Optimal Allocation And Sizing Of Distributed Generators/ Distributed Static Compensator By Using Heuristic Algorithm

BY

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CERTIFICATE

We accept the work contained in this report as a confirmation to the required standard for the partial fulfilment of the degree of MS(EE).

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DEDICATION

Dedicated to my devoted parents.

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UNDERTAKING

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ABSTRACT

Distribution system needs to be optimized due to increase in load demand. It is significant to optimally allocate distributed generators (DGs) in the distribution systems to minimize power losses and voltage drops. However, DGs incur certain investment and operational costs, and their placement is only viable if these costs overcome energy losses. Therefore, current thesis investiG.Ates the optimal placement and sizing of DGs in distribution systems with an aim to simultaneously minimize total energy cost along with power loss and average voltage drop. An artificial bee colony (A.B.C) algorithm is proposed in this thesis to solve the considered multi-objective problem. The performance of the proposed A.B.C algorithm is tested with already published standard algorithms. Newton Raphson load flow (NRLF) analysis is conducted in IEEE ‘33’ and ‘69’-bus radial systems and on CIGRE low voltage (LV) benchmark grid. Two test cases have been formed and investiG.Ated. The results prove that proposed A.B.C algorithm outperforms other algorithms.

KEYWORDS Distributed generation (DG), Newton Raphson Load flow (NRLF) analysis, optimal placement and sizing of DGs, line loss, voltage drop, artificial bee colony algorithm

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LIST OF ‘TABLE’

ABBREVIATIONS

A.B.C	Artificial Bee Colony
B.A	Bat Algorithm
B.B.O	Biogeography Based Optimization
B.F.A	Bacterial Foraging Algorithm
B.F.O	Bacterial Foraging Optimization
B.S.O	Backtracking Search Algorithm
C.B(s)	Capacitor Banks
C.S.A	Cuckoo Search Algorithm
DG	Distributed Generators
E.A	Efficient Analytical
G.A	Genetic Algorithm
H.G.W.O	Hybrid Grey Wolf Optimization
I.W.D	Intelligent Water Drop
I.W.O	Invasive Weed Optimization
LF	Load Flow
MI	Maximum Iterations
NRLF	Newton Raphson Load Flow
P.S.O	Particle Swarm Optimization
RDS	Radial Distribution System
S.K.H.A	Strud Kill Herd Algorithm

NOMENCLATURE

β	net present factor
B_e	employed bees
B_o	onlooker bees
C_T	sum of all costs
C_{DGi}	capacity of ith DG
$fitness_p$	fitness value of solution p
i_{pj}	current flow between bus p and j
IC_i	installation cost
I_k	branch current of kth bus
I_{k_R}	maximum thermal limit
k	index for bus
MC_i	maintenance cost
N	total number of buses
N_e	total number of employed bees
P_{loss}	active power loss
P_{in}	power flow from grid towards load
P_{DG}	active power supplied by each DG
P_{load}	total load
P_{t_loss}	active power loss reduction
P_{0_loss}	total loss before adding DGs
P_{DG_loss}	total loss after adding DGs
p	population size
P_s	selection probability
P_k	injected active power at kth bus
Q_k	injected reactive power at kth bus
S_{loss}	total apparent power loss
S_p	apparent power at pth bus
S_j	apparent power at pth bus
$\mathrm{T_G}$	grid tariff
$\mathrm{V_p}$	voltage at pth bus
$\mathrm{V_j}$	voltage at jth bus
V_D	voltage drop
V_{avg}	average value of all buses
V_k	voltage at kth bus
V_{rated}	rated bus voltage
V_{low}	minimum value of voltage
V_{up}	maximum value of voltage
Y	admittance matrix
y_{mp}	p^{th} parameter of solution y_m
Z	impedance matrix
δ	voltage angle
θ	impedance angle
Δ_T	time period

Chapter No. 1

Introduction

CHAPTER NO. 1 INTRODUCTION

1.1. Overview

The generation, transmission and distribution network form an electrical power system. The generating plant generate electricity, transmission network ties generating units and distribution networks distribute electricity to the consumers. The distribution and transmission networks vary in terms of system structure. There is a radial structure in distribution network and loop structure in transmission network.

In Pakistan, the distribution network is the weakest link among whole power area. Most of the power losses are formed by secondary and primary distribution lines. The main factors that take part in power losses are transmission of power form long distances, low voltage, technical losses and low power factor of distribution network. The increase of population causes increase in electrical demand. It is becoming more and more challenging for power distribution firms to meet the increase demand of consumers efficiently. The complexity of distribution network increases. Due to large current drawn in the distribution of power, the instability of the system occurs, and it causes power losses and voltage drop.

1.2. Problem Description

The electrical load demand has been seen to have an extensive rise in the last decades, which in turn has increased overall line loss and voltage drop. As distribution systems have low X/R ratio when matched with transmission systems, therefore line loss and voltage drop is more significant in distribution systems [1]. Conventionally, this loss was overcome by expanding the infrastructures [2]. However, it was observed that only 20% of expanded infrastructure is utilized in serving peak load for 5% of overall operating time [3].

There were many techniques which have been proposed from past few years for minimization of power loss and voltage drop by allocation of capacitor banks and inserting reactive power. The placement of capacitor bank method is promising but the voltage profile improvement is under the desired voltage value i.e. 1 per unit (p.u). This process is less effective due to passive design of radial distribution system. Many methods were proposed to overcome the passiveness of radial distribution system and to minimize voltage drop by adding renewable energy resources. This renewable generations technology in RDS is called as Distributed Generation (DG). The technology of distributed generators (DGs) has G.Ained enough popularity due to its limited commissioning time and fast response [4]. These DGs could minimize line loss and voltage drop in electricity grids, if they are optimally sized and placed. Both reactive and active power can be delivered by a DG, and therefore can decrease the peak load demand. This eventually reduces the power loss and voltage drop and enhance the stability and power factor of power system [5]. These complications can be resolved by optimally allocation of distributed generators. Therefore, current thesis investiG.Ates the optimal sizing and placement of DGs in distribution systems with an objective to simultaneously minimize total energy cost, total power loss and average voltage drop.

1.3. Objectives

This project has following objectives:

1. The implementation of A.B.C algorithm to find best location and size of DGs to minimize energy cost, power loss and voltage drop of distributed generators. The results found from proposed method are then compared with genetic algorithm (G.A).
2. Carrying out a thorough analysis of performance of proposed approach in IEEE ‘33’, ‘69’-bus radial, and CIGRE MV/LV benchmark distribution system for explaining the efficiency of the suggested technique.

1.4. Thesis OrG.Anization

The orG.Anization of thesis is as follow:

- Chapter No. 1 reviews introduction of power system, the literature review, motivation and problem statement, objectives, & orG.Anization of dissertation.
- Chapter No. 2 explains the literature review
- Chapter No. 3 describes power flow analysis and mathematical mode of radial distribution.
- Chapter No. 4 explains the proposed A.B.C algorithm
- Chapter No. 5 details the test systems and results obtained after the proposed system.

- Chapter No. 6 summarizes the conclusion and some future works.

Chapter No. 2

Literature Review

CHAPTER NO. 2 LITERATURE REVIEW

In distribution systems, ratio of R/X is relatively higher than transmission system, which implies that distribution system has high power losses as compared to transmission system. It has been stated that 13% of the power generated dissipates as copper loss in distribution system [6]. And it directly impacts in the increment of cost of energy with the imbalance in voltage profile. Due to power dissipation in distribution system, the economical operation effects and can be improved by reducing power loss in distribution system [6].While there are several methods to reduce or overcome the losses such as higher voltage levels, induction of capacitors, reconductoring and reconfiguration of networks. The DG installation are one of the most effective approaches to reduce the voltage drop and to overcome the issue of power loss, which can increase the overall efficiency of distribution network [7]. DGs are tiny power making plants that are linked to the consumer side or distribution network. The application of DGs allocation in distribution system has been growing remarkably, and ecological, technical, and economic effects of them on power network are being investiG.Ated. The important parameters which can be impacts on the economic and technical factors are optimal position, type, and size of DGs in power system.

The published literature shows numerous approaches for optimally allocation of DGs in different distribution grids. In [8], authors have used nature based genetic algorithm (G.A) in order to search out optimal position and size of DGs. The author minimizes the power loss and tested the proposed algorithm in IEEE ‘16’,’ 37’ and ‘75’-bus distribution networks. The authors in [9], have introduced an improved re-initialized socially structured particle swarm optimization algorithm (IRS-PSO) to optimally locate multiple number of DGs in microgrid. The multi objectives of power loss and voltage drop minimization have been achieved. Authors have tested the proposed algorithm in IEEE ‘69’-bus radial system.

In [10], authors have used sensitivity test technique to find out optimal sizing and location of DGs. The author minimizes power loss and tested the proposed algorithm in IEEE ‘33’, and ‘69’-bus networks. An artificial bee colony (A.B.C) based optimal sizing and location of a single DG has been proposed for minimization of power loss in the system. Authors have tested the proposed algorithm in IEEE ‘33’ and ‘69’-bus systems [11].

In [12], the optimal placement of multiple DGs was searched by using hybrid grey wolf optimization (H.G.W.O). The main target of the research is to minimize the problem of power loss and tested the proposed method in IEEE ‘33’, ‘69’ and Indian ‘85’-bus radial networks. The authors in [13], have proposed bat algorithm (B.A) for optimal assignment of PV power. The author minimizes the power loss and tested in IEEE ‘33’-bus distribution model. Authors in [14] have applied particle swarm optimization (P.S.O) technique to locate capacitors and DGs. The objective was to maximize the profit. The presented scheme was tested in IEEE ‘33’ and ‘69’-bus networks.

In [15], the optimal placement of multiple DGs was searched by using strud krill herd algorithm (S.K.H.A). The authors have achieved the objective of line loss minimization and tested the proposed method in IEEE ‘33’, ‘69’-bus and Portuguese ‘94’-bus radial distribution grid. The authors in [16], have optimally placed DGs by proposing an improved version of P.S.O algorithm. The objective was the maximization of the profit. The presented scheme was examined in IEEE ‘34’-bus network. The authors in [17], have implemented P.S.O to evaluate the effect of sizing and siting of a single DG. The aim of authors was to decrease power loss. The proposed algorithm was verified in IEEE ‘33’ and ‘69’-bus systems.

The authors in [18], have applied the bat-inspired algorithm (B.A) to optimally locate and size a single DG. The presented method was verified in IEEE ‘33’ and ‘69’-bus network. A hybrid population-based approach was introduced along with the integration of P.S.O and gravitational search algorithm to optimize size of DGs along with their placement in distribution networks [19]. The authors in [20], have introduced a bacterial foraging algorithm (B.F.A) to optimally allocate DGs in IEEE ‘12’, ‘34’ and ‘69’-bus distribution models. The objectives were to enhance bus voltages and to decrease power losses. In [21], an efficient analytical (E.A) approach was adopted for optimal distribution of various DGs. The author minimizes the power loss and tested in IEEE standard distribution systems.

In [22], authors have presented genetic algorithm (G.A) for optimal placement and sizing of capacitor banks (C.B(s)) and DGs. The objectives were to enhance reliability and to reduce power loss. The proposed algorithm was verified in IEEE radial systems. The authors in [23], have proposed biogeography-based optimization (B.B.O) to place PV arrays. The single aim of the research work is the minimization of power loss. The presented optimization technique was verified in IEEE ‘33’ and ‘69’-bus radial systems. Authors have utilized Harmony Search Algorithm (H.S.A) in order to search the DG optimal location and reconfiguration of the network simultaneously by considering the power loss minimization as only objective function [24].

The cuckoo search algorithm (C.S.A) has been presented in [25], to search optimal site and capacity of DGs. The objectives were to lower line losses and voltage drops. The proposed algorithm was verified in IEEE ‘69’-bus radial distribution grid. In [26], authors have presented a reconfiguration by using C.S.A. The main targets were to reduce overall power loss and total voltage drop. The proposed optimization method was verified in IEEE ‘33’, ‘69’ and ‘119’-bus distribution models. In [27], invasive weed optimization (I.W.O) has been evaluated while optimally allotting a single DG. The proposed optimization problem was tested in IEEE ‘33’ and ‘69’-bus radial distribution systems. The objectives were to minimize total power loss, operating cost and voltage violation.

In [28], a hybrid technique (H.A) has been presented to optimally size and position DGs. The size of DGs has been optimized by analytical method and location has been found by P.S.O. The verification of the technique was performed on standard IEEE networks. The objectives include minimization of overall power loss and to enhance voltage profile. The authors in [29], have proposed backtracking search optimization (B.S.O) to search optimal capacity and site of DGs. IEEE ‘33’-bus and Portuguese ‘94’-bus radial networks were used for the verification of the proposed method. The objectives were to reduce power loss and voltage drop. In [30], bacterial foraging optimization (B.F.O) has been proposed to place and size a single DG in IEEE distribution system. The objectives were the reduction in active power loss, operating cost and voltage drop. In [31], nature intelligent water drops (I.W.D) optimization has been presented to optimally place DGs. The proposed optimization scheme is tested in IEEE ‘10’, ‘33’ and ‘69’-bus radial grids. The objectives were to reduce total line loss.

Previously, A.B.C algorithm has been implemented on various problems in power system, that includes optimal power dispatch (PD), loss minimization in distribution networks, economic dispatch (ED) of power sources and tuning of power system stabilizers [32]. According to the authors’ knowledge, till date A.B.C algorithm has not been applied to the same problem, that is investigated in this thesis.

2.1 Discussion on Literature Review

From above literature survey, it can be seen that the majority of authors optimally placed or sized DGs to minimize power loss or to improve voltage profile or simultaneously both of them by using different algorithms. However, whenever a DG is optimally selected, there are certain investment and operational costs attached to it. The impact of these costs couldn't be ignored, as addition of DGs must be economically viable as well. Therefore, in this thesis, third objective of total energy cost has been considered, which is simultaneously minimized along with first two objectives including total active power loss and average voltage drop. The total energy cost is the cost of power flow from grid towards total load demand. It includes the cost of total input power and loss power. This cost will increase if there are more power losses and vice versa.

The authors have proposed A.B.C algorithm to find optimal values of multiple objectives while performing a Newton Raphson load flow (NRLF) analysis. A.B.C algorithm is swarm intelligence-based algorithm which searches solution based on foraging behaviours of bees. The limit cycle ability of the A.B.C algorithm reduces the chance of local optimization, and therefore increases its diversity.

Two test cases have been formed and investigated. In the 1st case, two objectives, including total active power loss and average voltage drop, have been simultaneously minimized in IEEE '33' and '69'-bus radial networks with proposed A.B.C algorithm, and the results have been compared with previously applied algorithms. In the 2nd case, three objectives, including total active power loss, average voltage drop, and total energy cost have been simultaneously minimized in IEEE '33' and '69'-bus radial networks and in CIGRE LV benchmark grid with proposed A.B.C algorithm and the results have been compared with G.A.

Chapter No. 3

Methodology

CHAPTER NO. 3 METHODOLOGY

The ultimate target is to simultaneously minimize three objectives, including total active power loss, average voltage drop and total energy cost in three test systems. The ‘test-system-1’ is IEEE ‘33’-bus radial networks, ‘test-system-2’ is IEEE ‘69’-bus radial networks [18], and ‘test-system-3’ is CIGRE LV benchmark grid [33]. These objectives are subject to constraints of voltage limitations of buses, generation capacity limitations of DGs, limitations of branch currents and power balance. These objectives are minimized by performing a NRLF analysis on above-mentioned distribution networks. The optimal values of objectives are selected by using A.B.C algorithm.

3.1 Objectives to be minimized

3.1.1 Active Power Loss

Active power loss P_{loss} (kW) minimization is the first objective and is calculated by using eq’s. (3.1-3.7) [34].

$$P_{loss} = P_p - P_j \tag{3.1}$$

Where, P_{loss} is defined as total active power loss in kW. P_p and P_j represent active powers at buses p and j. The injected active power P_k and reactive power Q_k at any k^{th} bus is calculated by using eq. (3.2) and eq. (3.3).

$$P_k = \sum_{i=1}^{N} V_i Y_{ki} V_k \cos(\delta_i + \theta_{ki} - \delta_k) \tag{3.2}$$

$$Q_k = -\sum_{i=1}^{N} V_i Y_{ki} V_k \sin(\delta_i + \theta_{ki} - \delta_k) \tag{3.3}$$

Apparent power loss S_{loss} (kVA) is defined as:

$$S_{loss} = S_p - S_j \tag{3.4}$$

S_p and S_j represent apparent powers at buses p and j and calculated by suing eq. (3.5) and eq. (3.6)

$$S_p = V_p \times i_{pj}^{*} \tag{3.5}$$

$$S_j = V_j \times i_{pj}^{*} \tag{3.6}$$

Where, i_{pj} is current flow between buses p and j and calculated by using eq.(3.7)

$$i_{pj} = \frac{V_p - V_j}{Z_{pj}} \tag{3.7}$$

Total active power loss reduction P_{t_loss} is measured in percentage (%) and is calculated by eq.(3.8) [35]. P_{t_loss} shows difference in loss minimization in percentage after adding DGs.

$$P_{t\_loss} = \frac{P_{0\_loss} - P_{DG\_loss}}{P_{0\_loss}} \times 100 \tag{3.8}$$

Where, P_{0_loss} is defined as total active power loss before adding DGs and P_{DG_loss} is defined as total active power loss after adding DGs.

3.1.2 Voltage Drop

Minimization of average voltage drop is the second objective and is calculated by using eq's. (3.9-3.11).

$$V_D = V_{rated} - V_{avg} \tag{3.9}$$

Where, V_{avg} is the average voltage of all buses and V_{rated} is the nominal bus voltage and it is 1 per unit (p.u). Average voltage is calculated by using eq. (3.10)

$$V_{avg} = \frac{\sum_{k=1}^{N} V_k}{N} \tag{3.10}$$

Where, V_k is defined as voltage at kth bus and N is defined as total number of buses. Voltage at kth bus is calculated by using eq. (3.11)

$$V_k = \frac{1}{Y_{kk}}[\frac{(P_k - jQ_k)}{V_k^*} - \sum_{\substack{i=1 \\ i \neq k}}^{N} Y_{ki} \times V_i] \tag{3.11}$$

3.1.3 Total Energy Cost

The third objective is minimization of total energy cost C_T (\$) and is calculated by using eq. (3.12).

$$C_T = \sum_{i=1}^{Z} (\mathrm{C}_{DGi} \times IC_i) + \sum_{i=1}^{Z} (C_{DGi} \times MC_i) + P_{in} \Delta T T_G \beta \tag{3.12}$$

Where, C_T is the sum of installation, maintenance and operational costs [14]. The first part in equation (12) represents installation cost, the second part represents maintenance cost, and third part represents operational cost. C_{DGi} is rating of i^{th} DG and it's unit is MW and IC_i is installation cost of i^{th} DG and it's unit is \$/MW. Similarly, MC_i is maintenance cost of i^{th} DG and it's unit is \$/MW. P_{in} is total power flow from grid towards total load and is defined in eq. (3.13).

$$P_{in} = P_{loss} + \sum_{k=1}^{N} P_{load_k} - \sum_{i=1}^{Z} P_{DG_i} \tag{3.13}$$

Where, ΔT is time period in hours, T_G is grid tariff and β is net present factor. P_{DG} is active power (kW) injected by DG. P_{load} is total load at i^{th} bus.

As mentioned before, these objectives are subject to four constraints. These constraints are listed below.

- **Voltage Limitations of Buses**

  The nodal voltages are constrained by upper and lower limits, as shown in eq. (3.14).

  $$V_{low} \leq V_k \leq V_{up} \tag{3.14}$$

  Where, V_{low} is minimum value of voltage and measured in p.u and V_{up} is maximum value and it is also measured in p.u.

- **Capacity Limitations of DGs**

The active power supplied by each DG is also constrained by its upper and lower limits, as shown in eq. (3.15).

$$0 \le P_{DG_i} \le \sum P_{load} \tag{3.15}$$

Where, P_{DG} is active power supplied by each i^{th} DG and measured in kW. P_{load} is total load and also measured in kW.

- **Limitations of Branch Current**

The placement of DGs might increase branch currents in network. Therefore, branch currents are also constrained by upper limits, as shown in eq. (3.16).

$$I_k < I_{k\_R} \ , k = 1, 2, ...(\mathrm{N}-1) \tag{3.16}$$

Where, I_k is branch current of k^{th} bus and I_{k_R} is its maximum thermal limit.

- **Power Balance**

The total active power which is supplied by DGs and grid must be enough to fulfil total load and losses, as shown in eq. (3.17).

$$\sum_{i=1}^{Z} P_{DG_i} + P_{base} = \sum_{k=1}^{N} P_{load_k} + P_{loss} \tag{3.17}$$

Where, P_{base} is the base power coming from grid.

3.2 Load Flow Analysis

In estimating the control and process of electrical power system and then decision of future extension, the approach of determining the condition of power system are very essential. The condition of power system is assessed by the means of load flow study to determine the energy flows through the network lines. The load flow for a specific system is calculated by various methods which are: Fast Decoupled, Newton Raphson Load Flow (NRLF) and Gauss Siedel method. Digital computer techniques for load flow of power system were found in the last few years. The digital computer techniques are more reliable, and their convergence is fast. Few failures in technically achievable programs can be irrational when used on a routine basis.

The primary aim of load flow study is to find out phase voltages at each bus of network that meet the system requirements. For every bus, there are restrictions to calculate the unknown parameters which are voltage angles and magnitudes, active and reactive powers. The buses are divided into two categories i.e. generator and load buses. As a reference bus a special generator type of bus is used which is slack bus. The limitations are different for different types of buses [36] [37]. Due to numerous benefits, the Newton Raphson method is the best load flow process. Compared with other methods it has strong convergence property. Sparse system equations are determined by sparsely programmed elimination techniques which achieve considerably low calculation times [38].

3.2.1 Newton Raphson Load Flow (NRLF) Analysis

Following is the algorithm for computation of load flow study by using the technique of Newton Raphson:

Step # 1: Make the admittance matrix (Y_{pj})

Step # 2: Estimate the bus voltages and set bus *k* as reference bus as defined in equation (3.18) and equation (3.19):

$$V_p = V_{\mathrm{p},spec} < 0^o \text{ (for all the PV Buses)} \tag{3.18}$$

$$V_p = 1 < 0^o \text{ (for all the PQ Buses)} \tag{3.19}$$

Step # 3: Estimate the active power P_p by using the load flow equation (3.20):

$$P_p = G_{pp} \, |V_p|^2 + \sum_{j=1}^{N} |V_p| \, |V_j| \, (G_{pj} \cos\theta_{pj} + B_{pj} \sin\theta_{pj}) \tag{3.20}$$

Step # 4: Estimate the reactive power Q_p by using the load flow equation (3.21):

$$Q_p = -B_{pp} |V_p|^2 + \sum_{j=1}^{N} |V_p||V_j| (G_{pj} \sin\theta_{pj} + B_{pj} \cos\theta_{pj}) \tag{3.21}$$

Step # 5: Make the jacobian matrix

Step # 6: Find the difference of powers ΔP_p and ΔQ_p for i=1, 2, 3… (k-1) by using equation (3.22) and (3.23)

$$\Delta P_p = P_{p,spec.} - P_{p,cal.} \tag{3.22}$$

$$\Delta Q_p = Q_{p,spec.} - Q_{p,cal.} \tag{3.23}$$

Step # 7: Select the values of tolerance.

Step # 8: If ΔP_p and ΔQ_p are all within values of tolerance, break the iteration.

Step # 9: Update values of V_p and δ_p by using the equation (3.24)

$$x^{l+1} = x^l + \Delta x^l \tag{3.24}$$

Chapter No. 4

Proposed Algorithm

CHAPTER NO. 4 PROPOSED ALGORITHM

4.1 Artificial Bee Colony (A.B.C Algorithm)

Optimization technique is essential for searching the best solution for all conditions. For instance, in an organization administrative and industrial plans are required to enhance the rating. The aim of the plans is to make the profit maximum or to minimize the effort. The minimization or maximization both are includes in optimization. To find the function of minimization, take the additive inverse of maximization function so in this way both can be interchanged. Hence, optimization methods are very essential for all fields.

A.B.C algorithm is a swarm-based optimization algorithm and its objective is to search solution based on hunting of bees. Karobaga [39] introduced this algorithm in 2005 after that several versions and modifications in this algorithm have been made by several researchers [40-42].

There exist three type of bees, first type is employee bee, second type is onlooker bee and third type is scout bee. The working of employee bees is to search different solutions of optimization problem which are defined as food sources. The employee bees find different food sources then obtain their nectar amount and then send all information to the onlooker bees. It is important that the number of employee and onlooker bees are same in number. The working of onlooker bees is to evaluate the food sources which are searched by the employee bees. The probability of onlooker bees accepting a food source depends upon the information and nectar amount. The employee bees which give same nectar amount for certain number of cycles, called limit cycle, are converted to scout bees and they find new food sources randomly. This can reduce the chances of local optimization and can help to increase the diversity of algorithm. The A.B.C algorithm search process is presented as follows:

Step No. 1: In this step the algorithm parameters which includes number of employee bees, onlooker bees and then limit cycle are initialized.

Step No. 2: In this step, population of food sources is generated. Generally, initial population of p random solutions (p=1, 2, 3,….. N_e) is generated where p is a V dimensional vector representing a food source.

Step No. 3: In this step, employee bees find the food sources, calculate nectar amount of each food source and update the position in their storage by testing the quality of nectar amount. If new position has a better nectar quality than that of last one, the employee bees remember the new position, else no changes will be made.

Step No. 4: In this step, based on nectar amount onlooker bees evaluate the food sources. The onlooker bees compare the neighbouring food source position with the selected position. This is done by changing one of the randomly chosen parameter by using eq. (4.1). y_{mp} is the p^{th} parameter of solution y_m.

$$y_{mp}^{new} = y_{mp}^{old} + v(y_{mp}^{old} - y_{kp}) \tag{4.1}$$

The probability to find the best food source can be calculated by using eq. (4.2).

$$P_p = \frac{fitness_p}{\sum_{p=1}^{N_e} fitness_p} \tag{4.2}$$

Step No. 5: If onlooker bees find any employee bee with same nectar amount for fixed number of limit cycle, they convert them into scout bees, and searches new food source randomly to increase diversity of food sources.

Step No. 6: Once the food sources are evaluated, they are stored in archives and next cycle of algorithm begins.

The flowchart of proposed A.B.C algorithm is shown in 'fig.' (4.1). The pseudocode of A.B.C algorithm for problem considered in this thesis is given below:

Step No. 1: Read and load line data, and perform LF analysis, and compute all system parameters for without adding DGs.

Step No. 2: Initialize A.B.C Parameters (population size, number of iterations and limit cycle).

Step No. 3: Generate population by performing LF analysis and compute all system parameters with adding DGs.

Step No. 4: Set Iteration=1

Step No. 5: Employee bee phase

Find new food sources for each employee bee

Compute fitness value.

Replace old position with new one, if the new position is better.

Step No. 6: Compute the fitness function and probability for solution.

Step No. 7: Onlooker bee phase

For each onlooker bee, find a food source of high probability and update a new position of food source.

Compute the fitness value.

if new position is better, replace old position with new one,

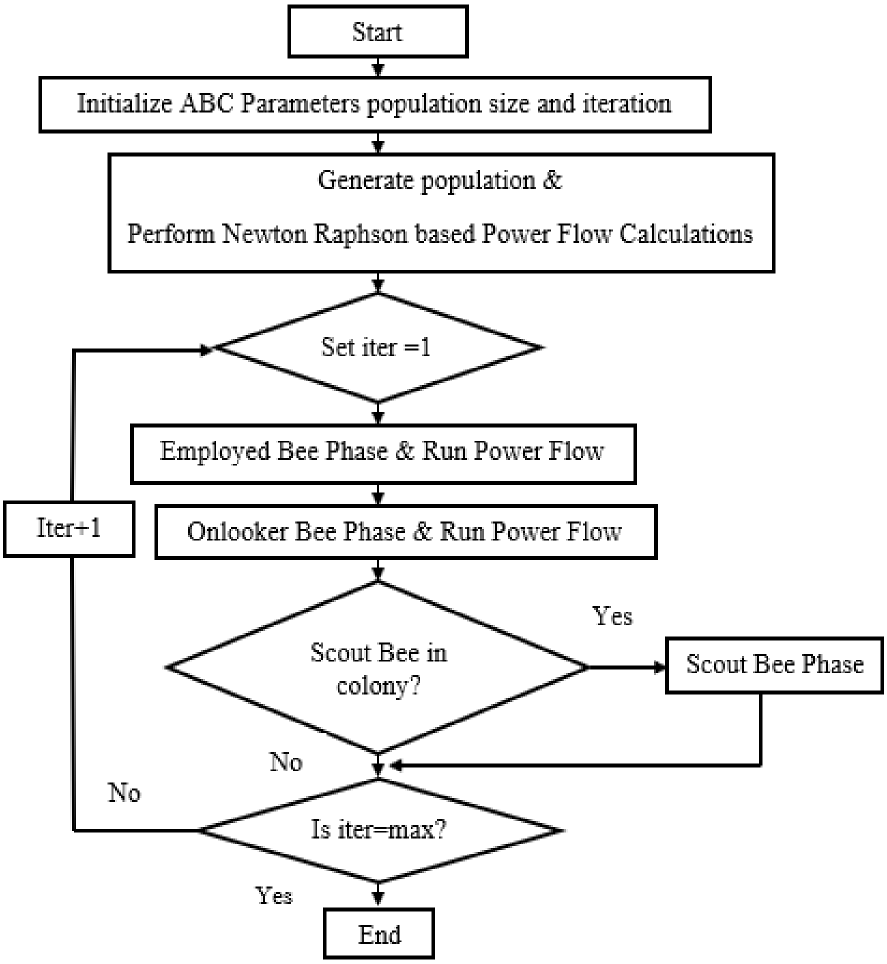
End

Step No. 8: Scout bee phase

Employee bee is replaced with random source position if it becomes a scout bee.

Step No. 9: Save the best solution in the memory.

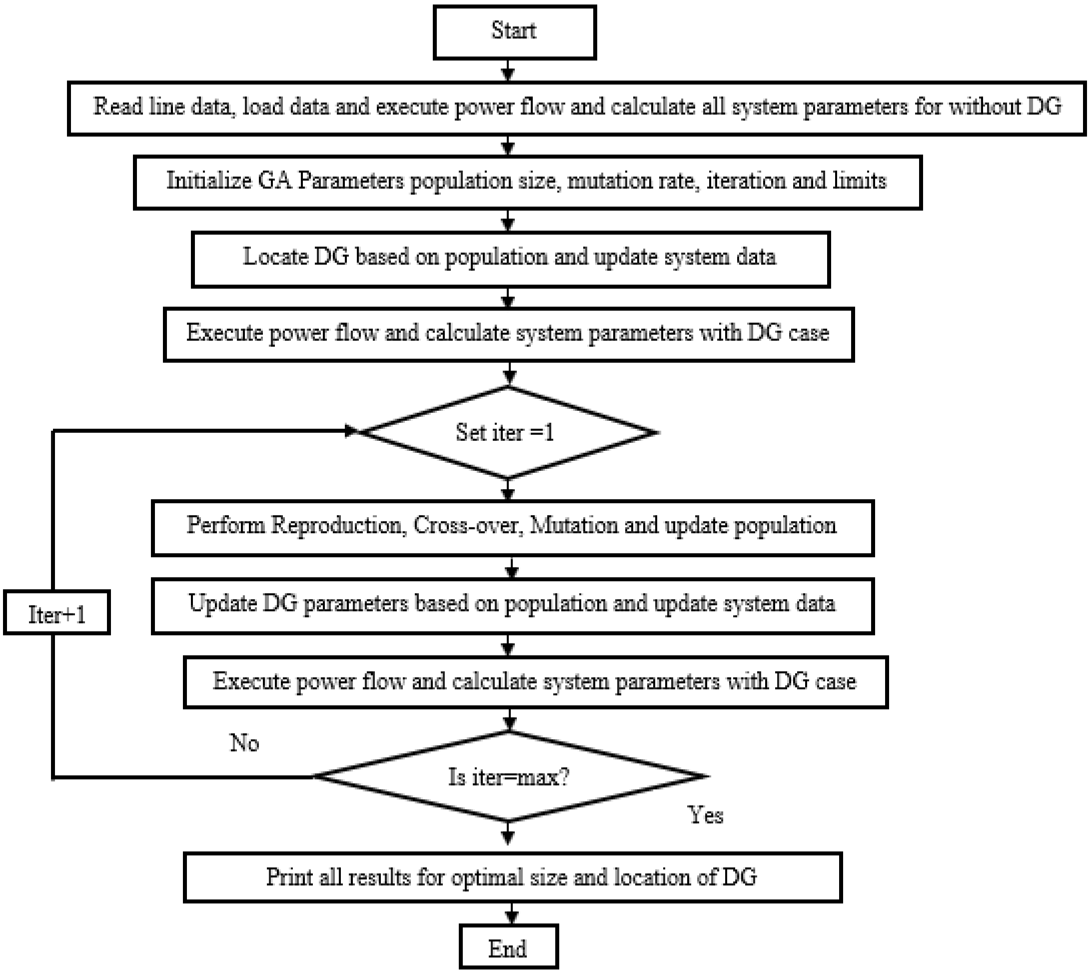
Step No. 10: iteration = iteration + 1 until iteration = MI



‘fig.’ 4.1 **Flow Chart of A.B.C Algorithm**

4.2 Genetic Algorithm (G.A)

Genetic algorithm technique based on natural selection [35]. In this thesis, multi-objective functions are minimized with A.B.C algorithm and results are then compared with G.A. ‘fig.’ 4.2 shows the flow chart of G.A.



‘fig.’ 4.2 **Flow Chart of G.A Algorithm**

Chapter No. 5

Results and Discussions

CHAPTER NO.5 RESULTS AND DISCUSSIONS

The NRLF calculations have been performed with proposed A.B.C algorithm ‘Test-System-1’, ‘Test-System-2’ and ‘Test-System-3’. The complete system has been coded and realized in MATLAB, and two test cases have been formed. In the 1st case, simultaneous minimization of P_{loss} and V_D has been done in ‘Test-System-1’ and ‘Test-System-2’ by adding three DGs with the proposed A.B.C algorithm. In 2nd case, simultaneous minimization of P_{loss}, V_D and C_T has been done in ‘Test-System-1’, ‘Test-System-2’ and ‘Test-System-3’ by adding three DGs with proposed A.B.C algorithm. ‘table’. 5.1 shows details of input parameters of A.B.C algorithm and G.A, and related costs.

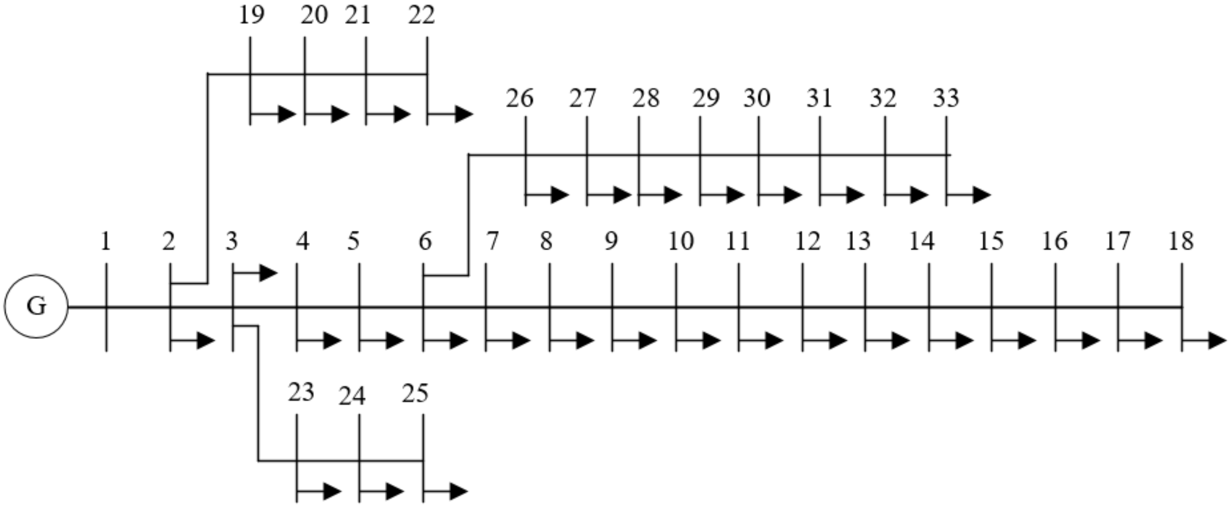
‘table’. 5.1

Inputs Parameters for A.B.C and G.A

Parameters	**IEEE 33- BUS SYSTEM**	**IEEE 69-BUS SYSTEM**	**CIGRE MV/LV network**
No. of Iterations	100	150	100
Population Size	400	800	400
Size Range of DGs (kW)	100 ~ 1000	100 ~ 1000	100 ~ 1000
ICi ($/kW)	350	350	350
MCi ($/kW)	350	350	350
TG ($/kWh)	0.15	0.15	0.15
IR (%)	12.5	12.5	12.5
IF (%)	9	9	9

5.1 'Test-System-1'

'Test-System-1' with 33 buses and 37 branches is shown in 'fig.' (5.1). The total active load demand of this system is 3720 kW and reactive load demand of this system is 2300 kVAR. The NRLF calculations of this system result in a P_{loss} of 232.9 kW and a V_{min} of 0.8778 (p.u) without DGs. The V_{avg} of this system is 0.9297 (p.u) which results in a V_D of 0.0703 (p.u). C_T without DGs is $4298861.

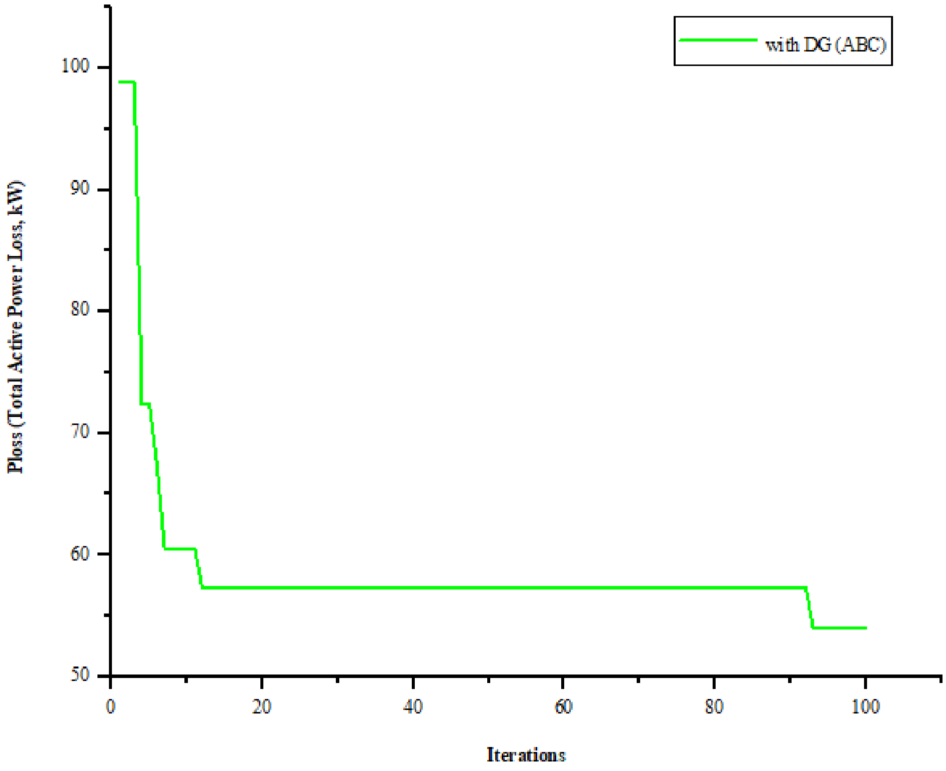


'fig.' 5.1 **'Test-System-1'**

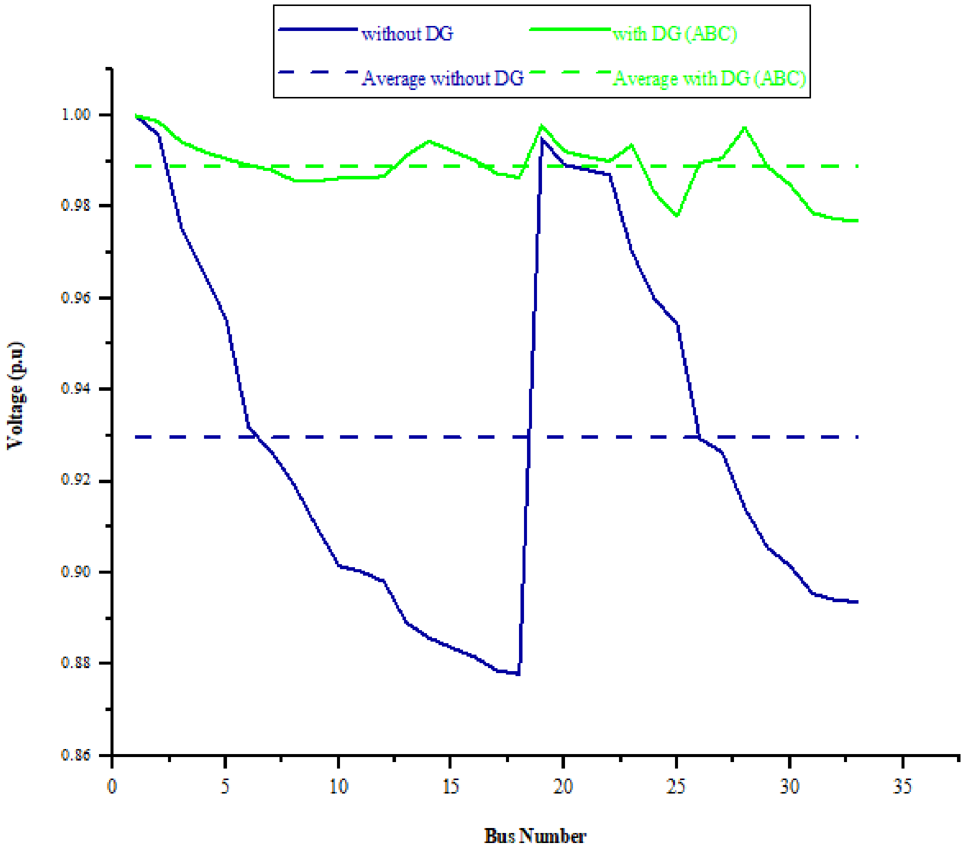
5.1.1 CASE-1 (SIMULTANEOUS MINIMIZATION OF P_{LOSS} AND V_D)

By performing a NRLF analysis with proposed A.B.C algorithm P_{loss} has been minimized to 54kW which shows a loss reduction 76.8%. Similarly, V_D has been minimized to 0.011 (p.u) with a V_{min} of 0.9770 (p.u). 'fig.' (5.2) shows the convergence curve of P_{loss} minimization with proposed A.B.C algorithm for this case.

'fig.' (5.3) shows the voltage profile and V_{avg} for this case with and without DGs. It is observed that without adding DGs the value of V_{min} is 0.8778 p.u and after adding DGs V_{min} value is improved to 0.9770. Hence it is clearly shown from graph the voltage profile is improved tremendously after adding DGs.



‘fig.’ 5.2 **Convergence Curve for ‘Test-System-1’ (Case-1)**



‘fig.’ 5.3 **Voltage profile improvement of ‘Test-System-2’ (Case-1)**

‘table’. 5.2 shows a comparison of the proposed A.B.C algorithm with other algorithms, which were applied to minimize same objectives in ‘Test-System-1’. It can be seen from ‘table’. 5.2 that for same problem, highest P_{t_loss} (%) and V_{min} (p.u) have been achieved with proposed A.B.C algorithm. Similarly, both of these objectives have been minimized with fairly compact DG sizes as well.

‘table’. 5.2

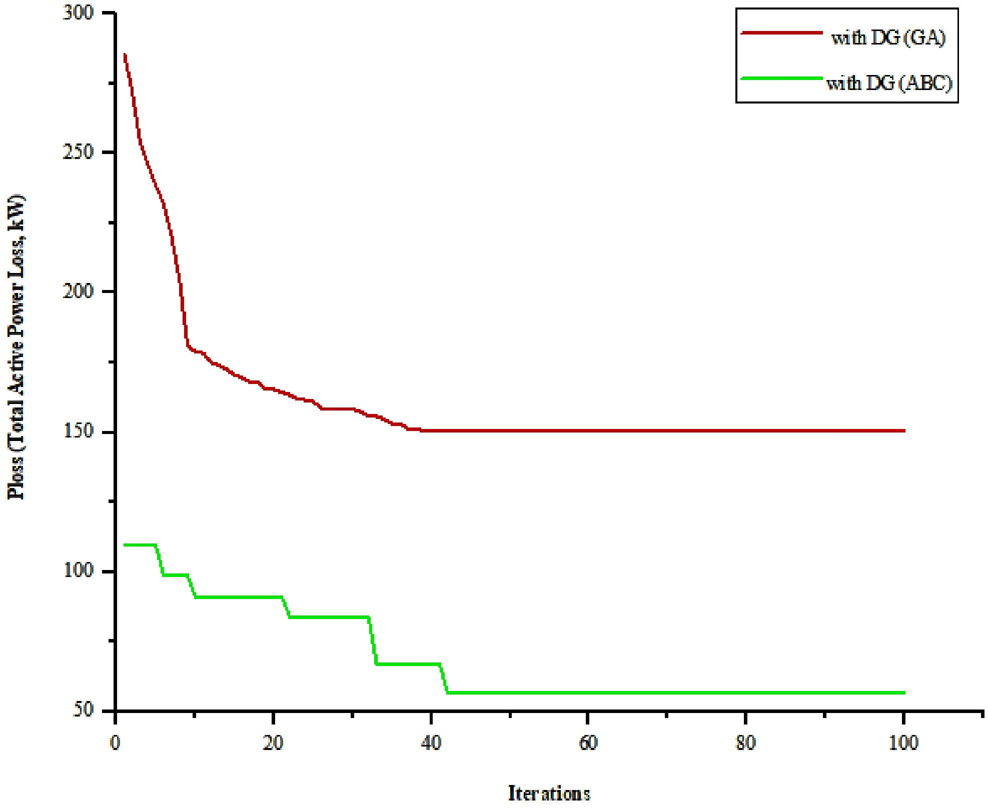
Comparison ‘table’. for ‘Test-System-1’

Algorithm	**DG Size(kW)**	**DG Location**	**P_{loss} (%)**	**V_{min} (p.u)**
G.A [36]	1500,422.8, 1071.4	11,29,30	47.6	0.981
P.S.O [36]	1176.8, 981.6, 829.7	8,13,32	48.2	0.980
G.A/P.S.O [36]	925,863, 1200	11,16,32	49.2	0.967
H.S.A [37]	572.4,107, 1046.2	17, 18, 33	52.3	0.967
I.W.D [27]	600.3,300, 1011.2	9,16,30	57.7	0.9696
B.F.O.A [30]	633,90,947	17, 18, 33	51.5	0.964
ACO-A.B.C [38]	754.7,1099.9,1071.4	14, 24, 30	62.8	0.9735
B.S.O.A [29]	632,487,550	13, 28, 31	56.1	0.9554
B.A [13]	816.3,952.35,952.35	15, 25, 30	63	0.98
I.W.O [27]	624.7,104.9, 1056	14, 18, 32	57.7	0.9716
P.S.O & analytical [28]	790,1070, 1010	13, 24, 30	64.1	NA
H.G.W.O [12]	802,1090, 1054	13, 24, 30	64.4	NA
S.K.H.A [15]	801.81,1091, 1053.6	13, 24, 30	64.4	0.9687
W.C.A [43]	854.6,1101.7,1181	14, 24, 29	65	0.973
S.S.A [44]	753.6,1100.4,1070.6	13, 23, 29	64.8	0.9686
Proposed A.B.C	**514.9,948.9, 635.16**	**14,28,23**	**76.8**	**0.9770**

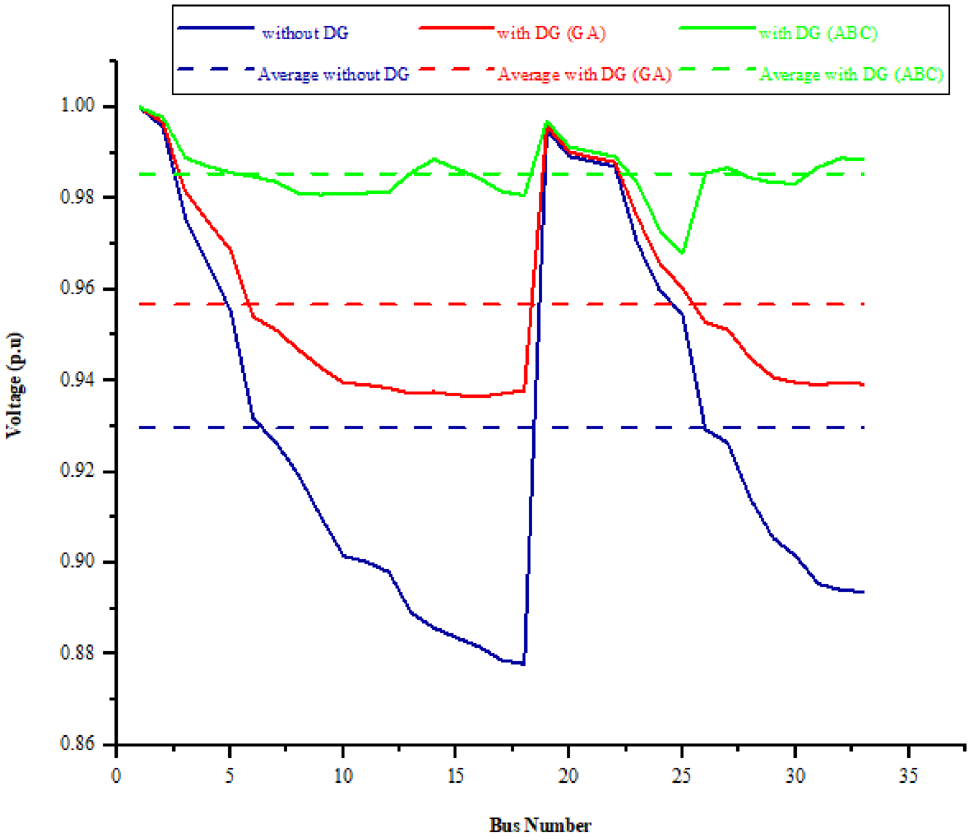
5.1.2 Case-2 (Simultaneous minimization of P_{loss}, V_D and C_T)

By performing a NRLF analysis with proposed A.B.C algorithm P_{loss} has been minimized to 56.9kW which shows a loss reduction of 75.6%, V_D has been minimized to 0.0145 (p.u) with a V_{min} of 0.9678 (p.u), and C_T has been minimized to $2814898.

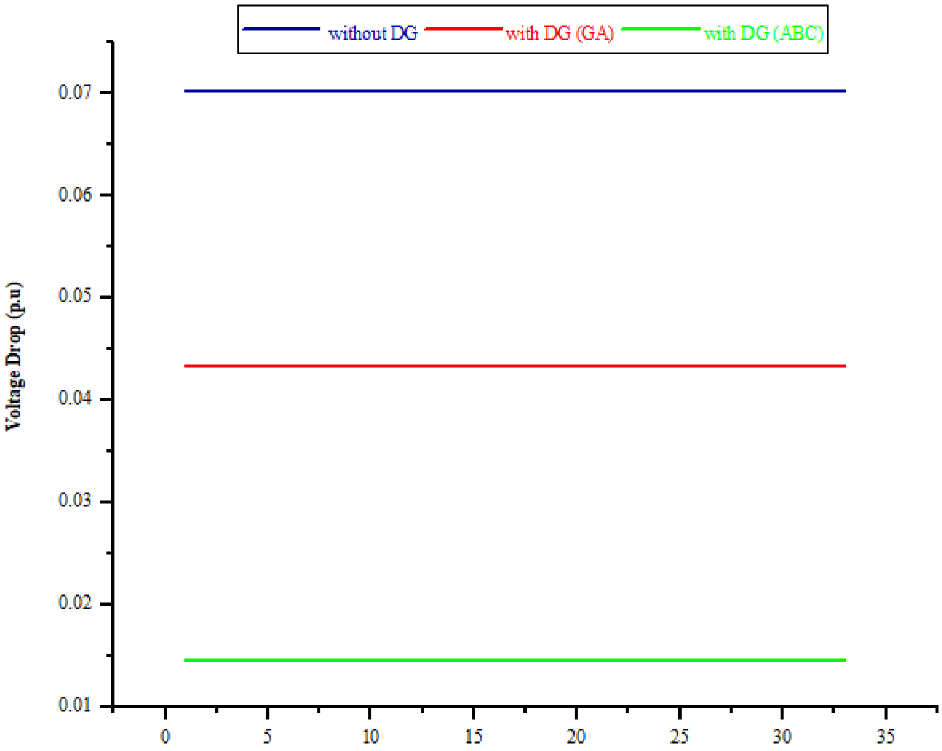
'fig.' (5.4) compares the convergence of proposed A.B.C algorithm with G.A while calculating P_{loss}. It can be seen that A.B.C algorithm converges in less no. of iterations as compared to G.A. 'fig.' (5.5) shows the voltage profile and V_{avg} for this case. It is observed that without adding DGs the value of V_{min} is 0.8778 p.u. After adding DGs V_{min} value is improved to 0.9678 and 0.9364 by applying A.B.C and G.A respectively. Hence it is clearly shown from graph the voltage profile is improved tremendously after adding DGs with A.B.C algorithm. 'fig.' (5.6) shows the comparison of respective V_D. It is concluded that with A.B.C algorithm voltage drop minimizes better than G.A.



'FIG.' 5.4 **Convergence Curve for IEEE-33 bus system (Case-2)**



'fig.' 5.5 Voltage profile improvement of 'Test-System-1' (Case-2)



'fig.' 5.6 Voltage drop comparison of 'Test-System-1' (Case-2) ‘table’. 5.3 shows comparison of A.B.C algorithm with G.A to minimize same objectives. It is observed from ‘table’. 5.3, that P_{t_loss} (%) has been significantly minimized with proposed A.B.C algorithm to 75.6% as compared to G.A which is 35.5%. Similarly, V_D is minimized to 0.0145 (p.u) by proposed A.B.C algorithm as compared to G.A which is 0.0434 (p.u). C_T without DGs is $4298861 and it is minimized to $2814898 by proposed A.B.C algorithm as compared to G.A which is $2932969.

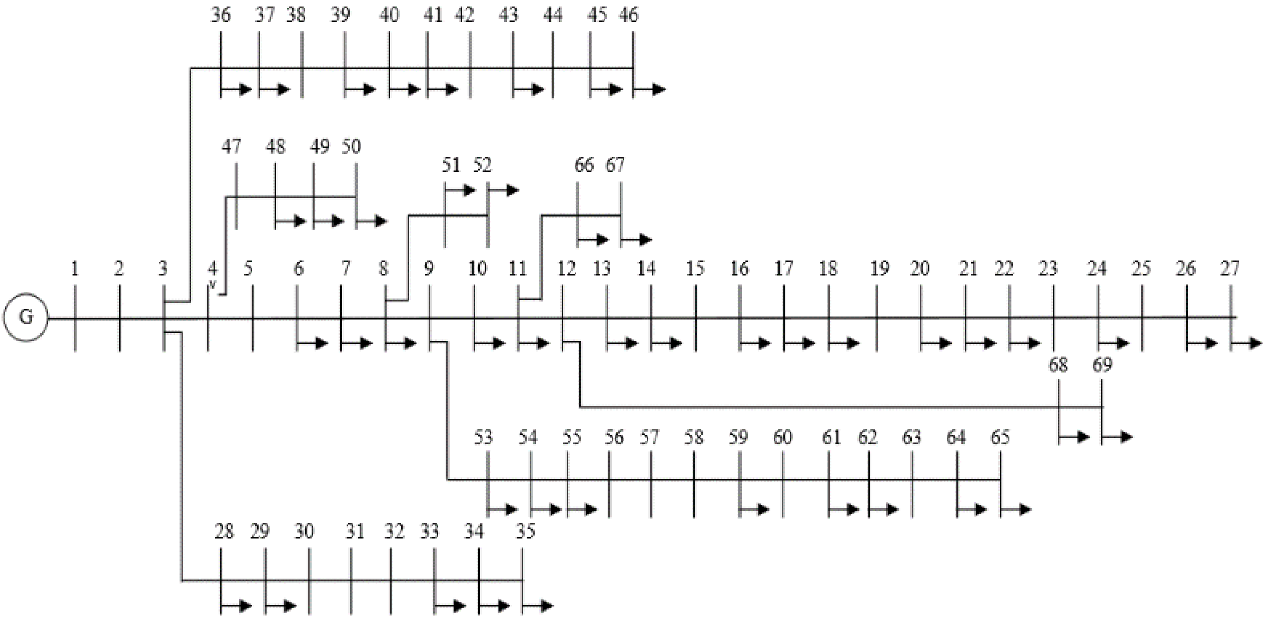
‘table’. 5.3

Results for ‘Test-System-1’

System Parameter	**Without DGs**	**With DGs (with G.A)**	**With DGs (with A.B.C)**
Optimal Location	-	19, 20, 18	32, 27, 14
Optimal DG Size (kW)	-	500, 500, 500	500, 500, 500
P_{loss} (kW)	232.9	150.5	56.9
P_{t_loss}(%)	-	35.5	75.6
V_{min} (p.u.)	0.8778	0.9364	0.9678
V_{avg} (p.u.)	0.9297	0.9566	0.9855
V_D (p.u.)	0.0703	0.0434	0.0145
C_T ($)	4298861	2932969	2814898

5.2 ‘Test-System-2’

‘Test-System-2’ with 69 buses and 73 branches is shown in ‘fig.’ (5.7). The total active load demand of this system is 3802 kW and reactive load demand of this system 2696 kVAR. The NRLF calculations of this system result in a P_{loss} of 318.4.9 kW and a V_{min} of 0.8592 (p.u) without DGs. The V_{avg} of this system is 0.9592 (p.u) which results in a V_D of 0.0408 (p.u). C_T without DGs is $5195114.

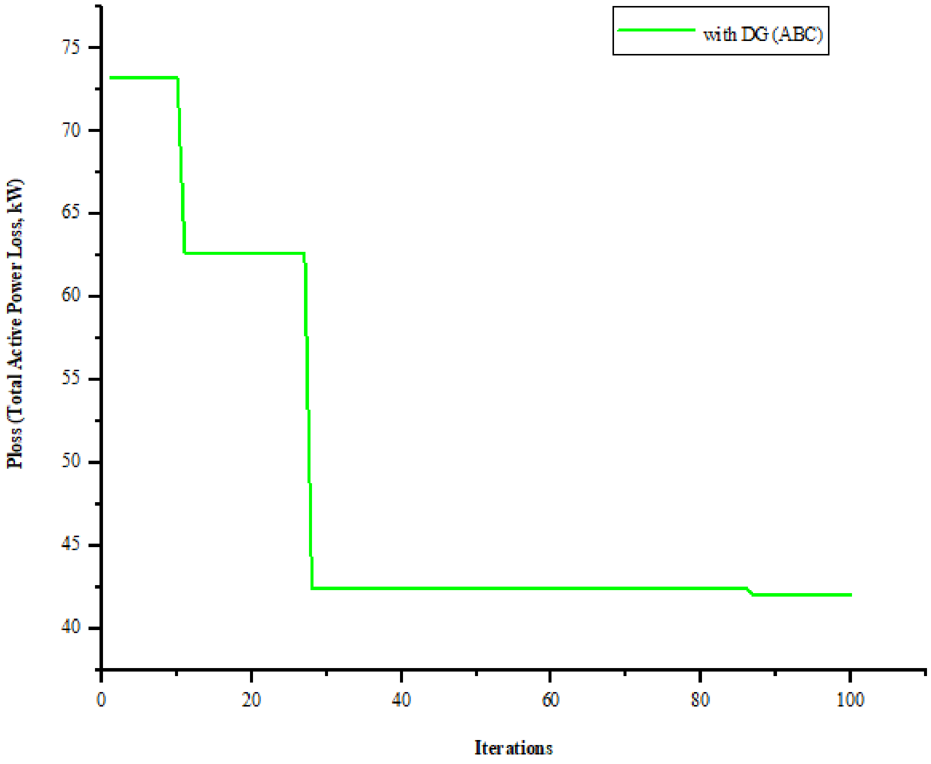


‘fig.’ 5.7 **‘Test-System-2’**

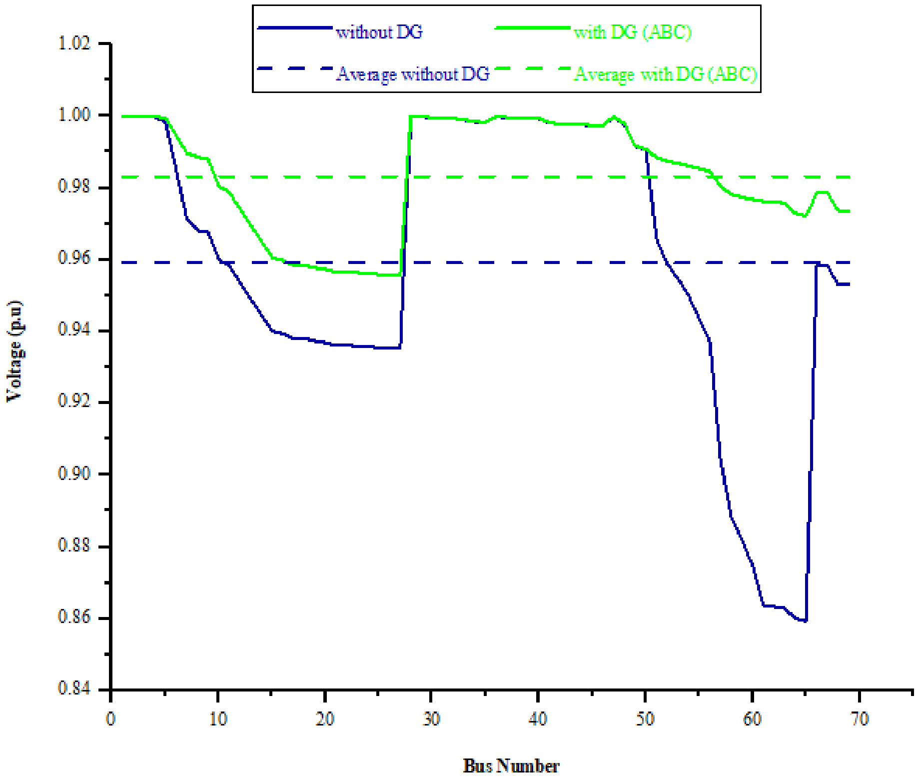
5.2.1 CASE-1 (SIMULTANEOUS MINIMIZATION OF P_{LOSS} AND V_D)

By performing a NRLF analysis with proposed A.B.C algorithm P_{loss} has been minimized to 42kW which shows a loss reduction 86.8%. Similarly, V_D has been minimized to 0.0168 (p.u) with a V_{min} of 0.9600 (p.u). ‘fig.’ (5.8) shows convergence curve of P_{loss} by proposed A.B.C algorithm for this case.

‘fig.’ (5.9) shows the voltage profile and V_D for this case with and without DGs. It is observed that without adding DGs the value of V_{min} is 0.8592 p.u and after adding DGs V_{min} value is improved to 0.9600. Hence it is clearly shown from graph the voltage profile is improved tremendously after adding DGs.



'fig.' 5.8 Convergence Curve for 'Test-System-2' (Case-1)



'fig.' 5.9 Voltage profile improvement of 'Test-System-2' (Case-1) ‘table’. 5.4 shows a comparison of the A.B.C algorithm with other algorithms, which were applied to minimize same objectives in ‘Test-System-2’. It is observed from ‘table’. 5.4 that for same problem, highest P_{t_loss} (%) and V_{min} has been achieved with proposed A.B.C algorithm. Similarly, both objectives have been minimized with drastically compact DG sizes as well.

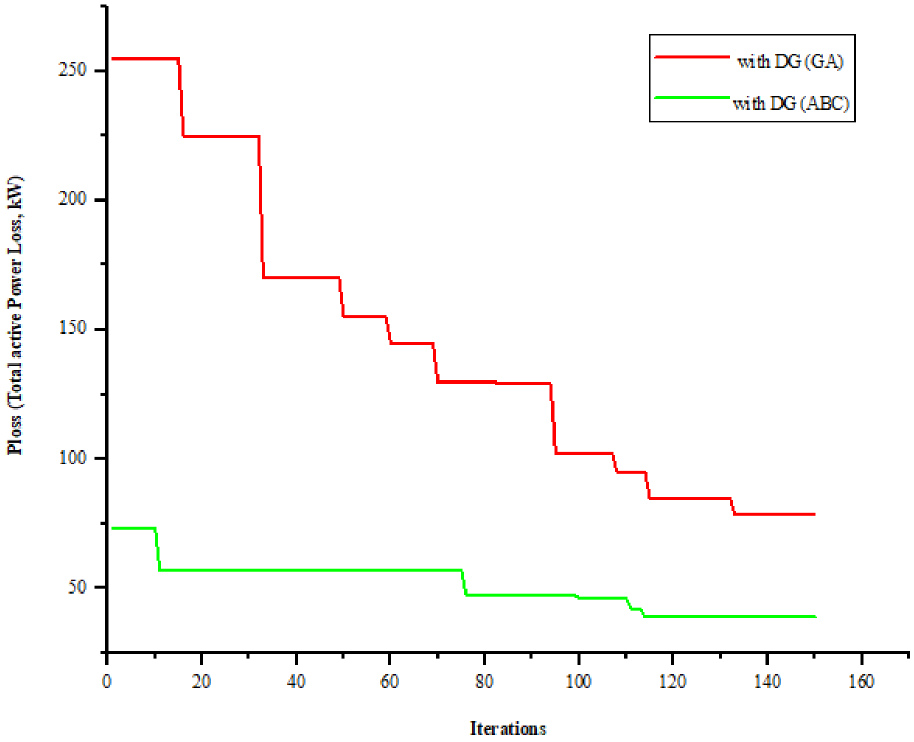
‘table’. 5.4

Comparison ‘table’. for ‘Test-System-2’

Algorithm	**DG Size (kW)**	**DG Location**	**Ploss (%)**	**Vmin (p.u)**
G.A [36]	929.7,1075.2, 984.8	21, 62, 64	60.4	NA
P.S.O [36]	1199.8, 795.6, 992.5	61,63,17	63.02	NA
G.A/P.S.O [36]	910.5, 1192.6, 884.9	21, 61, 63	63.9	NA
H.S.A [37]	1302.4, 369, 101.8	63, 64, 65	61.4	0.967
B.F.O.A [30]	295.4, 447.6, 1345.1	27, 65, 61	66.56	0.9808
H.G.W.O [12]	527,380, 1718	11, 17, 61	69.14	0.98
W.C.A [43]	775, 1105, 438	61, 62, 23	68.2	0.987
S.S.A [44]	380,527, 1718	17, 10, 60	69.1	0.9789
Proposed A.B.C	**1000, 200, 338.2**	**61, 51, 62**	**86.8**	**0.96**

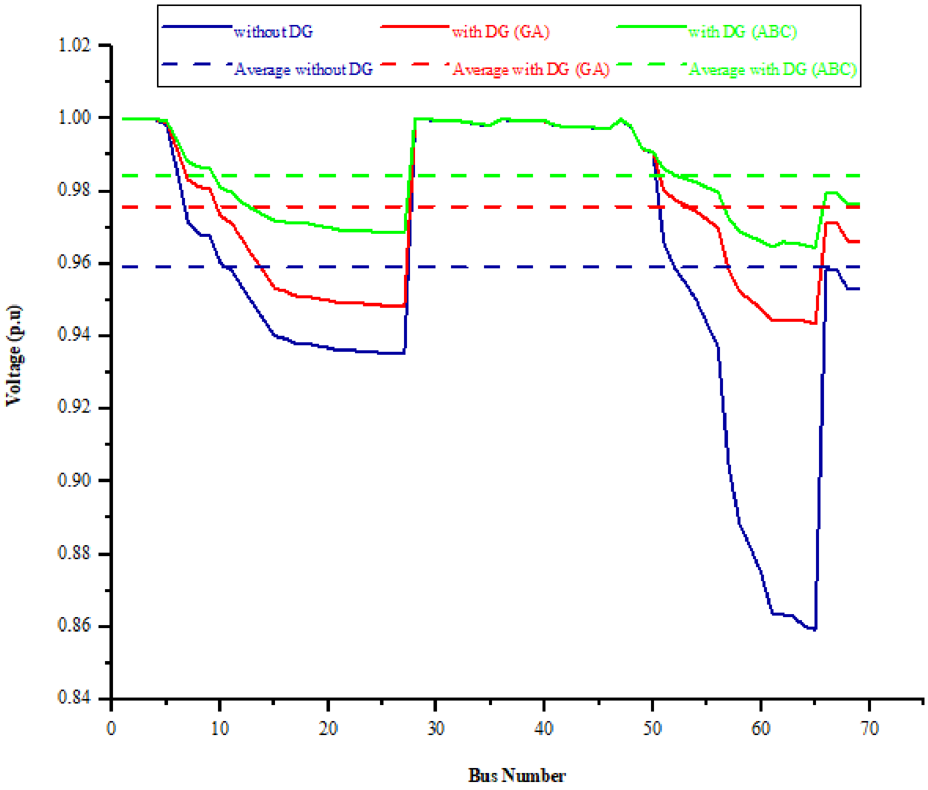
5.2.2 CASE-2 (SIMULTANEOUS MINIMIZATION OF P_{LOSS}, V_D AND C_T)

By performing a NRPF analysis with proposed A.B.C algorithm P_{loss} has been minimized to 38.7kW which shows a loss reduction of 87.8%, V_D has been minimized to 0.0157 (p.u) with a V_{min} of 0.9644 (p.u), and C_T has been minimized to $3706484. ‘fig.’ (5.10) compares the convergence of proposed A.B.C algorithm with G.A while calculating P_{loss}. It can be seen that A.B.C algorithm converges in less no. of iterations as compared to G.A.

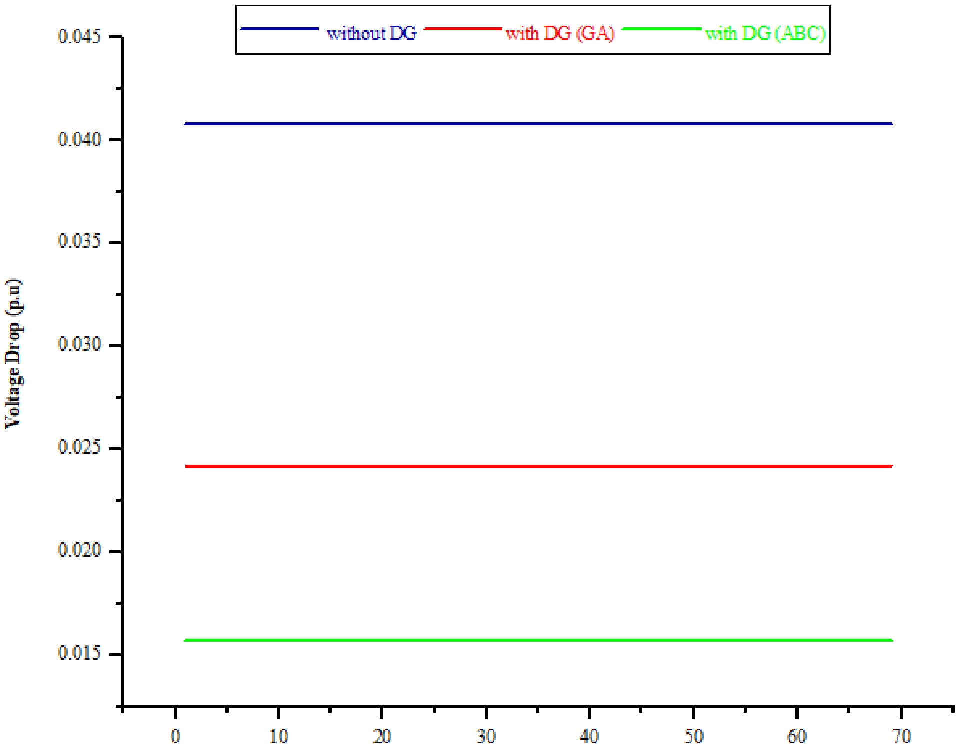


‘fig.’ 5.10 **Convergence Curve ‘Test-System-2’(Case-2)**

‘fig.’ (5.11) shows the voltage profile and V_D for this case. It can be seen that without adding DGs V_{min} is 0.8592 p.u. After adding DGs V_{min} is improved to 0.9644 and 0.9434 by applying A.B.C and G.A respectively. Hence it is clearly shown from graph the voltage profile is improved tremendously after adding DGs with A.B.C algorithm. ‘fig.’ (5.12) shows the comparison of respective voltage drops. It is observed that with A.B.C algorithm voltage drop minimizes better than G.A.



‘fig.’ 5.11 **Voltage profile improvement of ‘Test-System-2’ (Case-2)**



‘fig.’ 5.12 **Voltage profile improvement of ‘Test-System-2’ (Case-2)** ‘table’. 5.5 shows comparison of proposed A.B.C algorithm with G.A. It is observed from ‘table’. 5.5, that P_{t_loss} (%) has been significantly minimized with proposed A.B.C algorithm to 87.8% as compared to G.A which is 75.3%. Similarly, V_D is minimized to 0.0157 (p.u) by proposed A.B.C algorithm as compared to G.A which is 0.0242 (p.u). C_T without DGs is $5195114 and it is minimized to $3706484 by proposed A.B.C algorithm as compared to G.A which is $4281574.

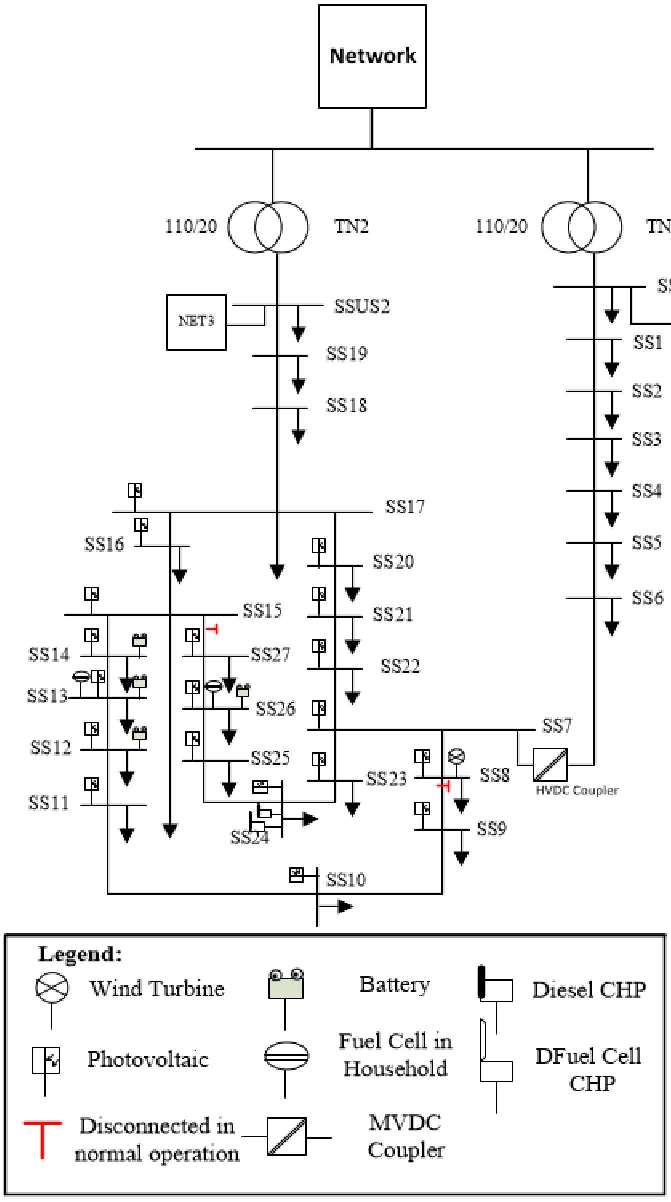
‘table’. 5.5

Results for ‘Test-System-2’

System Parameter	**Without DGs**	**With DGs (with G.A)**	**With DGs (with A.B.C)**
Optimal Location	-	64, 62, 61	62, 17, 64
Optimal DG Size (kW)	-	233.6, 210, 540.9	1000, 200, 200
P_{loss} (kW)	318.4	78.6	38.7
P_{t_loss} (%)	-	75.3	87.8
V_{min} (p.u)	0.8592	0.9434	0.9644
V_{avg} (p.u)	0.9592	0.9758	0.9843
V_D (p.u)	0.0408	0.0242	0.0157
C_T ($)	-	64, 62, 61	62, 17, 64

5.3 ‘Test-System-3’

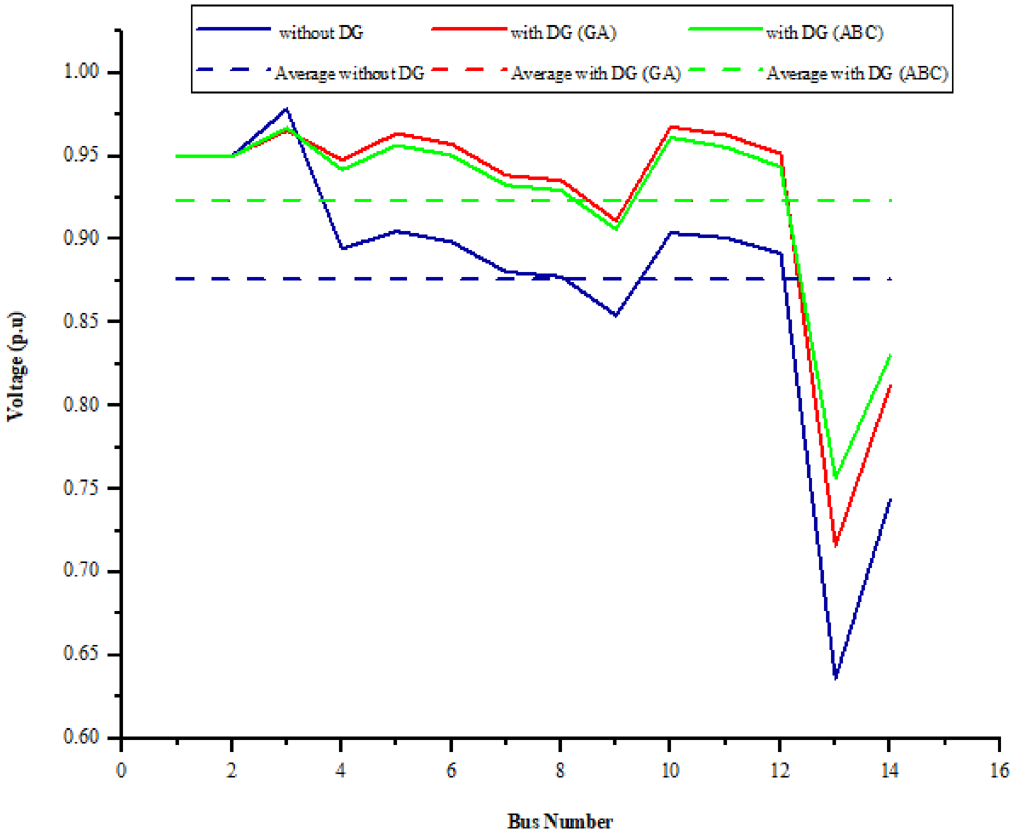
‘Test-System-3’ with 14 buses and 30 branches is shown in ‘fig.’ (5.13). The total active load demand of this system is 31310 kW and reactive load demand of this system is 7783 kVAR. The NRLF calculations of this system result in a P_{loss} of 22170 kW and a V_{min} of 0.6363 (p.u) without DGs. The V_{avg} of this system is 0.8761 (p.u) which results in a V_D of 0.01239 (p.u).



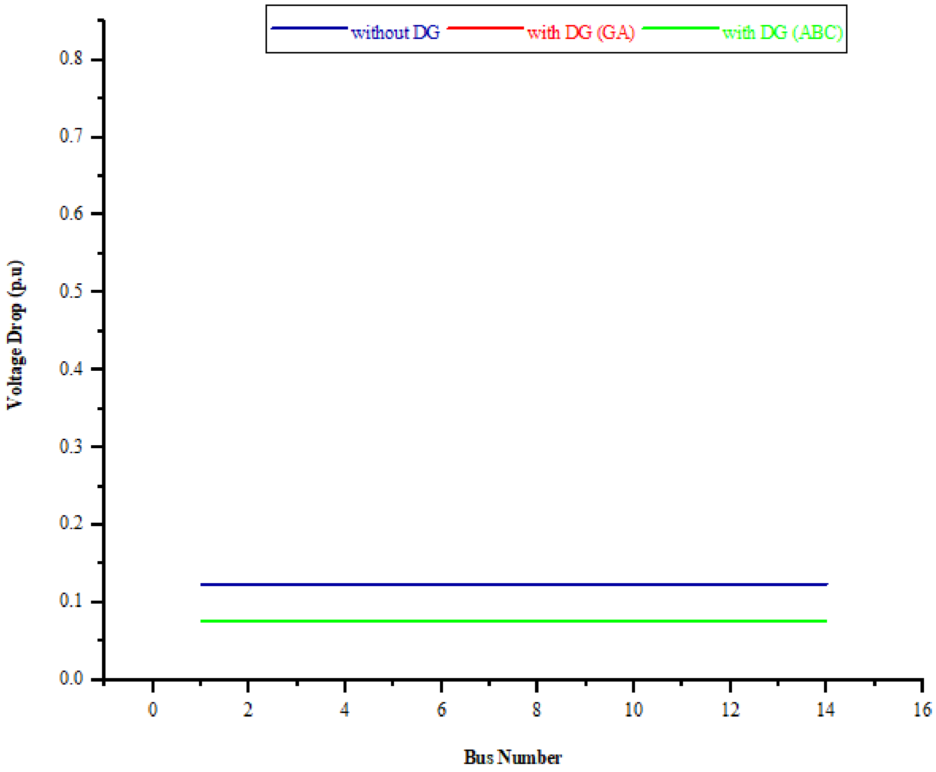
‘fig.’ 5.13 ‘Test-System-3’

5.3.1 CASE-2 (SIMULTANEOUS MINIMIZATION OF P_{LOSS}, V_D AND C_T)

By performing NRLF analysis with proposed A.B.C algorithm P_{loss} has been minimized to 11400 kW which shows a loss reduction of 48.5%, VD has been minimized to 0.0764 (p.u) with a Vmin of 0.9236 (p.u), and CT has been minimized to \$14374860. ‘fig.’ (6.14) shows the voltage profile improvement graph for this case. It is observed that without adding DGs the value of V_{min} is 0.6363 p.u. After adding DGs V_{min} value is improved to 0.7708 and 0.7151 by applying A.B.C and G.A respectively. Hence it is clearly shown from graph the voltage profile is improved tremendously after adding DGs with A.B.C algorithm. ‘fig.’ (5.15) shows the comparison of respective voltage drops. It is observed that with A.B.C algorithm voltage drop minimizes better than G.A.



‘fig.’ 5.14 **Voltage profile improvement of ‘Test-System-3’**



‘fig.’ 5.15 **Voltage drop comparison of ‘Test-System-3’**

It can be seen from ‘table’. 5.6, that Ploss (%) has been significantly minimized with proposed A.B.C algorithm to 48.5% as compared to G.A which is 30.17%. Similarly, V_D is minimized to 0.0764 (p.u) by proposed A.B.C algorithm as compared to G.A which is 0.0765 (pu). CT without DGs is $65816893 and it is minimized to $14374860 by proposed A.B.C algorithm as compared to G.A which is $19143103.

‘table’. 5.6
Results for ‘Test-System-3’

System Parameter	**Without DGs**	**With DGs (with G.A)**	**With DGs (with A.B.C)**
Optimal Location	-	8, 11, 12	12, 12, 12
Optimal DG Size (kW)	-	1200, 1100, 1000	1000, 1000, 1000
P_{loss} (kW)	22170	15480	11400
P_{t_loss} (%)	-	30.17	48.5
V_{min} (p.u)	0.6363	0.7151	0.7708
V_{avg} (p.u)	0.8761	0.9235	0.9236
V_D (p.u)	0.1239	0.0765	0.764
C_T ($)	65816893	19143103	14374860

Chapter No. 6

Conclusion and Future Work

CHAPTER NO. 6 CONCLUSION AND FUTURE WORK

6.1 Conclusion

In current thesis optimum allocation and sizing of DGs has been completed and objective was to simultaneously minimize total active power loss, average voltage drop and total energy costs. Newton Raphson load flow (NRLF) analysis is conducted in ‘Test-System-1’, ‘Test-System-2’ and ‘Test-System-3’. A.B.C algorithm is proposed to simultaneously minimize considered multiple objectives. Two test cases have been solved by using proposed A.B.C algorithm. In 1st case, two objectives, two objectives including total active power loss and average voltage drop were simultaneously minimized and results were compared with other algorithms. It has been seen that proposed A.B.C algorithm pointedly minimizes active power loss and average voltage drop to highest level than other algorithms, in both ‘Test-System-1’ and ‘Test-System-2’. In 2nd case, three objectives, including total active power loss, average voltage drop and total energy cost were simultaneously minimized, and results were compared with G.A. Again, it has been seen that proposed A.B.C algorithm significantly minimizes total active power loss, average voltage drop and total energy cost than G.A as well, in both ‘Test-System-1’ and ‘Test-System-2’ and in ‘Test-System-3’. Moreover, proposed A.B.C algorithm converges in a smaller number of iterations than G.A in both cases.

6.2 Future Work

It is recommended to apply the proposed technique in large distribution system.

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