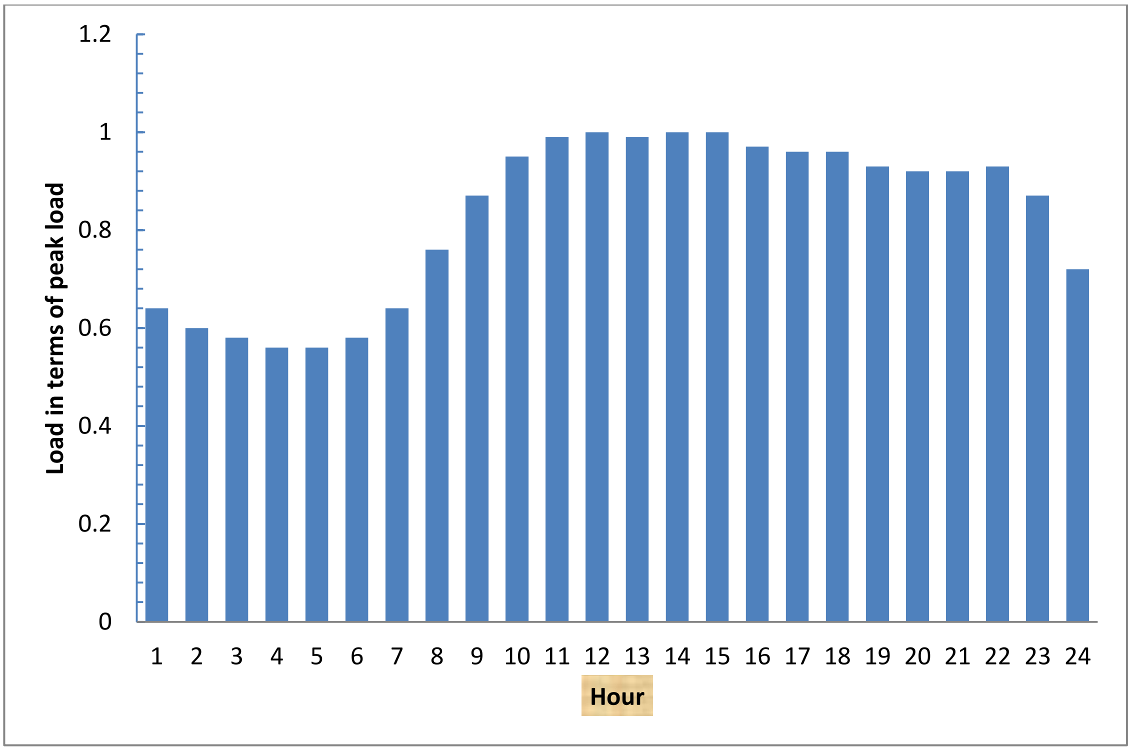

Fig. 5.2. Typical load variation for 24 hours during summer season

For this type of load profile, ABC algorithm has been used to find out the suitable locations and sizes of the DGs and the result has been summarized in table 5.2. For this three cases have been considered. Case 1 is without placing DG, Case 2 is for placing single DG and Case 3 is for placing three DGs. For case 2, optimized location is at bus no. 6 and for case 3, the three optimized locations are at bus nos. 14, 24 and 30. Load in terms of Peak load is considered.

TABLE 5.2: Allocation of Type-1 DGs in 33 bus RDS with varying load by ABC Algorithm

Load (p.u.)	Power Loss (kW)			DG size (MW)	
	Case1	Case2	Case3	Case2 with DG at Bus 6	Case3with DG at bus 14,24 and 30
0.56	59.541	31.488	21.813	1.407	0.419 0.609 0.592
0.58	64.050	33.830	23.427	1.459	0.434 0.631 0.614
0.6	68.738	36.259	25.100	1.511	0.449 0.653 0.635
0.64	78.655	41.383	28.627	1.615	0.479 0.697 0.678
0.72	100.705	52.704	36.408	1.825	0.540 0.786 0.765
0.76	112.866	58.908	40.665	1.931	0.570 0.830 0.808
0.87	150.356	77.872	53.650	2.224	0.654 0.953 0.928
0.92	169.425	87.430	60.180	2.358	0.692 1.009 0.983
0.93	173.395	89.412	61.534	2.385	0.700 1.021 0.994
0.95	181.493	93.450	64.289	2.439	0.716 1.043 1.016
0.96	185.622	95.505	65.690	2.467	0.723 1.054 1.027
0.97	189.805	97.584	67.108	2.494	0.731 1.066 1.038
0.99	198.332	101.814	69.991	2.548	0.746 1.088 1.060
1	202.677	103.966	71.457	2.575	0.754 1.099 1.071

5.4.3 Placement of Type-2 DG (DSTATCOM) in 33 bus RDS

TABLE 5.3: Allocation of Type-2 DG in 33 bus RDS by ABC algorithm

No. of DSTATCOM	Real Power Loss (kW)	Power loss Reduction (%)	Location (bus no)	Size (MVAr)
0	202.677	-	-	-
1	143.602	29.15	30	1.252
2	135.753	33.02	12 30	0.469 1.058
3	132.173	34.78	13 24 30	0.378 0.544 1.036
4	130.688	35.51	7 14 24 30	0.442 0.276 0.482 0.904
5	130.315	35.70	7 14 24 30 32	0.442 0.276 0.482 0.709 0.194

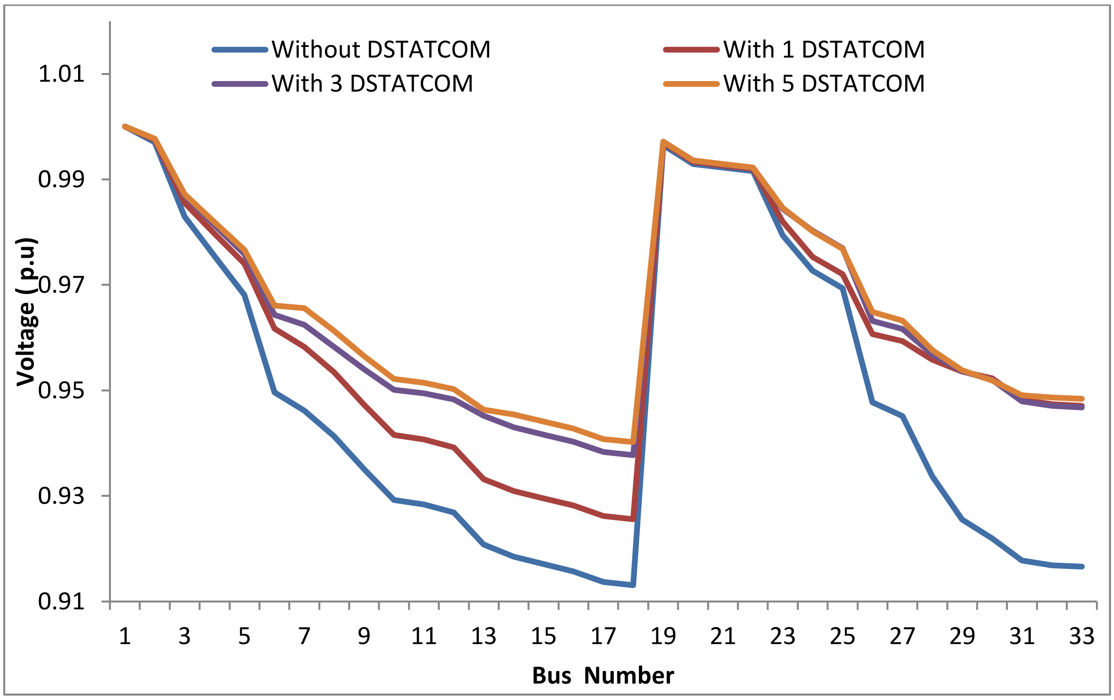

Fig. 5.3. Voltage profile with and without placing Type-2 DG in 33 bus RDS by using ABC algorithm

5.4.4 Placement of Type-3 DG in 33 bus RDS

TABLE 5.4: Allocation of Type-3 DGs in 33 bus RDS by ABC algorithm

No. of DG	Active Power Loss (kW)	Power loss Reduction (%)	Optimal DG size MW	MVAr	Optimal Location
0	202.677	-	-	-	-
1	61.363	69.72	2.545	1.750	6
2	28.492	85.94	0.839 1.140	0.395 1.065	13 30
3	11.629	94.26	0.747 1.078 1.048	0.350 0.521 1.021	14 24 30
4	6.427	96.83	0.788 0.585 0.964 0.788	0.376 0.272 0.467 0.896	7 14 24 30
5	5.07	97.50	0.817 0.553 0.957 0.401 0.386	0.393 0.259 0.464 0.707 0.189	7 15 24 30 32

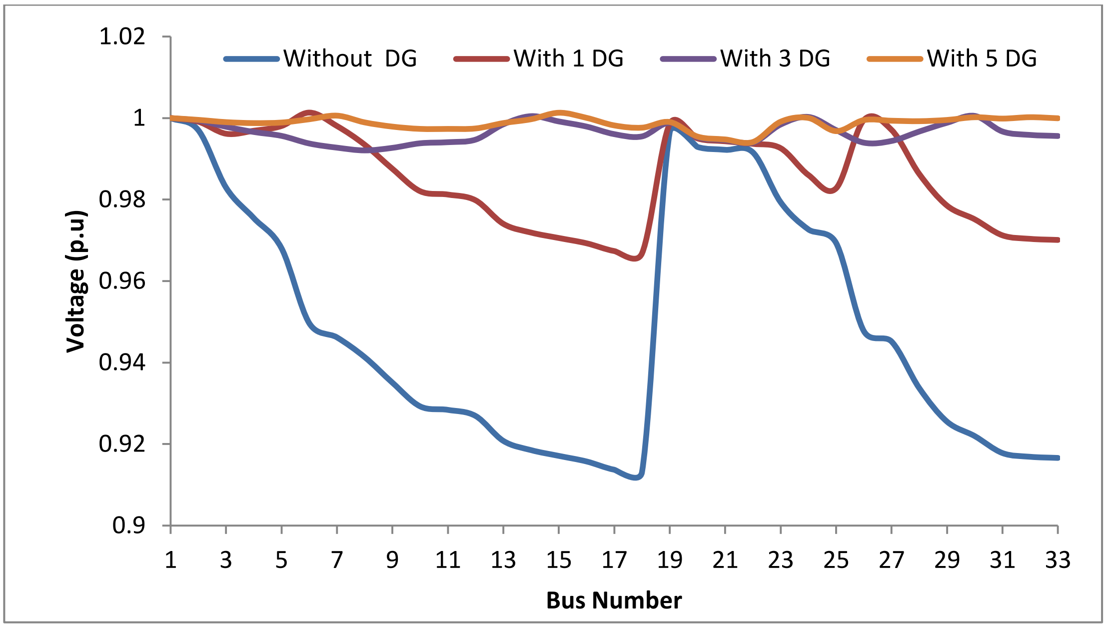

Fig. 5.4. Voltage profile with and without placing Type-3 DG in 33 bus RDS by using ABC algorithm

5.5 OPTIMAL LOCATION FOR 69 BUS RADIAL DISTRIBUTION SYSTEM

5.5.1 Placement of Type-1 DG in 69 bus RDS

TABLE 5.5: Allocation of Type-1 DG in 69 bus RDS by ABC algorithm

No. of DG	Active Power Loss (kW)	Power loss Reduction (%)	Location	Size (MW)
0	224.995	-	-	-
1	83.222	63.01	61	1.873
2	71.675	68.14	17 61	.531 1.781
3	69.426	69.14	11 18 61	.526 .380 1.719
4	67.917	69.81	11 18 50 61	.520 .382 .719 1.719
5	67.372	70.06	11 18 50 61 64	0.526 0.379 0.717 1.427 0.289

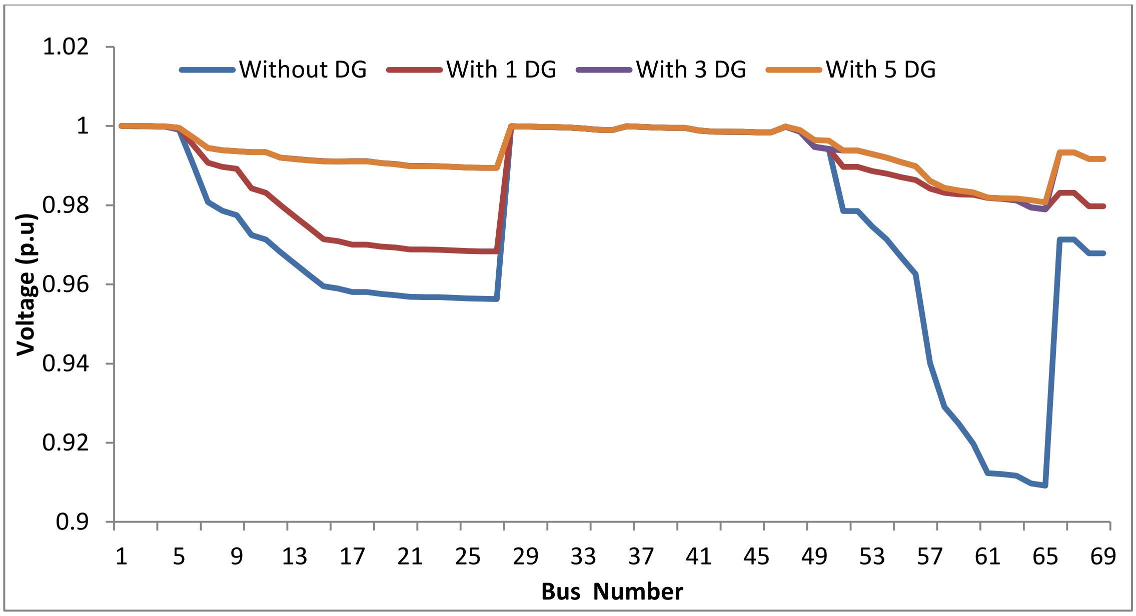

Fig. 5.5. Voltage profile with and without placing Type-1 DG in 69 bus radial distribution system by using ABC algorithm

5.5.2 Placement of Type-2 DGs (DSTATCOMs) in 69 bus RDS with constant load

TABLE 5.6: Allocation of DSTATCOM in 69 bus RDS by ABC algorithm

No. of DSTATCOM	Active Power Loss (kW)	Power loss Reduction (%)	Location	Size (MVAr)
0	224.995	-	-	-
1	152.039	32.43	61	1.329
2	146.439	34.91	17 61	0.361 1.275
3	145.114	35.50	11 21 61	0.413 0.230 1.232
4	144.331	35.85	11 21 50 61	0.413 0.231 0.517 1.232
5	143.995	36.00	11 18 50 61 64	0.412 0.231 0.517 1.025 0.206

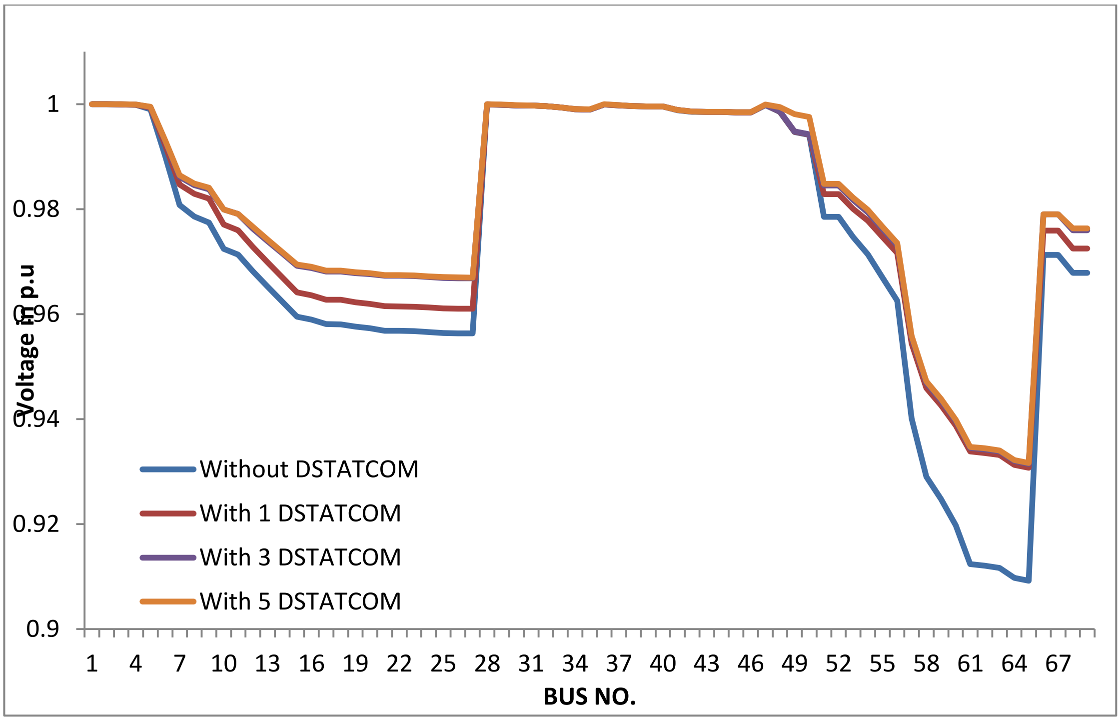

Fig. 5.6. Voltage profile with and without placing Type-2 DG in 69 bus RDS by using ABC algorithm

5.5.3 Placement of Type-2 DGs (DSTATCOM) in 69 bus RDS with varying load

For this case, 24 hours load data is shown in Fig. 5.2.Case 1 is for without any Type-2 DG, Case 2 is for placement of a single Type-2 DG and Case 3 is for placing three Type-2 DGs. For case 2, optimized location is at bus no. 61 and for case 3 three optimized locations are at bus nos. 11, 21 and 61.

TABLE 5.7: Allocation of Type-2 DG (DSTATCOM) in 69 bus RDS for varying load by ABC algorithm

Load (p.u.)	Power Loss (kW)			DSTATCOM Size (MVAr)	
	Case1	Case2	Case3	Case 2 with DSTATCOM at bus 61	Case 3 with DSTATCOM at bus 11,21 and 61
0.56	65.364	45.040	43.044	0.736	0.221 0.129 0.680
0.58	70.345	48.434	46.285	0.763	0.237 0.138 0.729
0.6	75.527	51.960	49.653	0.789	0.237 0.138 0.730
0.64	86.504	59.416	56.770	0.843	0.254 0.147 0.779
0.72	110.967	75.963	72.565	0.950	0.288 0.166 0.879
0.76	124.490	85.073	81.258	1.004	0.306 0.175 0.929
0.87	166.313	113.091	107.985	1.153	0.354 0.201 1.067
0.92	187.658	127.306	121.539	1.221	0.377 0.212 1.131
0.93	192.109	130.267	124.357	1.234	0.381 0.214 0.114
0.95	201.193	136.291	130.104	1.262	0.390 0.219 1.169
0.96	205.828	139.362	133.032	1.275	0.395 0.221 1.194

0.97	210.525	142.473	135.996	1.289	0.399 0.224 1.194
0.99	220.108	148.811	142.037	1.316	0.408 0.228 1.220
1	224.995	152.038	145.113	1.330	0.413 0.231 1.232

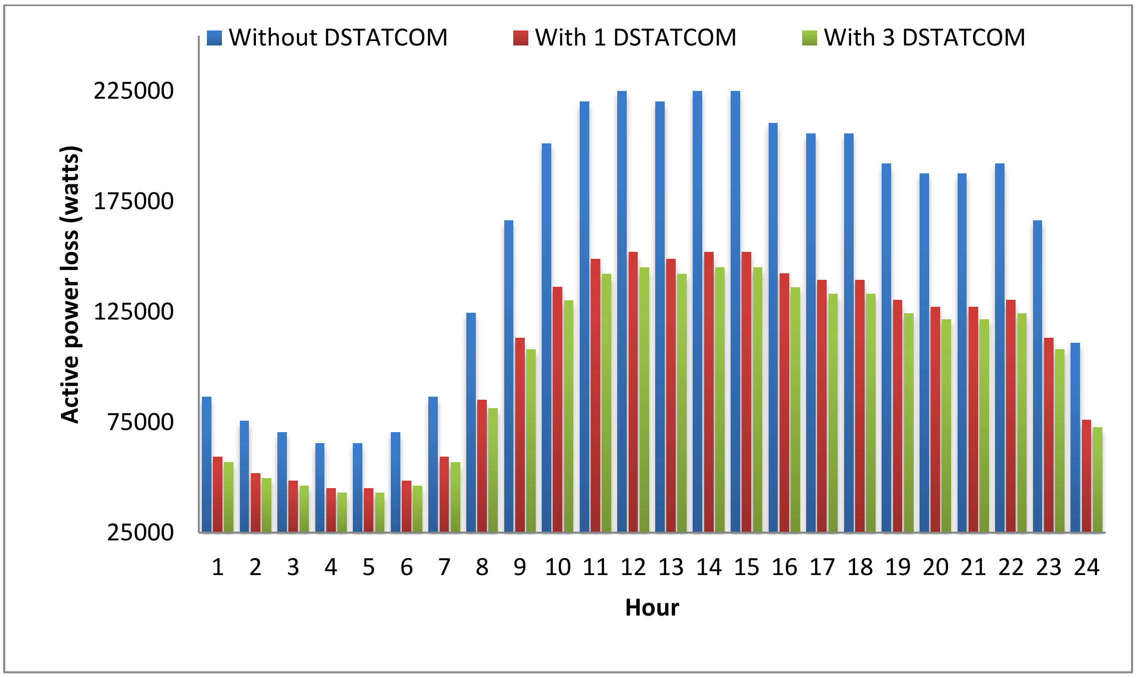

Fig. 5.7. Comparison of active power losses in different cases with 24 hour varying load in case of 69 bus RDS

5.5.4 Placement of Type-3 DGs in 69 bus RDS

TABLE 5.8: Allocation of Type-3 DGs in 69 bus RDS by ABC algorithm

No. of DG	Active Power Loss (kW)	Power loss Reduction (%)	DG size MW	DG size MVAr	DG Location	Optimal Power Factor
0	224.995	-	-	-	-	-
1	23.1709	89.701	1.828	1.301	61	0.8148
2	7.2041	96.7980	0.522 1.735	0.353 1.238	17 61	0.8282 0.8138
3	4.2677	98.1031	0.494 0.379 1.674	0.354 0.251 1.195	11 18 61	0.8132 0.8332 0.8138
4	1.9951	99.1132	0.494 0.379 0.718 1.674	0.353 0.251 0.513 1.195	11 18 50 61	0.8132 0.8332 0.8138 0.8138
5	1.3558	99.39	0.514 0.352 0.775 1.321 0.366	0.352 0.225 0.598 1.075 0.121	11 21 49 61 64	0.8246 0.8432 0.7917 0.7756 0.9494

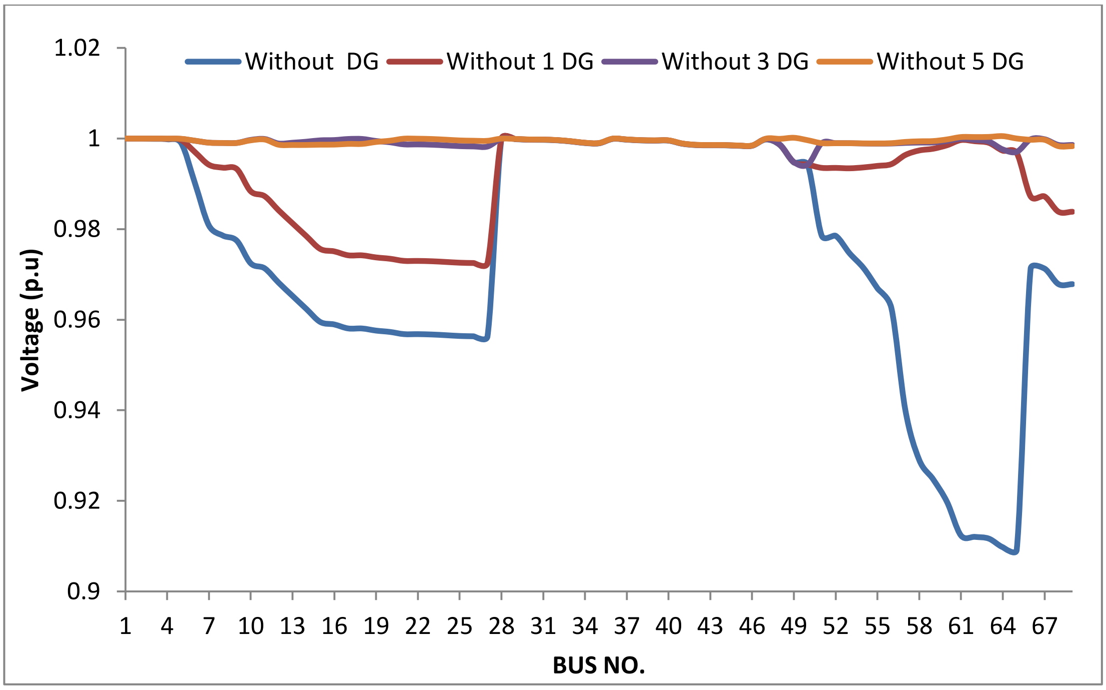

Fig. 5.8. Voltage profile with and without placing Type-3 DG in 69 radial distribution system by using ABC algorithm

5.6 OPTIMAL LOCATIONs FOR 119 BUS RADIAL DISTRIBUTION SYSTEM

5.6.1 Placement of Type-1 DGs in 119 bus RD

TABLE 5.9: Allocation of Type-1 DGs in 119 bus RDS by ABC algorithm

No. Of DG	Active Power Loss (kW)	Power loss Reduction (%)	Location	Size (MW)
0	1298.091617	-	-	-
1	1016.75852	21.67	72	2.978
2	805.249	37.97	72 110	2.978 3.119
3	667.294	48.59	51 72 110	2.883 2.978 3.119
4	616.154	52.53	51 73 97 110	2.883 2.606 1.820 3.119
5	574.952	55.70	51 74 81 97 111	2.883 2.417 2.107 1.688 2.869

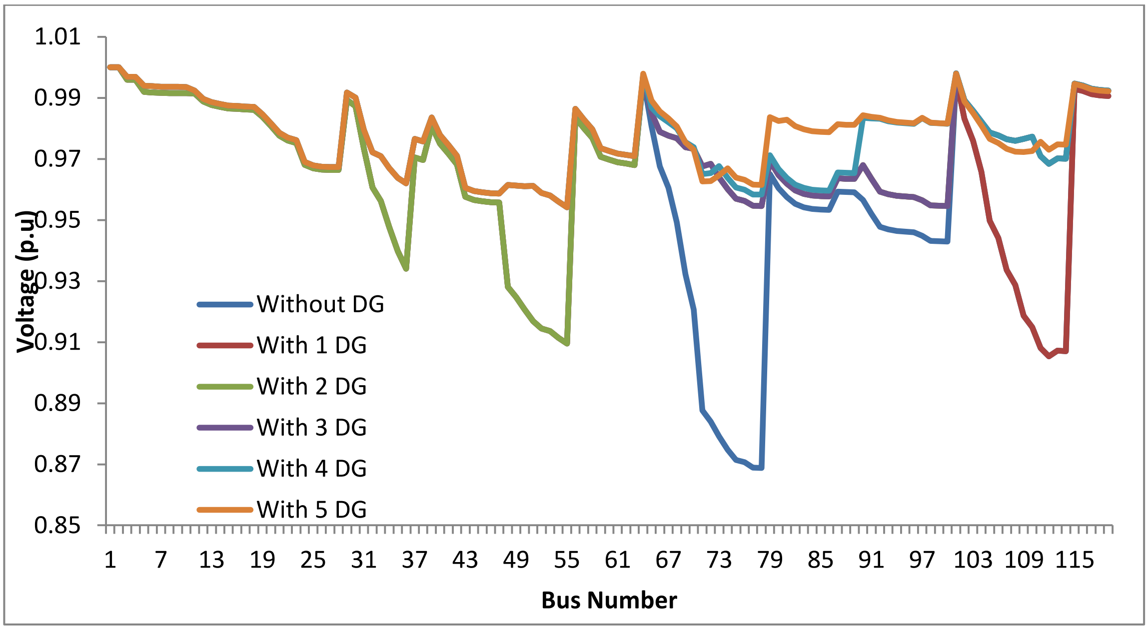

Fig. 5.9. Voltage profile with and without placing Type-1 DGs in 119 bus RDS

5.6.2 Placement of Type-2 DGs (DSTATCOM) in 119 bus RDS

TABLE 5.10: Allocation of Type-2 DGs in 119 bus RDS by ABC algorithm

No. of DSTATCOM	Real Power Loss (kW)	Power loss Reduction (%)	Location	Size (MVAr)
0	1298.092	-	-	-
1	1153.301	11.15	111	2.333
2	1027.750	20.83	72 111	1.956 2.333
3	913.060	29.66	51 72 111	2.610 1.956 2.333
4	882.163	32.04	51 73 81 111	2.610 1.781 1.794 2.333
5	861.526	33.63	51 75 81 97 111	2.610 1.538 1.672 1.138 2.333

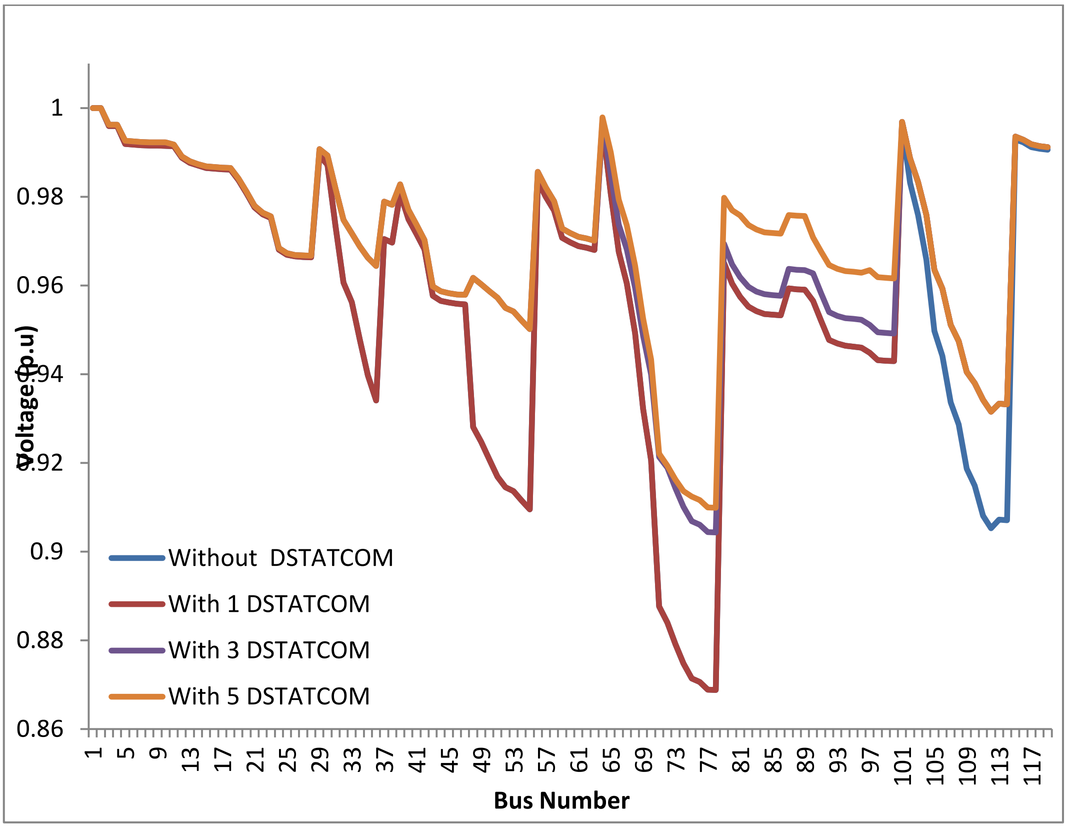

Fig. 5.10 . Voltage profile with and without placing Type-2 DGs in 119 bus RDS

5.6.3 Placement of Type-3 DGs in 119 bus RDS

TABLE 5.11: Allocation of Type-3 DGs in 119 bus RDS by ABC algorithm

No. of DG	Real Power Loss (kW)	Power loss Reduction (%)	DG size MW	MVAr	DG Location	Power Factor
0	1298.09	-	-	-	-	-
1	919.847	29.14	2.935	1.889	72	0.8408
2	584.900	54.94	2.935 2.799	1.889 2.318	72 111	0.8408 0.7702
3	344.432	73.47	2.874 2.935 2.799	2.588 1.889 2.318	51 72 111	0.7432 0.8408 0.7702
4	269.217	79.26	2.874 2.680 2.275 2.799	2.588 1.716 1.711 2.318	51 73 81 111	0.7432 0.8421 0.7991 0.7702
5	210.999	83.74	2.877 2.299 2.089 1.669 2.799	2.588 1.479 1.583 1.074 2.318	51 75 81 97 111	0.7435 0.8410 0.7969 0.8408 0.7702

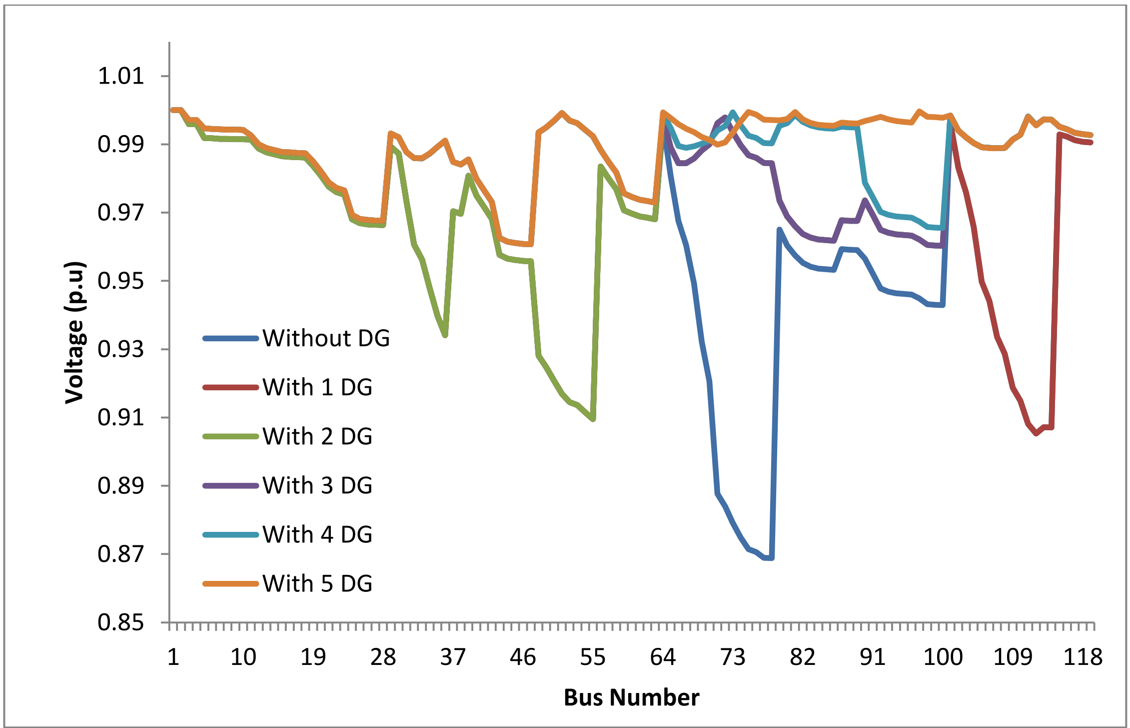

Fig. 5.11. Voltage profile with and without placing Type-3 DGs in 119 bus RDS

CHAPTER-6

PERFORMANCE COMPARISON AND ANALYSIS

6.1 INTRODUCTION

In this chapter, results obtained using TLBO and the ABC have been shown and compared with other techniques like bat algorithm, PSO with constriction factor etc. The results have been categorized into various subsections depending upon the RDS, type, and numbers of DGs. Different comparisons have been done to reflect the efficiency of the algorithm in power loss reduction and voltage profile improvement.

6.2 RESULTS FOR 33 BUS RADIAL DISTRIBUTION SYSTEM

6.2.1 For Type-1 DGs

TABLE 6.1: Comparison of allocation of Type-1 DG in 33 bus RDS by various techniques

No. of DG	Method	DG Location (Bus No.)	DG Size (MW)	Power Losses (MW)
1 DG	ABC	6	2.575	0.104
	TLBO	6	2.575	0.104
	PSOCFA[40]	6	2.575	0.104
3DG	ABC	14 24 30	0.754 1.099 1.071	0.071
	TLBO	14 24 30	0.754 1.099 1.071	0.071
	PSOCFA[40]	10 25 33	1.049 0.878 0.805	0.076
	ABC	7 14 21 24 31	0.909 0.585 0.277 0.970 0.708	0.065

5DG	TLBO	7 14 21 24 31	0.909 0.585 0.277 0.970 0.708	0.065
	PSOCFA[40]	4 15 25 26 32	0.517 0.584 0.727 0.824 0.639	0.066

6.2.2 For Type-2 DG

TABLE 6.2: Comparison of allocation of Type-2 DGs in 33 bus RDS by various techniques

No. of DG	Method	DSTATCOM Location (Bus No.)	DSTATCOM Size (MVAr)	Power Losses (MW)
1 DG	ABC	30	1.253	0.144
	TLBO	30	1.253	0.144
3DG	ABC	13 24 30	0.379 0.544 1.037	0.132
	TLBO	13 24 30	0.379 0.544 1.037	0.132
5DG	ABC	7 14 24 30 32	0.442 0.277 0.482 0.709 0.194	0.130
	TLBO	7 14 21 24 31	0.442 0.276 0.483 0.709 0.194	0.130

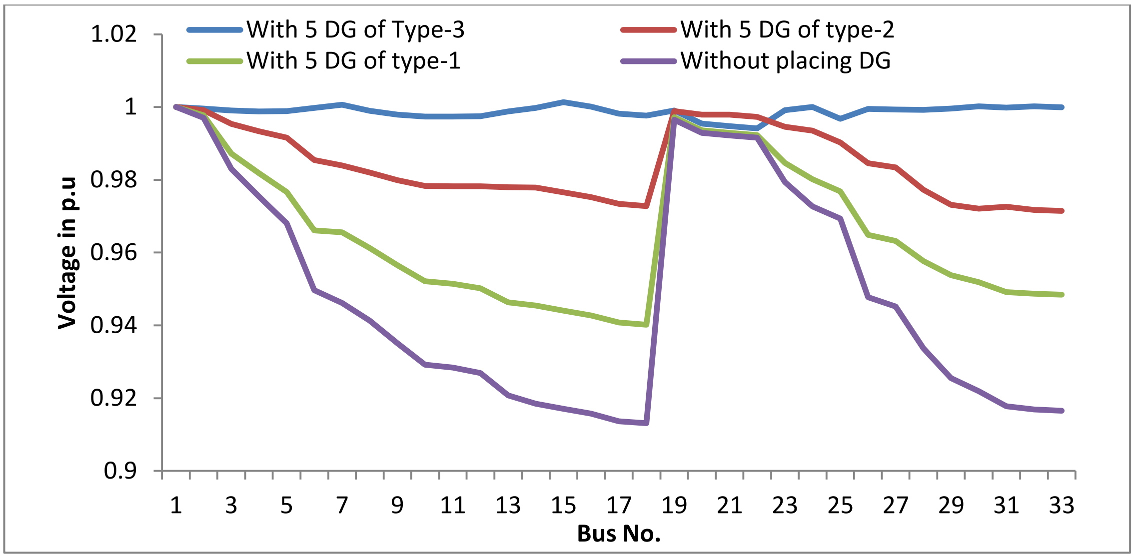

Fig. 6.1. Voltage profile comparison for various cases in 33 bus RDS

6.2.3 For Type-3 DGs

TABLE 6.3: Comparison of allocation of Type-3 DGs in 33 bus RDS by various techniques

No. of DG	Method	DG Location (Bus No.)	DG Size (MW/MVAr)	Power Loss (kW)
1 DG	ABC	6	2.545 / 1.750	61.363
	TLBO	6	2.545 / 1.750	61.363
3DG	ABC	14 24 30	0.747 / 0.350 1.078 / 0.521 1.049 / 1.021	11.629
	TLBO	14 24 30	0.747 / 0.350 1.078 / 0.521 1.048 / 1.021	11.629
5DG	ABC	7 15 24 30 32	0.817 / 0.393 0.553 / 0.259 0.957 / 0.464 0.401 / 0.707 0.386 / 0.189	5.073
	TLBO	7 14 25 30 32	0.831 / 0.398 0.586 / 0.272 0.782 / 0.378 0.404 / 0.701 0.384 / 0.193	5.073

6.3 RESULTS FOR 119 BUS RADIAL DISTRIBUTION SYSTEM

6.3.1 For Type-1 DG

TABLE 6.4: Comparison of allocation of Type-1 DGs in 119 bus RDS by various techniques

No. of DG	Method	DG Location (Bus No)	DG Size (MW)	Power Losses (MW)
1 DG	ABC	72	2.979	1.017
	TLBO	72	2.979	1.017
	BFA[41]	93	2.871	1.017
3DG	ABC	51 72 110	2.883 2.978 3.120	0.667
	TLBO	51 72 110	2.883 2.978 3.120	0.667
	BFA [41]	58 93 115	2.836 2.871 2.769	0.668
5DG	ABC	51 74 81 97 111	2.883 2.417 2.107 1.688 2.869	0.575
	TLBO	51 73 81 97 110	2.883 2.533 2.095 1.663 3.119	0.575
	BFA [41]	58 70 84 96 115	2.836 2.075 1.664 2.277 2.769	0.576

6.3.2 For Type-2 DG

TABLE 6.5: Comparison of allocation of Type-2 DGs in 119 bus RDS by various techniques

No. of DSTATCOM	Method	DSTATCOM Location (Bus No.)	DSTATCOM Size (MVAr)	Power Losses (MW)
1	ABC	111	2.333	1.153
	TLBO	111	2.333	1.153
3	ABC	51 72 111	2.610 1.956 2.333	0.913
	TLBO	51 72 111	2.610 1.956 2.333	0.913
5	ABC	51 75 81 97 111	2.610 1.538 1.672 1.138 2.331	0.861
	TLBO	51 75 81 97 110	2.610 1.538 1.672 1.138 2.333	0.861
	BFOA[30]	38 46 74 91 118	2.514 1.425 1.521 1.715 2.021	0.871

6.3.3 For Type-3 DG

TABLE 6.6: Comparison of allocation of Type-3 DGs in 119 bus RDS by various techniques

No. of DG	Method	DG Location	DG Size (MW)/ p.f	Power Loss (MW)
1 DG	ABC	72	2.935 / 0.841	0.919
	TLBO	72	2.935 / 0.841	0.919
3DG	ABC	51 72 111	2.874 / 0.7432 2.935 / 0.841 2.799 / 0.770	0.344
	TLBO	51 72 111	2.874 / 0.743 2.935 / 0.841 2.799 / 0.770	0.344
5DG	ABC	51 75 81 97 111	2.877 / 0.743 2.299 / 0.841 2.088 / 0.797 1.669 / 0.841 2.799 /0.770	0.211
	TLBO	51 75 81 97 110	2.874 / 0.743 2.291 / 0.841 2.0761 / 0.797 1.745 / 0.839 2.799 / 0.770	0.213
	BFOA[30]	38 46 74 91 118	2.952 / 0.76 2.141 / 0.83 2.803 / 0.84 2.346 / 0.79 3.029 / 0.77	0.229

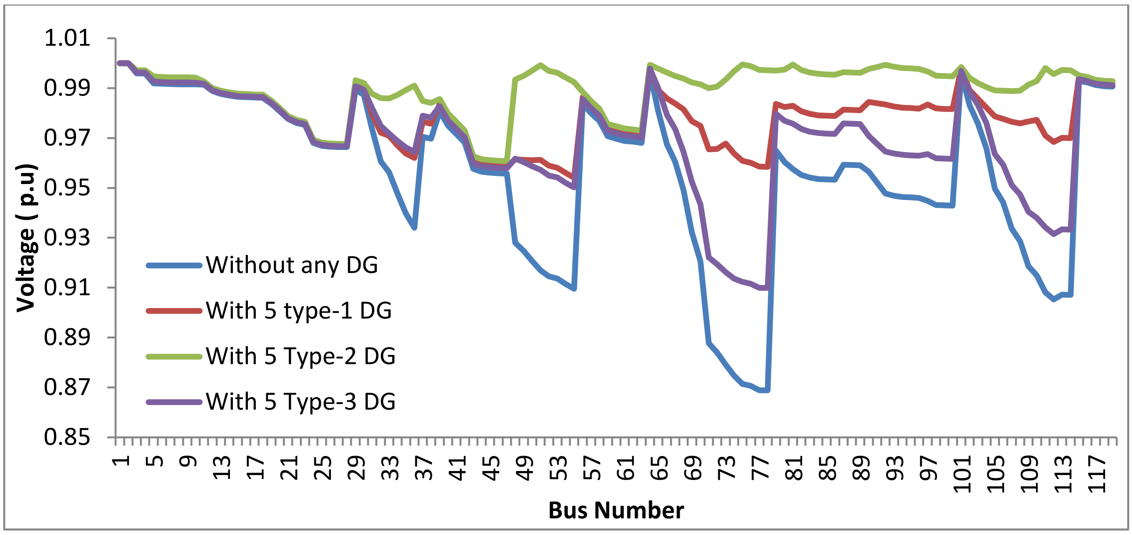

Fig. 6.2. Voltage profile comparison for various cases in 119 bus RDS

6.4 CONVERGENCE COMPARISON OF TLBO and ABC

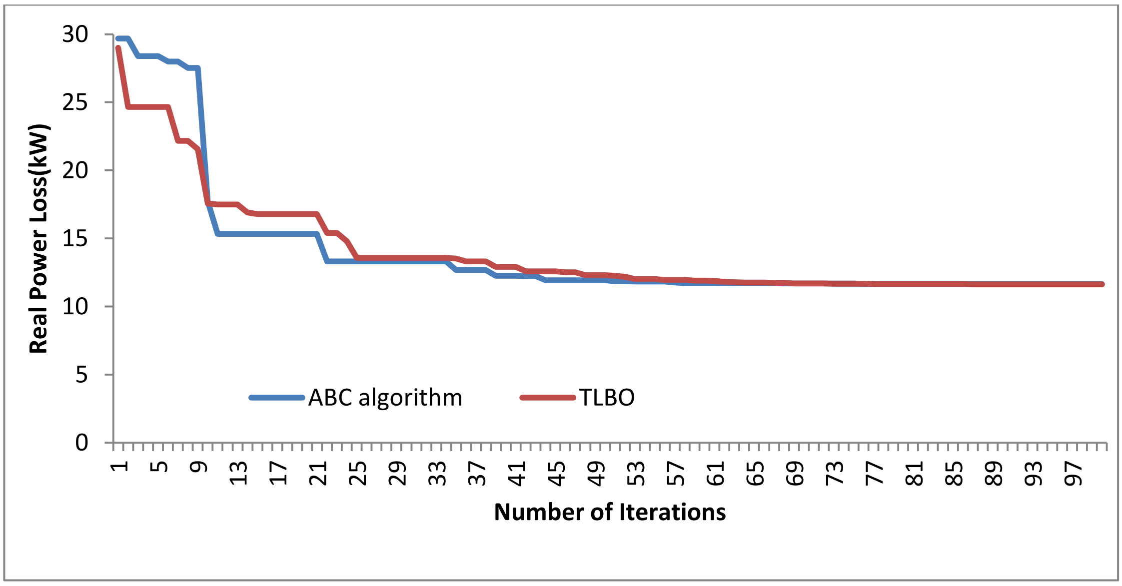

Fig. 6.3. Convergence comparison for placing Type- 3 DG using TLBO and ABC

It is observed from fig. 6.3 that TLBO algorithm shows continuous convergence towards final solution while ABC algorithm is showing abrupt changes in convergence graph due to exploration nature of scout bee phase.

This behaviour of TLBO algorithm is due to its nature of equation(4.2) which enable it to move towards mean of the all vectors which helps in providing final solution with continuous change towards converged solution .

6.4 CONCLUSIONS

This work presents the implementation of ABC algorithm and TLBO for optimal allocation of different types of DGs in radial distribution systems (RDS) which resulted in active power loss reduction and bus voltage profile improvement. The proposed algorithm was implemented for allocation of DGs in the IEEE 33-bus, 69-bus and 119-bus radial bus distribution systems. Results show that the best result is obtained when Type-3 DGs are connected. As an example, by installing 5 Type-1 DGs in the 119 bus RDS, the active power losses are reduced by 55.70 %. When 5 Type-3 DGs are installed, the same losses are reduced by 83.74%.

ABC and TLBO both presented good results when compared to other techniques but ABC is slightly superior to TLBO when the system is more complex like 119 bus system as TLBO has only two phases which are related to exploration but not in exploitation while ABC is also good in exploration also.

APPENDIX

TABLE A.1: Bus Data for 33bus radial distribution system

Branch No.	Sending Bus	Receiving Bus	R (ohm)	X (ohm)
1	1	2	0.0922	0.047
2	2	3	0.493	0.2511
3	3	4	0.366	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.819	0.707
6	6	7	0.1872	0.6188
7	7	8	0.7114	0.2351
8	8	9	1.03	0.74
9	9	10	1.044	0.74
10	10	11	0.1966	0.065
11	11	12	0.3744	0.1238
12	12	13	1.468	1.155
13	13	14	0.5416	0.7129
14	14	15	0.591	0.526
15	15	16	0.7463	0.545
16	16	17	1.289	1.721
17	17	18	0.732	0.574
18	2	19	0.164	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.898	0.7091
24	24	25	0.896	0.7011
25	6	26	0.203	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.059	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.963
31	31	32	0.3105	0.3619
32	32	33	0.341	0.5302

TABLE A.2: Load Data for 33bus radial distribution system

BUS NO.	LOAD	
	kW	kVAR
1	0	0
2	0.1	0.06
3	0.09	0.04
4	0.12	0.08
5	0.06	0.03
6	0.06	0.02
7	0.2	0.1
8	0.2	0.1
9	0.06	0.02
10	0.06	0.02
11	0.045	0.03
12	0.06	0.035
13	0.06	0.035
14	0.12	0.08
15	0.06	0.01
16	0.06	0.02
17	0.06	0.02
18	0.09	0.04
19	0.09	0.04
20	0.09	0.04
21	0.09	0.04
22	0.09	0.04
23	0.09	0.05
24	0.42	0.2
25	0.42	0.2
26	0.06	0.025
27	0.06	0.025
28	0.06	0.02
29	0.12	0.07
30	0.2	0.6
31	0.15	0.07
32	0.21	0.1
33	0.06	0.04

TABLE A.3: Bus Data for 69 bus radial distribution system

Branch No.	Sending Bus	Receiving Bus	R (ohm)	X (ohm)
1	1	2	0.0005	0.0012
2	2	3	0.0005	0.0012
3	3	4	0.0015	0.0036
4	4	5	0.0251	0.0294
5	5	6	0.366	0.1864
6	6	7	0.3811	0.1941
7	7	8	0.0922	0.047
8	8	9	0.0493	0.0251
9	9	10	0.819	0.2707
10	10	11	0.1872	0.0619
11	11	12	0.7114	0.2351
12	12	13	1.03	0.34
13	13	14	1.044	0.345
14	14	15	1.058	0.3496
15	15	16	0.1966	0.065
16	16	17	0.3744	0.1238
17	17	18	0.0047	0.0016
18	18	19	0.3276	0.1083
19	19	20	0.2106	0.0696
20	20	21	0.3416	0.1129
21	21	22	0.014	0.0046
22	22	23	0.1591	0.0526
23	23	24	0.3463	0.1145
24	24	25	0.7488	0.2475
25	25	26	0.3089	0.1021
26	26	27	0.1732	0.0572
27	3	28	0.0044	0.0108
28	28	29	0.064	0.1565
29	29	30	0.3978	0.1315
30	30	31	0.0702	0.0232
31	31	32	0.351	0.116
32	32	33	0.839	0.2816
33	33	34	1.708	0.5646
34	34	35	1.474	0.4873
35	3	36	0.0044	0.0108
36	36	37	0.064	0.1565
37	37	38	0.1053	0.123
38	38	39	0.0304	0.0355
39	39	40	0.0018	0.0021
40	40	41	0.7283	0.8509

41	41	42	0.31	0.3623
42	42	43	0.041	0.0478
43	43	44	0.0092	0.0116
44	44	45	0.1089	0.1373
45	45	46	0.0009	0.0012
46	4	47	0.0034	0.0084
47	47	48	0.0851	0.2083
48	48	49	0.2898	0.7091
49	49	50	0.0822	0.2011
50	8	51	0.0928	0.0473
51	51	52	0.3319	0.1114
52	9	53	0.174	0.0886
53	53	54	0.203	0.1034
54	54	55	0.284	0.1447
55	55	56	0.2813	0.1433
56	56	57	1.59	0.5337
57	57	58	0.7837	0.263
58	58	59	0.3042	0.1006
59	59	60	0.3861	0.1172
60	60	61	0.5075	0.2585
61	61	62	0.0974	0.0496
62	62	63	0.145	0.0738
63	63	64	0.7105	0.3619
64	64	65	1.041	0.5302
65	11	66	0.2012	0.0611
66	66	67	0.0047	0.0014
67	12	68	0.7394	0.2444
68	68	69	0.0047	0.0016

TABLE A.4: Load Data for 69 bus radial distribution system

BUS NO.	LOAD	
	kW	kVAr
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0.0026	0.0022
7	0.0404	0.03
8	0.075	0.054
9	0.03	0.022
10	0.028	0.019
11	0.145	0.104
12	0.145	0.104

13	0.008	0.0055
14	0.008	0.0055
15	0	0
16	0.0455	0.03
17	0.06	0.035
18	0.06	0.035
19	0	0
20	0.001	0.0006
21	0.114	0.081
22	0.0053	0.0035
23	0	0
24	0.028	0.02
25	0	0
26	0.014	0.01
27	0.014	0.01
28	0.026	0.0186
29	0.026	0.0186
30	0	0
31	0	0
32	0	0
33	0.014	0.01
34	0.0195	0.014
35	0.006	0.004
36	0.026	0.01855
37	0.026	0.01855
38	0	0
39	0.024	0.017
40	0.024	0.017
41	0.0012	0.001
42	0	0
43	0.006	0.0043
44	0	0
45	0.03922	0.0263
46	0.03922	0.0263
47	0	0
48	0.079	0.0564
49	0.3847	0.2745
50	0.3847	0.2745
51	0.0405	0.0283
52	0.0036	0.0027
53	0.00435	0.0035
54	0.0264	0.019
55	0.024	0.0172
56	0	0
57	0	0

58	0	0
59	0.1	0.072
60	0	0
61	1.244	0.888
62	0.032	0.023
63	0	0
64	0.227	0.162
65	0.059	0.042
66	0.018	0.013
67	0.018	0.013
68	0.028	0.02
69	0.028	0.02

TABLE A.5: Bus Data for 119 bus radial distribution system

Branch No.	Sending Bus	Receiving Bus	R (ohm)	X (ohm)
1	1	2	0	0
2	2	3	0.036	0.01296
3	3	4	0.033	0.01188
4	3	5	0.045	0.0162
5	5	6	0.015	0.054
6	6	7	0.015	0.054
7	7	8	0.015	0.0125
8	8	9	0.018	0.014
9	9	10	0.021	0.063
10	3	11	0.166	0.1344
11	11	12	0.112	0.0789
12	12	13	0.187	0.313
13	13	14	0.142	0.1512
14	14	15	0.18	0.118
15	15	16	0.15	0.045
16	16	17	0.16	0.18
17	17	18	0.157	0.171
18	12	19	0.218	0.285
19	19	20	0.118	0.185
20	20	21	0.16	0.196
21	21	22	0.12	0.189
22	22	23	0.12	0.0789
23	23	24	1.41	0.723
24	24	25	0.293	0.1348
25	25	26	0.133	0.104
26	26	27	0.178	0.134
27	27	28	0.178	0.134

28	5	29	0.015	0.0296
29	29	30	0.012	0.0276
30	30	31	0.12	0.2766
31	31	32	0.21	0.243
32	32	33	0.12	0.054
33	33	34	0.178	0.234
34	34	35	0.178	0.234
35	35	36	0.154	0.162
36	31	37	0.187	0.261
37	37	38	0.133	0.099
38	30	39	0.33	0.194
39	39	40	0.31	0.194
40	40	41	0.13	0.194
41	41	42	0.28	0.15
42	42	43	1.18	0.85
43	43	44	0.42	0.2436
44	44	45	0.27	0.0972
45	45	46	0.339	0.1221
46	46	47	0.27	0.1779
47	36	48	0.21	0.1383
48	48	49	0.12	0.0789
49	49	50	0.15	0.0987
50	50	51	0.15	0.0987
51	51	52	0.24	0.1581s
52	52	53	0.12	0.0789
53	53	54	0.405	0.1458
54	54	55	0.405	0.1458
55	30	56	0.391	0.141
56	56	57	0.406	0.1461
57	57	58	0.406	0.1461
58	58	59	0.706	0.5461
59	59	60	0.338	0.1218
60	60	61	0.338	0.1218
61	61	62	0.207	0.0747
62	62	63	0.247	0.8922
63	2	64	0.028	0.0418
64	64	65	0.117	0.2016
65	65	66	0.255	0.0918
66	66	67	0.21	0.0759
67	67	68	0.383	0.138
68	68	69	0.504	0.3303
69	69	70	0.406	0.1461
70	70	71	0.962	0.761

71	71	72	0.165	0.06
72	72	73	0.303	0.1092
73	73	74	0.303	0.1092
74	74	75	0.206	0.144
75	75	76	0.233	0.084
76	76	77	0.591	0.1773
77	77	78	0.126	0.0453
78	65	79	0.559	0.3687
79	79	80	0.186	0.1227
80	80	81	0.186	0.1227
81	81	82	0.26	0.139
82	82	83	0.154	0.148
83	83	84	0.23	0.128
84	84	85	0.252	0.106
85	85	86	0.18	0.148
86	80	87	0.16	0.182
87	87	88	0.2	0.23
88	88	89	0.16	0.393
89	66	90	0.669	0.2412
90	90	91	0.266	0.1227
91	91	92	0.266	0.1227
92	92	93	0.266	0.1227
93	93	94	0.266	0.1227
94	94	95	0.233	0.115
95	95	96	0.496	0.138
96	92	97	0.196	0.18
97	97	98	0.196	0.18
98	98	99	0.1866	0.122
99	99	100	0.0746	0.318
100	2	101	0.0625	0.0265
101	101	102	0.1501	0.234
102	102	103	0.1347	0.0888
103	103	104	0.2307	0.1203
104	104	105	0.447	0.1608
105	105	106	0.1632	0.0588
106	106	107	0.33	0.099
107	107	108	0.156	0.0561
108	108	109	0.3819	0.1374
109	109	110	0.1626	0.0585
110	110	111	0.3819	0.1374
111	111	112	0.2445	0.0879
112	111	113	0.2088	0.0753
113	113	114	0.2301	0.0828

114	101	115	0.6102	0.2196
115	115	116	0.1866	0.127
116	116	117	0.3732	0.246
117	117	118	0.405	0.367
118	118	119	0.489	0.438

TABLE A.6: Load Data for 119 bus radial distribution system

BUS NO.	LOAD	
	kW	kVAr
1	0	0
2	0	0
3	0.13384	0.10114
4	0.016214	0.011292
5	0.034315	0.021845
6	0.073016	0.063602
7	0.1442	0.068604
8	0.10447	0.061725
9	0.028547	0.011503
10	0.08756	0.051073
11	0.1982	0.10677
12	0.1468	0.075995
13	0.02604	0.018687
14	0.0521	0.02322
15	0.1419	0.1175
16	0.02187	0.02879
17	0.03337	0.02645
18	0.03243	0.02523
19	0.020234	0.011906
20	0.15694	0.078523
21	0.54629	0.3514
22	0.18031	0.1642
23	0.093167	0.054594
24	0.08518	0.03965
25	0.1681	0.095178
26	0.12511	0.15022
27	0.01603	0.02462
28	0.02603	0.02462
29	0.59456	0.52262
30	0.12062	0.059117
31	0.10238	0.099554
32	0.5134	0.3185
33	0.47525	0.45614

34	0.15143	0.13679
35	0.20538	0.083302
36	0.1316	0.093082
37	0.4484	0.36979
38	0.44052	0.32164
39	0.11254	0.055134
40	0.053963	0.038998
41	0.39305	0.3426
42	0.32674	0.27856
43	0.53626	0.24024
44	0.076247	0.066562
45	0.05352	0.03976
46	0.040328	0.031964
47	0.039653	0.020758
48	0.066195	0.042361
49	0.073904	0.051653
50	0.11477	0.057965
51	0.91837	1.2051
52	0.2103	0.14666
53	0.06668	0.056608
54	0.042207	0.040184
55	0.43374	0.28341
56	0.0621	0.02686
57	0.09246	0.08838
58	0.085188	0.055436
59	0.3453	0.3324
60	0.0225	0.01683
61	0.080551	0.049156
62	0.09586	0.090758
63	0.06292	0.0477
64	0.4788	0.46374
65	0.12094	0.052006
66	0.13911	0.10034
67	0.39178	0.1935
68	0.027741	0.026713
69	0.052814	0.025257
70	0.06689	0.038713
71	0.4675	0.39514
72	0.59485	0.23974
73	0.1325	0.084363
74	0.052699	0.022482
75	0.86979	0.614775
76	0.031349	0.029817
77	0.19239	0.12243
78	0.06575	0.04537

79	0.23815	0.22322
80	0.29455	0.16247
81	0.48557	0.43792
82	0.24353	0.18303
83	0.24353	0.18303
84	0.13425	0.11929
85	0.02271	0.02796
86	0.049513	0.026515
87	0.38378	0.25716
88	0.04964	0.0206
89	0.022473	0.011806
90	0.06293	0.04296
91	0.03067	0.03493
92	0.06253	0.06679
93	0.11457	0.081748
94	0.081292	0.066526
95	0.031733	0.01596
96	0.03332	0.06048
97	0.53128	0.22485
98	0.50703	0.36742
99	0.02639	0.0117
100	0.04599	0.030392
101	0.10066	0.047572
102	0.45648	0.3503
103	0.52256	0.44929
104	0.40843	0.16846
105	0.14148	0.13425
106	0.10443	0.066024
107	0.096793	0.083647
108	0.49392	0.41934
109	0.22538	0.13588
110	0.50921	0.38721
111	0.1885	0.17346
112	0.91803	0.89855
113	0.30508	0.21537
114	0.05438	0.04097
115	0.21114	0.1929
116	0.067009	0.053336
117	0.16207	0.090321
118	0.048785	0.029156
119	0.0339	0.01898

TABLE A.7: Hourly Peak Load In Terms Of Daily Peak Load

Summer Weekly Load	
Hour	Hourly load in terms of peak load
12-1 am	0.64
1-2	0.60
2-3	0.58
3-4	0.56
4-5	0.56
5-6	0.58
6-7	0.64
7-8	0.76
8-9	0.87
9-10	0.95
10-11	0.99
11-12pm	1.00
12pm-1	0.99
1-2	1.00
2-3	1.00
3-4	0.97
4-5	0.96
5-6	0.96
6-7	0.93
7-8	0.92
8-9	0.92
9-10	0.93
10-11	0.87
11-12	0.72

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