

# Optimal position and rating of DG in distribution networks by ABC–CS from load flow solutions illustrated by fuzzy-PSO

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**Abstract** In this work, load flow problems of both radial distribution networks (RDNs) and mesh distribution networks (MDNs) have been solved using hybrid fuzzy-PSO algorithm. A new voltage stability index (VSI) is also indicated. Based on the suggested load flow, distributed generation (DG) is ready to conduct through the requirement; and with the support of inserting the optimal-sized DG unit in an exact way, the distribution system's stability is also studied. The exact position of each DG unit has been computed using “loss sensitivity analysis,” whereas the optimal sizing of each DG unit has been done with the help of hybrid artificial bee colony and Cuckoo search algorithm. The suggested method is tested in the regular 33-node and 69-node RDNs as well as in 85-node and 119-node MDNs. The transcendence of the proposed operation has been centered with the aid of comparison to the other existing methods. The suggested VSI is also correlated with other two existing VSIs before and after placement of DG unit(s).

**Keywords** Distributed generation · Power loss · Sensitivity analysis · Fuzzy logic · Particle swarm optimization (PSO)

## 1 Introduction

In electrical engineering, the load flow analysis is a mathematical investigation of electric power flow into a connected network [1]. A load flow analysis normally utilizes streamlined documentation, for example, a single line diagram and p.u. network, and importance on numerous characteristics of power parameters, like voltages, angles, real power and reactive power [2]. Load flow study is foremost in forecasting forthcoming growth of electric systems and moreover in selecting the pleasant procedure of present programs [3]. The voltage magnitude and its angle of each node as well as the computation of the total losses are done by the load flow [4].

Marketable electric systems are most commonly excessively critical to consider hand result of the load flow [5]. To present research laboratory scale, physical representations of electrical networks in detail had been constructed in the past years. However, PC programs accomplish associated computations like stability studies, short-circuit fault analysis, economic dispatch and unit commitment [6]. Primarily, a few applications use linear programming to discover the optimal load flow and the circumstances that supply the lowermost cost per kilowatt hour are also conveyed [7].

A load flow gain knowledge is notably a large for the approaches with numerous load centers, equivalent to a refinery complex. The load flow is an analysis of the procedure's capability to correctly deliver the load connected [8]. The aggregate losses of the system, and furthermore line losses of the individual, are also tabularized. Tap positions of the transformer are selected to guarantee the precise voltage at principal locations equivalent to motor control centers. For the examination of the distribution

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system, a significant tool is the distribution load flow and it is utilized in the operation and the planning phases [9, 10].

Distribution network with the structure of radial and broad ranging reactance and resistance values are essentially unwell conditioned, and traditional power flow approaches like Newton–Raphson, Fast Decoupled and Gauss–Seidel strategies are incompetent in solving such systems [11]. Distribution losses are as excessive as 20–30% of whole power production. As a result, in the case of distributed systems, the venture is more stated. Due to higher value of R in distribution networks, distribution systems are the general cause behind these tremendous power losses. The distribution systems are also functioning at much decreased voltages [12, 13]. Appropriate location and operating tactics are the responsibilities in the DG application for loss reduction. Optimal location relies upon the type of DG as well. For this reason, a try is made in this method to strengthen easy analytical expressions for area, which will also be with ease computed [14, 15].

In both the radial and mesh distribution networks, the optimal DGs are set up at appropriate positions to curb the losses of power along with the improvement of the voltage profile within the distribution network. It is expected that within the distribution network maximum of total power generation is corrupted as losses. The currents that flow via the network are reason for a part of these losses. Via the DGs installation, the losses that occurred with reactive currents are condensed, which is also valuable for control of power flow, i.e., the curtailment of power loss and enhancement of stability of the system. As a result, it is essential to discover the ultimate position and rating of DG for curtailment of losses and to maintain voltage. The paper is organized to be geared up as follows. Previous works regarding the load flow solution and DG placement in the distribution networks are studied in Sect. 2. Section 3 shows the suggested procedure. The computational outcomes and comparative study are offered in Sect. 4. At last, Sect. 5 presents the conclusions.

## 2 Associated work

The latest research work involving the load flow solution of the distribution system is recorded underneath:

A brand new load model had been suggested by Marti et al. [16] that characterized the voltage-dependent load model. A curve-fitting method was utilized to derive it, which cut up the load as a mixture of current source and impedance. On the imaginary part of the voltages at nodes with this illustration and a few numerical estimates, as a linear power flow (LPF) resolution, it was feasible to develop the load flow concern, which once not required repetitions. The estimate was once proven in systems as

much as 3000 nodes with quality results. The LPF system used to be peculiarly main for computerized smart distribution systems for optimization purposes. In that method, the load was to be formed at first as a summation of an impedance and a current source and there was a need to approximate in the imaginary part of the nodal voltage.

To analyze the effect of alteration with the distribution system on power system threat evaluation, Jia et al. [17] had presented any hierarchical solution. To simulate the actual irregular output regarding DGs, the discrete possibility style was currently employed. Like a standard constraint, available supply capacity (ASC) was utilized to make sure the actual safety level of the distribution system that required large consistency. The repetitive computation involving transmission network and distribution network was also embraced to originate risk indices together with taking into consideration detail constructions with the distribution network. Additionally, in system risk computation, the influence regarding a few factors, for example, DGs' locations, capacities, component outage probabilities and also dispersions, was talking about. The power flow constraints were not taken into account in that method.

Carpinelli et al. [18] had suggested any probabilistic technique to review the actual steady-state operating circumstances associated with photovoltaic (PV) and wind (WD) generation plants along with an active electrical distribution system program. That technique took into reason the real questions through renewable generation regarding force production and power load requirements and mixes multi-linearized power flow equations and Monte Carlo simulation methods. Mathematical implementations were obtainable and reviewed with regards at 17 bus distribution systems seen as a WD and PV systems hooked up with diverse bus bars. The outcomes achieved with all the suggested criteria were better in contrast to the outcomes achieved employing a Monte Carlo simulation criteria. They did not implement their methods for medium-size and large-size distribution networks.

Das [19] proposed a method to place single DG in RDNs. She had used the loss sensitivity factor and Firefly algorithm to get the location of DG placement and its optimal size, respectively. She had used 33-node and 69-node RDNs. The reduction in loss obtained by the proposed method was not appreciable compared to the other methods available in the literature. The multi-DG placement was not suggested.

To discover the exact position and proper size of DG unit, Mohamed and Kowsalya [20] had presented a novel technique with network power loss minimization, operational costs and making improvements to voltage stability as an objective. To define the optimal locations of DG unit's installation, loss sensitivity factor was utilized. To search out the optimal size of DG, "Bacterial Foraging

Optimization Algorithm (BFOA)” was used. BFOA was a swarm intelligence method, for aging policies of the *Escherichia coli* microorganism, which modeled the individual and workforce as a distributed optimization procedure. The proposed technique was once confirmed on 33-node and 69-node RDNs at specific load levels with numerous load models, and the efficacy and efficiency of the method was validated. They did not execute their method on any large RDNs. They were silent about the placement of DG in MDNs.

Murty and Kumar [21] had provided an evaluation of new “power loss sensitivity,” “power stability index” (PSI), and VSI approaches to achieve the appropriate location and then found the size of the capacitor. The chief impact of the paper was that the optimal placement of DGs was established. They tested their method on 12-node, 69-node, 85-node and modified 15-node RDNs. They had used approximate VSI index to get the most sensitive node of the network. They were confined to place only single DG unit and silent for placement of multi-DG units. They had not considered any MDN to implement their method.

Hung and Mithulananthan [22] had examined the difficulty of multiple distributed generators (DG units) placement for obtaining loss reduction in RDNs. In that paper, an improved analytical (IA) approach was disclosed. On three distribution experiment techniques, IA procedure was once tested and authenticated with various sizes and difficulty. Results showed that IA procedure was once powerful as when put next with LSF and ELF solutions. They had used exhaustive load flow technique, and the loss for base case of 69-node RDN was lower compared to that obtained by the other load flow techniques. In some cases, the results obtained by ELF are not superior to those by IA or LSF. There was no implementation of their method to any large RDN and any type of MDN.

Kaur et al. [23] presented a MINLP method to place the appropriate size of DGs in the proper locations so that the system loss will be decreased and voltage profile will be enhanced. They tested their methods on 33-node and 69-node RDNs and also compared with ELF-, IA- and PSO-based methods. They provided the test results for small and medium RDNs. They were silent regarding the implementation of their method to any large RDNs and any type of MDN. They had not provided the comparison of CPU time with the other existing methods used by them for comparison.

Viral and Khatod [24] presented a novel technique to obtain the optimal positions of DGs and also their sizes. They had used the analytical approach. They at first identified the nodes for placement of DGs and then determined the size of DGs after minimizing the loss saving equations. They tested their methods on 15-node and 33-node RDNs. They did not execute the proposed method on medium- and large-type RDNs and any type of MDN.

Kansal et al. [25] presented a hybrid technique to place multiple DGs optimally in RDNs. They also placed different types of DGs in RDNs. They had used 33-node and 69-node RDNs to validate the proposed method, and they also compared their proposed method with the PSO and IA methods. The results in some cases obtained by PSO are superior to those obtained by the proposed method. They did not carry out their method on any large-size RDN and any type of MDN.

Saha and Mukherjee [26] proposed a novel method to place DG in RDNs using “chaos embedded SOS algorithm.” They placed the DGs in 33-node, 69-node and 118-node RDNs. They compared their method with other available method including “SOS studied.” The CPU time provided by them for different methods was not in the same platform, and hence proper comparison of speed of the proposed method with the other reported method was not feasible. They were silent regarding DG placement in MDNs.

Das et al. [27] used “symbiotic organism search algorithm” to place DGs in RDNs. They used LSF to find the sensitive nodes of the networks to place DGs, and SOS algorithm had been used to find the size. They compared their method with other available methods. They placed the DGs in 33-node and 69-node RDNs. In 69-node network, the Cuckoo search method has faster convergence compared to proposed SOS method as provided by the authors. They were also silent regarding the implementation of their method to any large-size RDN and any type of MDN.

However, all above-mentioned classical methods suffer from the disadvantage of finding the optimal solution for the nonlinear optimization problem. Placement of DG in the distribution system is highly nonlinear optimization problem. Conventional optimization techniques are not suitable for solving such type of problems. Moreover, there is no criterion to decide whether a local solution is also a global solution. Large computational time is another drawback of most of these techniques. And also, it may be found that most of these population-based optimization techniques have been successfully used to determine the size, placement and loss minimization problem of DG in RDNs. However, many of them suffer from local optimality and require large computational time for the simulation. These motivate the present authors to introduce new, simple, efficient and fast population-based optimization technique to solve optimal DG placement problem of the distribution networks.

### 3 Upgraded load flow solution for RDN and MDN using hybrid fuzzy-PSO approach

As the network is the ultimate connection between a large power system and customers, the investigation of distribution network is a major subject of exercise. In the present

work, a load flow solution as well as the stability analysis of radial and the mesh distribution networks will be boosted based on hybrid fuzzy-PSO algorithm. The proposed work comprises three phases; these are fuzzification, knowledge-based decision logic and defuzzification. In fuzzification, the power parameter like total power loads (active and reactive) shall be estimated and finally changes to fuzzy sets or linguistic terms. The knowledge base comprises data concerning the domains of the fuzzy sets, and variables related to the linguistic phrases and rule base within the type of semantic control principles are kept in the knowledge base. Decision logic defines expertise concerning the parameters with the aid of the input values that are measured and knowledge base. The knowledge-based decision logic is employed via making use of PSO algorithm, that is a global optimization technique, so that it will furnish the easier selection based on the input value and base knowledge.

The mission of defuzzification is to produce a crisp control price out of the expertise concerning the manipulate parameter of the decision logic with the aid of utilizing a suitable transformation. The fuzzy-PSO will provide a greater resolution of the power flow problem, which is suitable for each radial and mesh distribution approach. Then, on the basis of load flow solution multi-DGs are positioned to fulfill the requirement, and by using the DGs in a more effective method, the stability of the distribution system will probably be analyzed. To find the ultimate DG location, loss sensitivity analysis (LSA) is used, and for sizing DG, hybrid artificial bee colony and Cuckoo search (ABC-CS) algorithm is used here. The proposed process will be demonstrated in 33-node and 69-node RDNs as well as in 85-node and 119-node MDNs.

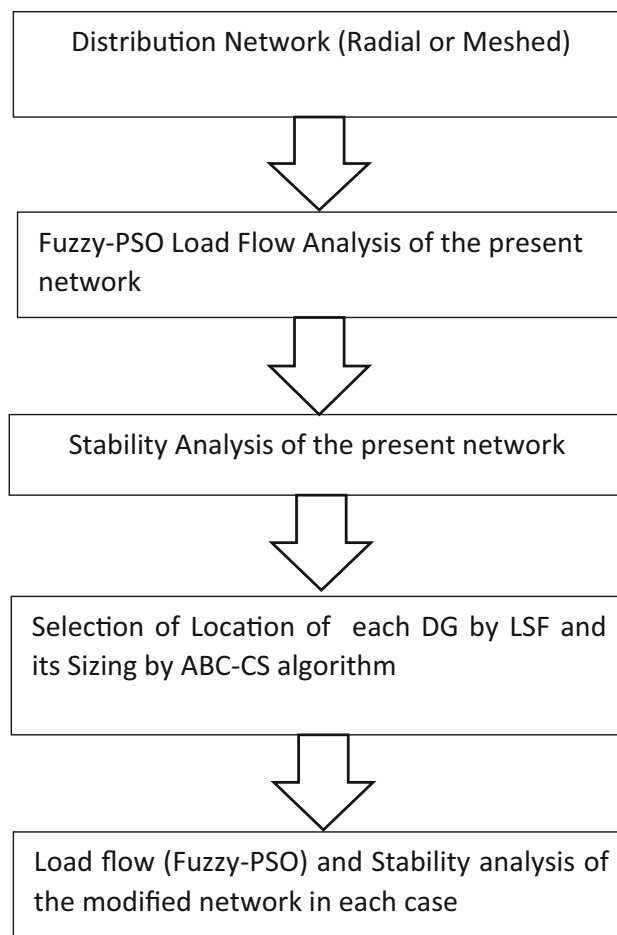
The proposed methodology begins with the evaluation of load flow and stability study of RDNs and MDNs given as input to the proposed approach for evaluation. This evaluation standard helps the fuzzy logic present within the proposed approach in making decision regarding the DG placement within the bus system. Figure 1 shows the proposed framework.

### 3.1 Stability analysis

In voltage stability study, the main aim is to suggest an exact VSI expression so that the exact values of VSI for each node will be obtained. The node, which will have the minimum value of VSI, will be the most sensitive node (MSN) of the network. The VSI is expressed from a two-bus system, and design equations are given below.

$$\bar{V}_{m1} = \bar{V}_{m2} + \bar{I}_k \bar{Z}_k \quad (1)$$

$$|V_{m1}| \angle \delta_{m1} = |V_{m2}| \angle \delta_{m2} + [I_{\text{real}_k} + jI_{\text{imag}_k}] [R_k + jX_k] \quad (2)$$



**Fig. 1** Proposed framework

where  $I_k$  is the flow of current through the branch  $k$ .

$|V_{m1}|$  and  $|V_{m2}|$  are the voltage magnitudes of nodes  $m1$  and  $m2$ .

$\delta_{m1}$  and  $\delta_{m2}$  are the respective angles of  $V_{m1}$  and  $V_{m2}$ .  $Z_k = R_k + jX_k$ , where  $R_k$  and  $X_k$  are the resistance and reactance of the branch  $k$  between bus  $m1$  and bus  $m2$ .

$$\begin{aligned} |V_{m2}| \cos \delta_{m2} + j|V_{m2}| \sin \delta_{m2} &= |V_{m1}| \cos \delta_{m1} \\ &+ j|V_{m1}| \sin \delta_{m1} - [I_{\text{real}_k} R_k - I_{\text{imag}_k} X_k] \\ &- j[I_{\text{real}_k} X_k + I_{\text{imag}_k} R_k] \end{aligned} \quad (3)$$

From (3), we have

$$|V_{m2}| \cos \delta_{m2} = |V_{m1}| \cos \delta_{m1} - A \quad (4)$$

$$|V_{m2}| \sin \delta_{m2} = |V_{m1}| \sin \delta_{m1} - B \quad (5)$$

where  $A = I_{\text{real}_k} R_k - I_{\text{imag}_k} X_k$ ,  $B = I_{\text{real}_k} X_k + I_{\text{imag}_k} R_k$ .

Then, we have

$$\tan \delta_{m2} = \frac{|V_{m1}| \sin \delta_{m1} - B}{|V_{m1}| \cos \delta_{m1} - A} \quad (6)$$

From (4) and (5), we have

$$|V_{m1}|^2 - 2[A \cos \delta_{m1} + B \sin \delta_{m1}]|V_{m1}| + (A^2 + B^2) = |V_{m2}|^2$$

Since  $|V_{m2}|$  is always greater than 0, the following condition must be met.

$$|V_{m1}|^2 - 2[A \cos \delta_{m1} + B \sin \delta_{m1}]|V_{m1}| + (A^2 + B^2) \geq 0$$

Let

$$L_{m2} = |V_{m1}|^2 - 2[A \cos \delta_{m1} + B \sin \delta_{m1}]|V_{m1}| + (A^2 + B^2) \geq 0 \tag{7}$$

The computed  $\delta_{m2}$  of branch  $k$  will be used as  $\delta_{m1}$  for the next branch, i.e.,  $k + 1$ .  $I_{real_k}$  is the real part of the current  $I_k$  through branch  $k$ , and  $I_{imag_k}$  is the imaginary part of the current  $I_k$  through branch  $k$ . The value of  $\delta_{m1} = 0.0$  when  $k = 1$ . The proposed voltage stability index is to be compared with the voltage stability indices available in [28, 29].

### 3.2 Radial and mesh distribution network load flow analysis

Here, both radial and mesh systems are evaluated for the analysis of load flow. The total  $I^2R$  loss ( $P_{TOTAL}$ ) in a network having a NB amount of branches is expressed by

$$P_{TOTAL} = \sum_{k=1}^{NB} I_k^2 R_k \tag{8}$$

Here,  $I_k$  is the current through branch  $k$  and  $R_k$  is the resistance of branch  $k$ . The current in each branch is bought from the load flow analysis. There are two components in branch current, active and reactive elements.  $P_{TOTAL}$  expressed in (8) is rewritten below in terms of  $I_{real}$  and  $I_{imag}$ .  $P_{ka}$  and  $P_{kr}$  are due to real and reactive components of  $I$ .

$$P_{TOTAL} = P_{ka} + P_{kr} \tag{9}$$

$$P_{TOTAL} = \sum_{k=1}^{NB} I_{real_k}^2 R_k + \sum_{k=1}^{NB} I_{imag_k}^2 R_k \tag{10}$$

From (10), the power loss in real and reactive components of current of any RDN or MDN is formulated.

### 3.3 Fuzzy- and PSO-based load flow analysis

Fuzzy logic is utilized to update  $\delta$  and  $V$  in fuzzy-based load flow analysis

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ M & L \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \tag{11}$$

#### 3.3.1 Algorithm involved in fuzzy logic

The expression in (11) specified above is stated as for projected fuzzy index given by

$$\Delta F = [J] \cdot \Delta X \tag{12}$$

It implies that at every node of the network the alteration of state vector  $\Delta X \propto \Delta F$ . On the prior equation, the designed load flow is developed. However, the repetitive state vector updating of the process might be carried out by

$$\Delta X = \text{fuzzy}(\Delta F) \tag{13}$$

In this procedure, the parameters like ( $\Delta F_p$  and  $\Delta F_q$ ) active and reactive power are computed and presented to the respective fuzzy logic controller (FLC) as shown in Fig. 2. The procedure performs the state vector  $\Delta X$  specifically alteration of  $\Delta \delta$  for the  $P - \delta$  cycle and  $\Delta V$  for the  $q - V$  cycle. Figure 2 shows the steps of load flow based on fuzzy logic.

#### 3.3.2 Controller structure

The core construction of the FLC contains three principle elements

- Fuzzification interface
- Knowledge base decision logic.
- Defuzzification.

#### 3.3.3 Fuzzification interface

The FLC includes the subsequent functions through iteration.

- Compute the p.u. power parameters at each system node.

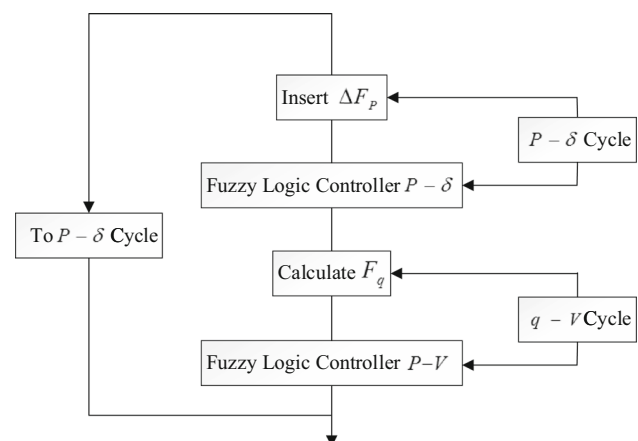
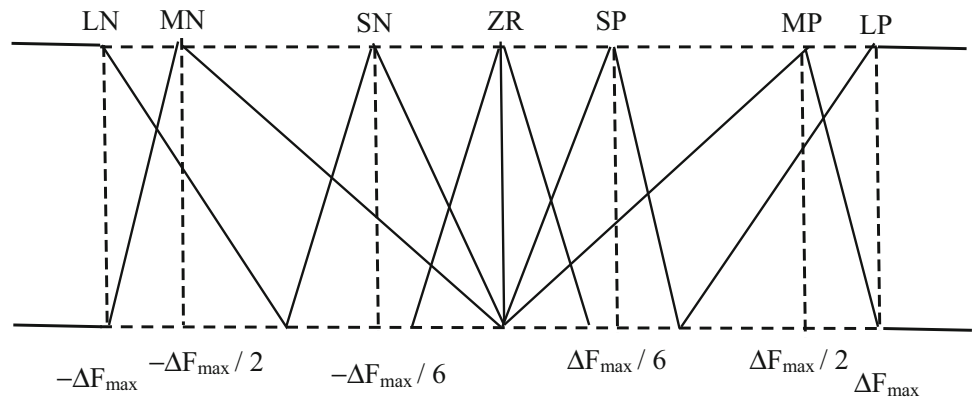


Fig. 2 Load flow based on fuzzy logic



**Fig. 3** Triangular membership function



– The variables are chosen as hard input signals. The extreme power parameter ( $\Delta F_{p_{max}}$  (or)  $\Delta F_{q_{max}}$ ) regulates the scope of rule plotting that handovers the input into an equivalent universe of dissertation at each iteration.

Then, into equivalent fuzzy signals the input signals are got fuzzified ( $\Delta F_{pfuz}$  or  $\Delta F_{qfuz}$ ) with seven linguistic variables. These are “small negative (SN), large negative (LN), zero (ZR), medium negative (MN), medium positive (MP), small positive (SP) and large positive (LP).”

### 3.3.4 Fuzzification

Then, in triangular membership function it is characterized as shown in Fig. 3, which outlines these functions.

Each three points are designed as

$$LN : [-\infty, -\Delta F_{max}, -\Delta F_{max}/3],$$

$$MN : [-\Delta F_{max}, -\Delta F_{max}/2, 0],$$

$$SN : [-\Delta F_{max}/3, -\Delta F_{max}/6, 0],$$

$$ZR : [-\Delta F_{max}/12, 0 - \Delta F_{max}/12],$$

$$SP : [0, -\Delta F_{max}/6, 0, \Delta F_{max}/3],$$

$$MP : [0, \Delta F_{max}/2, \Delta F_{max}],$$

$$LP : [\Delta F_{max}/3, \Delta F_{max}, \infty]$$

In a similar fashion the outputs signified in membership function, outlines of those functions are uncovered in Fig. 3. As a result, all three features of the triangular membership function  $\Delta X_{fuz}$  are considered as shown above.

### 3.3.5 Knowledge-based decision logic using PSO

In this proposed methodology, a PSO method is established to seek out the finest answer of the multi-objective issue of inserting DG units. PSO is among the

optimization technique and matches to evolutionary calculation methods. The technique is found via a model of basic social representations. The aspects of the approach are as trails:

1. On the basis of researches on swarms comparable to bird flocking and fish schooling, the procedure is created.
2. Here, the computation time is tiny that entails few recollections. In line with the research outcomes for flocking, birds are searching foodstuff by way of flocking.

An optimization method on the basis of above concept is labeled as trails: Specifically, definite objective function is enhanced bird flocking. Every agent to this point recognizes its finest value (pbest) and its XY function. In addition, every agent knows the finest value at this point among pbests in the group (gbest). For individual agent attempts are made to alter its location utilizing the subsequent data:

- existing locations (x,y),
- existing velocities (vx,vy),
- Distance among the existing spot, pbest and gbest.

This alteration is characterized by the velocity concept. Each agent velocity is altered by the subsequent expression [30].

$$v_i^{m+1} = wv_i^m + c_1 a \times (b_i - s_i^m) + c_2 a \times (d - s_i^m) \tag{14}$$

In (14),  $v_i^m$  is the agent velocity  $i$  at iteration  $m$ , the weighting factors are  $c_1$  and  $c_2$ , the weighting function is  $w$ ,  $s_i^k$  is the existing location of agent  $i$  at iteration  $m$ , “ $a$ ” is the random number, which is between 0 and 1,  $d$  is the gbest, which is the best of the group and  $b_i$  is the pbest $_i$ , which is the best of agent  $i$ . The above expression in (14) is used to get a certain velocity. This velocity steadily becomes close to “ $b$ ” and “ $d$ .” The present point is altered by (15).

$$s_i^{m+1} = s_i^m + v_i^{m+1} \tag{15}$$

### 3.3.6 Defuzzification

Extreme corrective act  $\Delta Y_{\max}$  of state parameters outlines the scope of map scale at every iteration, which handovers the produced signal into the equivalent universe of dis-  
sertation. The maximum alteration of values is computed by,

$$\frac{\Delta F_{\max 1}}{\Delta Y_{\max}} = \frac{dF_1}{dY_1} \tag{16}$$

$$\Delta Y_{\max} = \left[ \frac{dF_1}{dY_1} \right]^{-1} \Delta F_{\max 1} \tag{17}$$

With maximum power mismatch of the system,  $F_1$  is the power equilibrium equation at node and  $Y_1$  is the magnitude at node 1 or voltage angle. Lastly for each and every node of the system, the defuzzifier changes output signals  $\Delta Y_{fuz}$  into crisp values  $\Delta Y$ . The state vector is restructured, and the centroid-of-area defuzzification approach is modified,

$$Y^{i+1} = Y^i + \Delta Y \tag{18}$$

where “ $i$ ” indicates the number of iterations.

### 3.4 Location of DG by loss sensitivity analysis

Loss sensitivity analysis [31] is employed to get the position of DG in the distribution networks, which can predict the nodes that have a larger reduction of losses. Hence, these sensitive nodes are the nodes for DG placement that reduces the search space for the upcoming optimization action. A line connecting buses  $k - 1$  and  $k$  with impedance  $R_k + jX_k$  connected to a load  $P_{Lk,eff} + jQ_{Lk,eff}$ . If  $P_{Lk,eff}$  is the net supply of active power beyond the bus  $k$ , the sensitivity factor [31] is calculated using (19).

$$\frac{\partial P_{Loss,k}}{\partial P_{Lk,eff}} = \frac{2P_{Lk,eff}R_k}{V_k^2} \tag{19}$$

By using (19), loss sensitivity factors are calculated by load flow and these values are organized in descending order for any distribution network. By using this sensitivity factor, the nodes to be considered for DG installation are noted. The objective functions and the location of DG are utilized in the optimization, which is explained below.

### 3.5 ABC algorithm

On “artificial bee colony (ABC)” [32], a three-set the artificial bees are labeled: engaged bees, onlookers and scouts. Engaged bee manipulates a food source. With the

onlooker bees, the employed bees share information, which might be ready in the hive and observing the events of the employed bees. With probability proportional to the first rate of food origin, the onlooker bees then pick a food source. Then, the bad ones in the best food origins appeal to more bees. Randomly in the neighborhood of the hive, scout bees hunt for brand new food origins. When a food’s origin is caught by a scout or onlooker bee, it turns into engaged. The whole of the engaged bees associated with it is giving way to give up the place, when a food supply has been completely subjugated and could emerge as scouts once more. Hence, the job of “exploiting” is conducted by the engaged and viewer bees, whereas scout bees conduct the job of “exploration.” The operations in scout bee are carried out by means of using a Cuckoo search algorithm (CS), which facilitate the work of the scout bee segment extra effective. In the proposed algorithm, the nectar quantity of a food origin corresponds to the competence of the related result and a food supply agrees to a possible resemble to the optimization difficulties. Inside ABC, the opposite half are viewers and the first half of the colony comprise engaging bees. The digit of employed bees and the quantity of food origins (SN) are same in the view that it is presumed that there will be only one engaged bee for every food origin. For this cause, the number of results can also be identical to the number of onlooker bees into consideration. With a group of randomly produced food sources, the ABC algorithm initiates. The fundamental steps of ABC are given below.

- Initialization of sources of food.
- Individual employed bee begins to operate with a source of food.
- Individual onlooker bees elects a source of food, affording of the nectar data united by the employer.
- Define scout bees, which find sources of food in an arbitrary way.

Check whether the termination situation is happening. Else, go to the second step.

The complete explanation for every phase is specified below.

*Initialization* This is starting phase of the ABC algorithm. The SN primary solutions are arbitrarily produced D-dimensional real vectors.

$$FS_i = (FS_{i,1}, FS_{i,2}, \dots, S_{i,D}) \tag{20}$$

$FS_i$  signify the  $i$ th source, that is attained by

$$FS_{i,d} = FS_d^{\min} + r \times (FS_d^{\max} - FS_d^{\min}) \tag{21}$$

In (21)  $r$  is an arbitrary constant value in the scope  $[0, 1]$ , and  $FS_d^{\min}$  and  $FS_d^{\max}$  are lower and upper bounds for dimension  $d$  correspondingly where  $d = 1 \dots D$ .

*Employed bee phase* In this segment, with a solution every employed bee is connected. For discovering a novel solution, she applies an arbitrary alteration on the solution, which implements the function of hunt in the neighborhood. Using a different expression, the fresh solution is  $v_i$  produced from  $FS_i$ .

$$S_{id} = FS_{id} + r' \times (FS_{i,d} - FS_{k,d}) \tag{22}$$

where  $d$  is arbitrarily designated in  $\{1 \dots D\}$ ,  $k$  is arbitrarily designated in  $\{1 \dots SN\}$  such that,  $k \neq i$ , and  $r'$  is a constant arbitrary number in the scope  $[-1, 1]$ . As soon as  $s_i$  is attained, it is assessed and likened. If the fitness of  $s_i$  is healthier than  $x_i$ , the bee disremembers the old solution and memorizes the novel one. Else, keeps functioning on  $x_i$ .

*Onlooker bee phase* In this section, when all their local searches have been finished by employed bees, from their food source they share with onlookers about the data of nectar, then in a probabilistic method to each of whom will then decide on a food origin. The probability  $Pb_i$  through which an onlooker bee selects food origin  $x_i$  will be obtained by:

$$Pb_i = \frac{f_i}{\sum_{i=1}^{SN} f_i} \tag{23}$$

where  $f_i$  gives fitness value of  $x_i$ . Surely, onlooker bees are inclined to pick the sources from the food with bigger nectar quantity. When the onlooker has designated a food supply  $x_i$ , the behavior of a local search on  $x_i$  is done on the basis of (23). With previous circumstance, if the altered resolution has a healthier fitness, the fresh solution will substitute  $x_i$ .

*Scout bee phase* Within the scout bee of ABC, if the first-class of a solution is not enhanced after a fixed digit of the trials, the food source is thought to be unrestricted, and the scout equivalent engaged bee is converted.

Arbitrarily, a food’s origin is generated by the scout by means of utilizing (23). To enhance up the optimum performance of a Scout bee section, Cuckoo optimization is utilized here.

### 3.6 Framework for optimal DG rating by Cuckoo search optimization technique

The Cuckoo search is an algorithm [33] by utilizing some species of a bird family known as Cuckoo that is stimulated on the basis of their exact lifestyles variety and violent replica process. They lay their eggs in the nests and the hatching probability of their eggs are raised after putting off the prevailing eggs. Then again, one of vital host birds is capable of contesting this parasites conduct of Cuckoos and building their nests in new places or tossing out the exposed alien eggs.

The three idealized rules for Cuckoo search are

1. At a time each Cuckoo lays a single egg and dumps the egg at arbitrarily chosen nest.
2. A fraction of nests comprising the best eggs that are carried out for the succeeding generation.
3. The quantity of host nests that can be accessible is constant, and the egg placed via a Cuckoo is published via the host bird with a probability  $pa \in [0, 1]$ . If this occurs, the host bird can discard the eggs or abandon the nest, and fresh nest shall be developed elsewhere. The fraction  $pa$  of “ $n$ ” nest is substituted by way of fresh nest.

In Cuckoo search optimization, let the distributed generations be  $DG_i$ . The value of host nest is defined as  $DG_i$  ( $i = 1, 2 \dots N$ ). The host nest represents different DG sizes. The objective function corresponds to  $DG_i$ , and the population of DGs is derived as  $DG_i$ . The population generation of DGs is factored from L’evy Flight. The L’evy Flight process executes the Cuckoo until the DG population reaches maximum

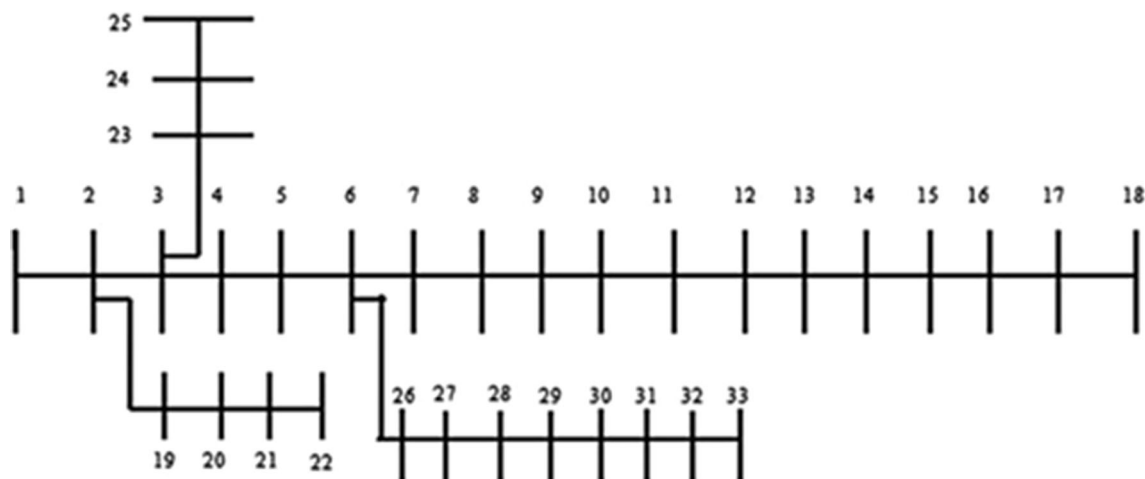


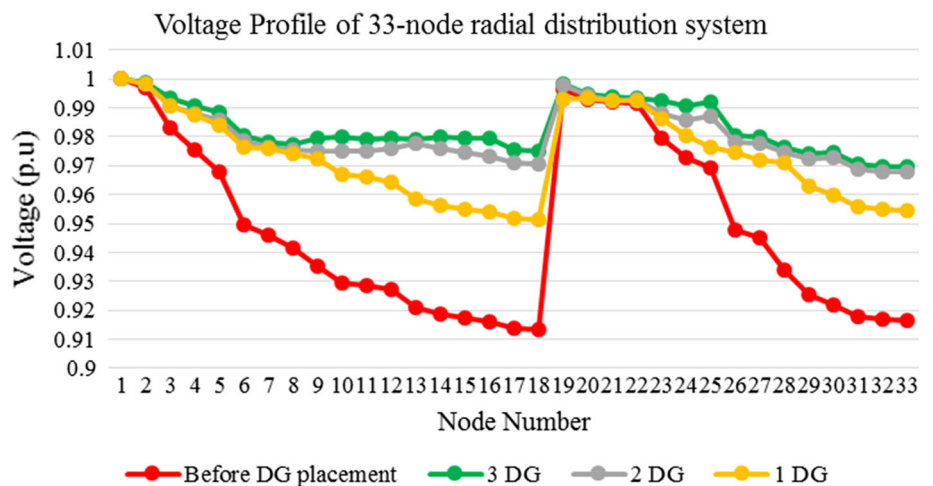
Fig. 4 33-node RDN



**Table 1** Results of 33-node RDN

Parameters	Excluding DG (normal load)	Including DG								
		Type of load								
		Normal (100%)			Medium (75%)			Light (50%)		
	Single DG unit	Double DG units	Triple DG units	Single DG unit	Double DG units	Triple DG units	Single DG unit	Double DG units	Triple DG units	
Real power loss (kW)	202.52	103.95	85.91	71.16	57.48	47.85	41.25	26.08	21.32	18.96
Reactive power loss (kVAr)	135.10	74.71	58.61	48.42	41.29	31.85	27.99	18.91	14.45	13.30
Minimum voltage (p.u.)	0.9132 (18)	0.9514 (18)	0.9680 (33)	0.9756 (33)	0.9628 (18)	0.9719 (33)	0.9741 (18)	0.9799 (18)	0.9824 (18)	0.9835 (18)
DG location (node number)	–	6	13, 30	13, 25, 30	6	13, 30	13, 25, 30	6	13, 30	13, 25, 30
DG size (MW)	–	2.58	0.84, 1.14	0.78, 0.84, 1.12	1.85	0.55, 0.75	0.45, 0.65, 0.94	1.54	0.34, 0.55	0.28, 0.49, 0.74
DG type	–	Type 1								
Power factor	–	Unity								
VSI (sensitive node) by proposed method	0.83411 (18)	0.9053 (18)	0.9371 (33)	0.9409 (33)	0.9282 (18)	0.9449 (33)	0.9488 (18)	0.9605 (18)	0.9645 (18)	0.9673 (18)
VSI (sensitive node) by [27]	0.6981 (18)	0.8215 (18)	0.8789 (33)	0.8853 (33)	0.8615 (18)	0.8928 (33)	0.9012 (18)	0.9224 (18)	0.9307 (18)	0.9372 (18)
VSI (sensitive node) by [28]	0.6867 (18)	0.8080 (18)	0.8645 (33)	0.8707 (33)	0.8474 (18)	0.8782 (33)	0.8868 (18)	0.9083 (18)	0.9165 (18)	0.9229 (18)
Cost of energy loss (\$/kWh)	106,444.512	54,636.12	45,154.296	3,7990.368	30,211.488	25,149.96	21,681	13,707.648	11,205.792	9965.376
Cost of DG (\$/h)	–	51.85	39.85	55.05	37.25	20.25	41.05	31.05	18.05	30.45

**Fig. 5** Voltage profile of 33-node RDN



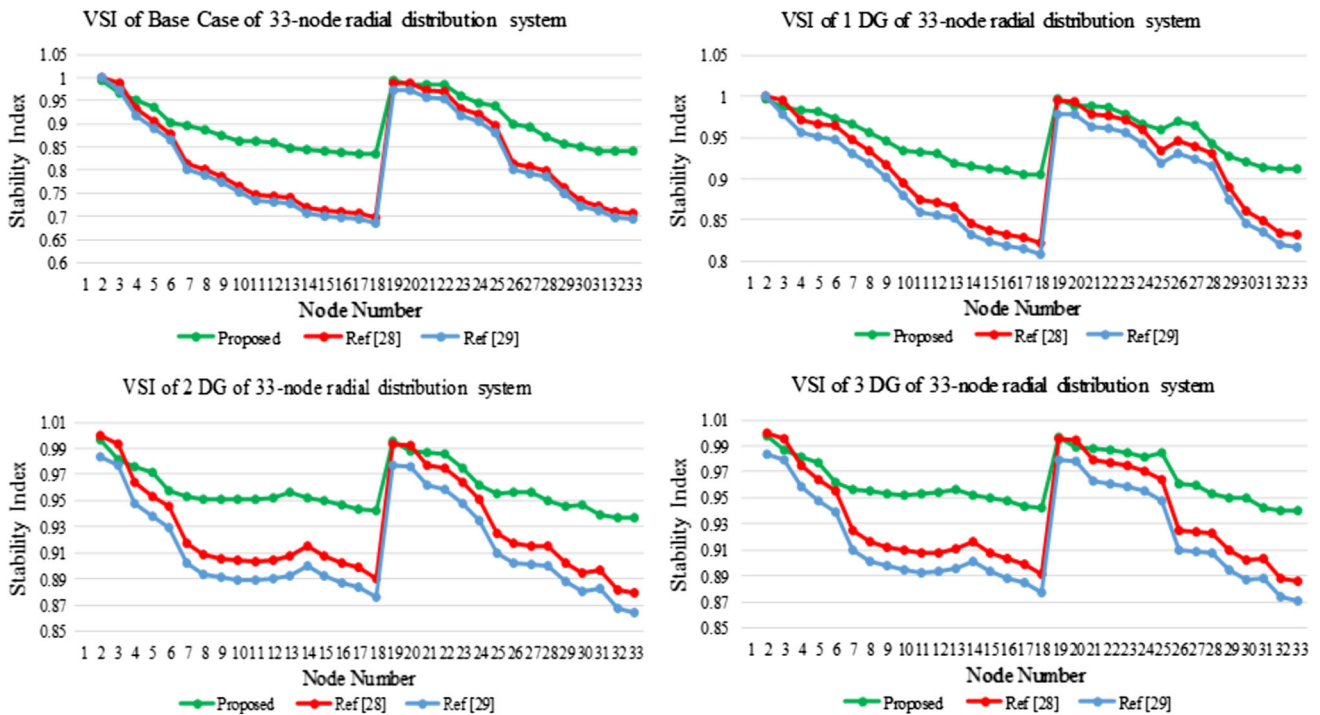


Fig. 6 VSI of 33-node RDN

generation. After populating the maximum DGs, the Cuckoo checks all the DGs to evaluate its quality and fitness  $F_i$ . The selected DGs are capable for network management, and the remaining DGs are discarded. The fitness function is sharp as the voltage profile-to-power loss ratio. The fitness function is

inversely proportional to the power loss. The fitness function  $F_i$  can be computed as.

$$F_i = \max \left[ \frac{V_P}{P_L} \right] \tag{24}$$

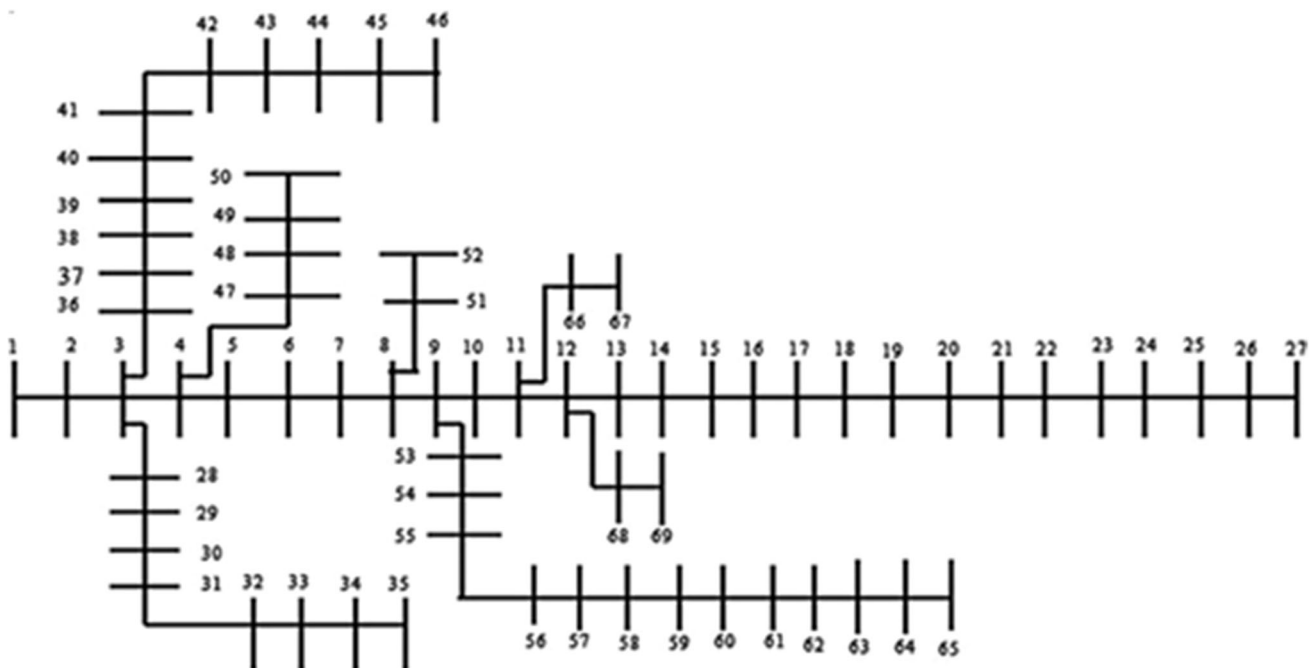


Fig. 7 69-node RDN

**Table 2** Results of 69-node RDN

Parameters	Excluding DG (normal load)	Including DG								
		Type of load								
		Normal (100%)			Medium (75%)			Light (50%)		
		Single DG unit	Double DG units	Triple DG units	Single DG unit	Double DG units	Triple DG units	Single DG unit	Double DG units	Triple DG units
Real power loss (kW)	224.94	83.21	71.70	68.10	47.19	40.85	39.54	25.77	19.45	17.98
Reactive power loss (kVAr)	102.19	40.62	35.81	34.02	23.19	19.99	19.85	12.56	9.69	8.90
Minimum voltage (p.u.)	0.9091 (65)	0.9683 (27)	0.9795 (65)	0.9848 (65)	0.9756 (27)	0.9781 (65)	0.9851 (65)	0.9759 (65)	0.9818 (65)	0.9930 (65)
DG location (node number)	–	61	18, 61	18, 61, 63	61	18, 61	18, 61, 63	61	18, 61	18, 61, 63
DG size (MW)	–	1.87	0.51, 1.80	0.52, 1.45, 0.29	1.43	0.52, 1.15	0.42, 1.05, 0.29	0.53	0.25, 0.65	0.25, 0.85, 0.15
DG type	–	Type 1								
Power factor	–	Unity								
VSI (sensitive node) by proposed method	0.8278 (65)	0.9381 (27)	0.9596 (65)	0.9605 (65)	0.9519 (27)	0.9568 (65)	0.9705 (65)	0.9521 (65)	0.9632 (65)	0.9870 (65)
VSI (sensitive node) by [27]	0.6853 (65)	0.8793 (27)	0.9258 (65)	0.9268 (65)	0.9055 (27)	0.9170 (65)	0.9439 (65)	0.9076 (65)	0.9291 (65)	0.9761 (65)
VSI (sensitive node) by [28]	0.6842 (65)	0.8779 (27)	0.9244 (65)	0.9253 (65)	0.9042 (27)	0.9158 (65)	0.9429 (65)	0.9065 (65)	0.9278 (65)	0.9749 (65)
Cost of energy loss (\$/kWh)	118,228.464	43,735.176	37,685.52	36,035.136	24,803.064	21,470.76	20,782.224	13,544.712	10,222.92	9450.288
Cost of DG (\$/h)	–	37.65	46.45	45.45	28.85	33.65	35.45	10.85	18.25	25.25

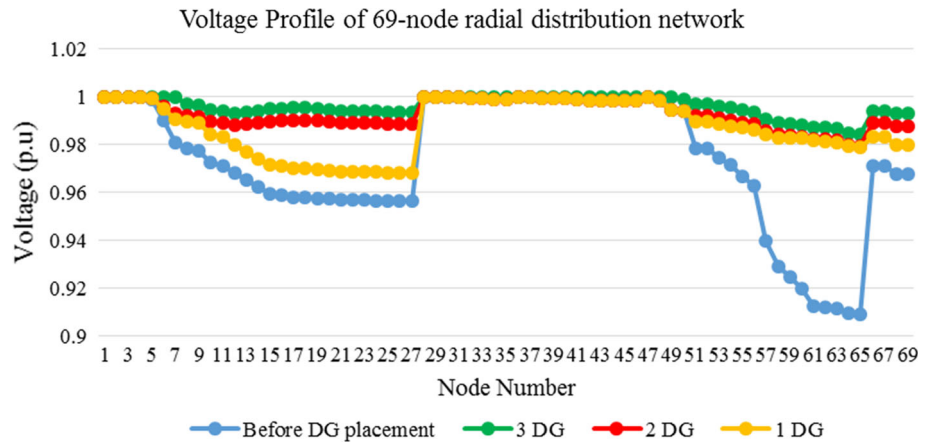
where  $V_p$  is the voltage profile and  $P_L$  is the power loss. The L’evy Flight can be computed using the following equation

$$DG_{t+1} = DG_t + xE_t \tag{25}$$

where  $DG_t$  represents the size of DG chosen for optimization,  $x$  represents how far-off the DG positions in the grid,  $E_t$  represents the L’evy distribution. The L’evy distribution is valued at stages  $1 < l \leq 3$ , where “1” represents L’evy distribution. After the fitness

computation, a DG is randomly decided and related to the fitness function. If the randomly chosen DG value is sophisticated, the chosen DG is kept as the answer else it is exchanged with the new DG value. For picking out the superlative place for DG, a fraction Pa is computed. By that fraction, the paramount DG is positioned in the grid. The most suitable DG placement is established based on the voltage profiles and path loss. Utilizing (26) available in [34], the power loss will also be computed.

**Fig. 8** Voltage profile of 69-node RDN



$$P_L = \sum_{k=1}^N \sum_{l=1}^N [\alpha_{kl}(P_k P_l + Q_k Q_l) + \beta_{kl}(Q_k P_l - P_k Q_l)] \tag{26}$$

where  $\alpha_{kl} = \frac{r_{kl}}{V_k V_l} \cos(\delta_k - \delta_l)$ ;  $\beta_{kl} = \frac{r_{kl}}{V_k V_l} \sin(\delta_k - \delta_l)$  are the complex voltages at bus  $i$  and  $j$ .

$r_{kl} + jx_{kl} = Z_{kl}$ — $ij$ -th element of  $[Z_{bus}]$  impedance matrix.

$P_k$  and  $Q_k$ —net real and reactive power injection in bus  $k$

$P_l$  and  $Q_l$ —net real and reactive power injection in bus  $l$

$V_k$  and  $\delta_k$ —voltage magnitude and angle at bus  $k$

$V_l$  and  $\delta_l$ —voltage magnitude and angle at bus  $l$

$N$ —number of buses

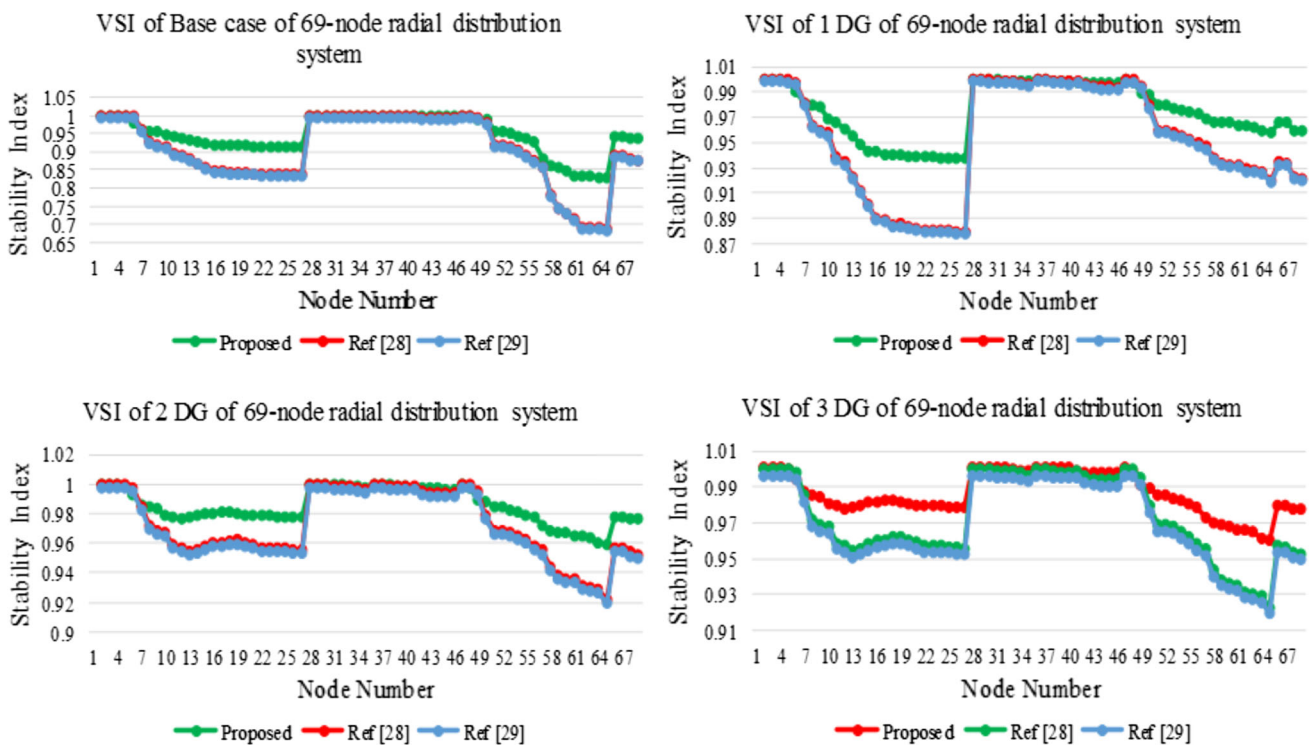
The voltage profile  $V_p$  can be defined as in (27)

$$V_p = \sum_{i=1}^n V_i L_i W_{fi} \tag{27}$$

where  $V_i$  represents the voltage magnitude of the bus  $i$ , load at bus  $i$  is represented by  $L_i$ , and the weighting factor of load bus is  $W_{fi}$ . The weighting factor of load bus is.

$$\sum_{i=1}^n W_{fi} = 1 \tag{28}$$

On the basis of voltage profile and power loss, the DG is sized optimally so that the grid network is managed



**Fig. 9** VSI of 69-node RDN

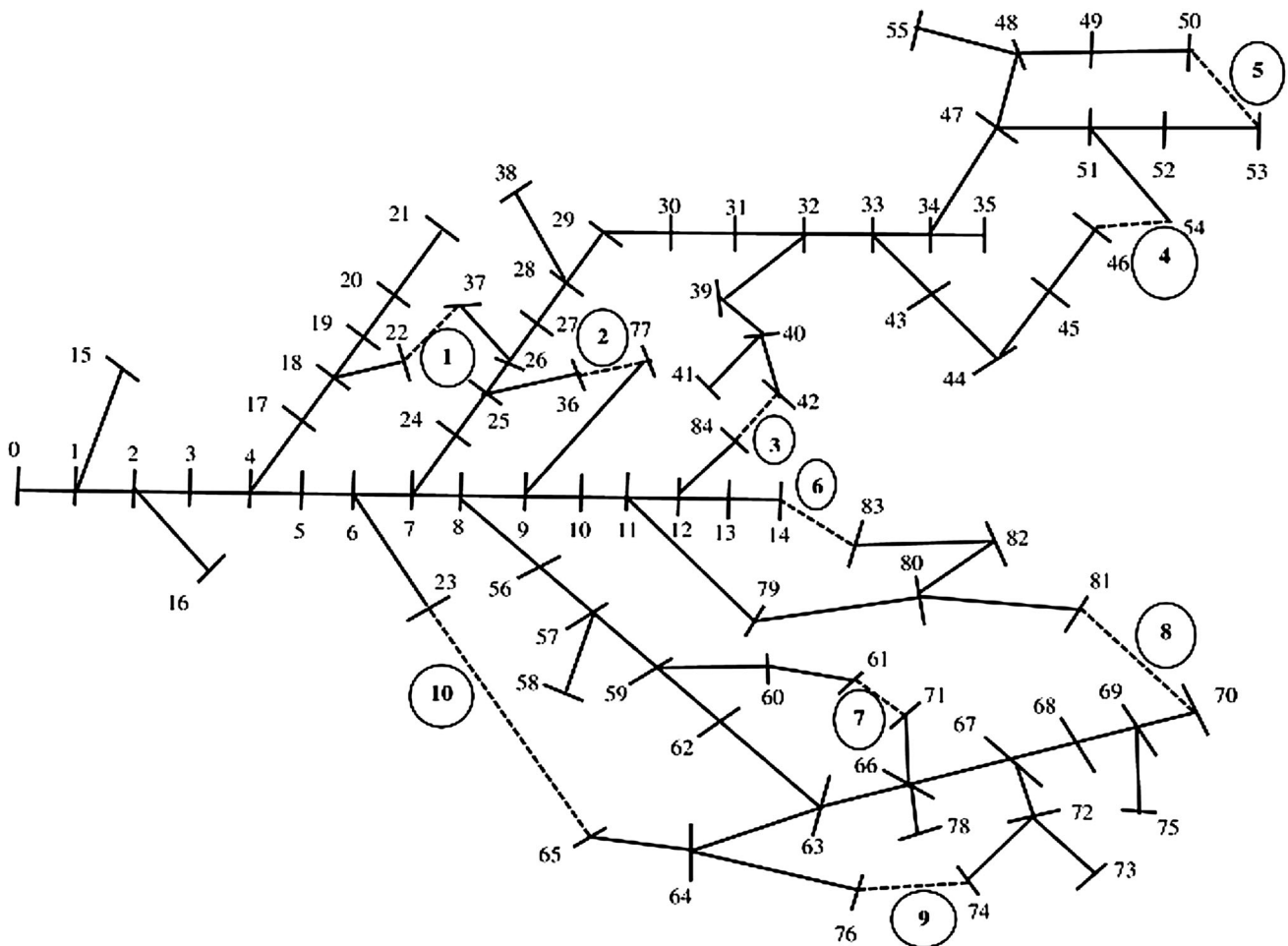


Fig. 10 85-node MDN

efficiently. The pseudocode of Cuckoo search for optimal sizing of DG is shown below.

```

Begin
Total number of Distributed Generation DGi
Generate initial population of n host nests DGi (i = 1, 2... N)
while (t < Max Generation) or (stop criterion)
Get a cuckoo randomly by Levy flights
Evaluate its quality/fitness in Fx
Choose a DG among N (say y) randomly
if (Fx > Fy),
Replace y by the new solution;
end
A fraction (pa) of worse nests are abandoned and new ones are built;
Keep the best solutions
Rank the solutions and find the current best
end while
Post process results and visualization
end
    
```

The above proposed work by utilizing ABC–CS presents a new deterministic methodology, which determines the optimal size for DG placement. This technique is easy to be applied.

Different types of DG have been introduced in [14]. The cost parameters have been presented in [21].

### 4 Simulation results and discussions

The proposed technique of the optimal size multi-DG placement using ABC–CS is applied in the Matlab platform. The technique is verified in the typical 33-node and 69-node RDNs, 85-node and 119-node MDNs.

#### 4.1 33-node RDN

Initially, it is applied to 33-node RDN having 12.66 kV and 100 MVA as base values. In Fig. 4, the single line illustration of the system is shown. In [35], the system data are available having net reactive and real power loads of 2.3 MVar and 3.7 MW, respectively.

Table 1 shows the detailed outcomes of excluding DG unit (base case) and including DG unit(s) (single DG unit, double DG units and triple DG units) in terms of real power loss, minimum voltage (p.u.), location and size of each DG unit, most sensitive node and its VSI value, price of energy loss and price of DG for 33-node RDN for light load (50%), medium load (75%) and normal load (100%).



**Table 3** Results of 85-node MDN

Parameters	Without DG	With DG
Real power loss (kW)	286.52	91.25
Reactive power loss (kVAr)	180.52	75.45
Minimum voltage (p.u.)	0.87749 (54)	0.9325 (54)
Number of DGs	–	3
DG location (node number)	–	8, 58, 27
DG size (MW)	–	2.2 (8), 1.53 (27), 0.16 (58)
DG type	–	Type 1
Power factor	–	0.88
VSI (sensitive node) (proposed method)	0.80111 (54)	0.92181 (54)
VSI (sensitive node) [28]	0.69112 (54)	0.87481 (54)
VSI (sensitive node) [29]	0.68423 (54)	0.86591 (54)
Cost of energy loss (\$/kWh)	150,594.912	47,961
Cost of DG (\$/h)	–	78.05

The voltage shape of 33-node RDN excluding and including placement of DG unit(s) (one DG, two DGs and three DGs) is shown in Fig. 5 for normal load (100%).

The plot of VSI vs node of 33-node RDN before and after placement of DG unit(s) (single DG unit, double DG units and triple DG units) is shown in Fig. 6 for normal load (100%) using proposed method and methods available in [28, 29].

**4.2 69-node RDN**

Now it is applied to 69-node RDN having 12.66 kV and 100 MVA as base values as shown in Fig. 7. The system data are available in [35] having net reactive and real power loads of 2.69 MVar and 3.80 MW, respectively.

Table 2 shows the results of excluding DG unit (base case) and including DG unit(s) (single DG unit, double DG units and triple DG units) in terms of active power loss, minimum voltage (p.u.), location and size of each DG unit, most sensitive node and its VSI value, price of energy loss and price of DG for 69-node RDN for three different loads light (50%), medium (75%) and normal (100%).

The voltage profile of 69-node RDN before and after placement of DG unit(s) (single DG unit, double DG units and triple DG units) is shown in Fig. 8 for normal load (100%).

The plot of VSI vs node of 69-node RDN before and after DG placement (single DG unit, double DG units and triple DG units) is shown in Fig. 9 for normal load (100%) using proposed method and methods available in [28, 29].

**Fig. 11** Voltage profile of 85-node MDN

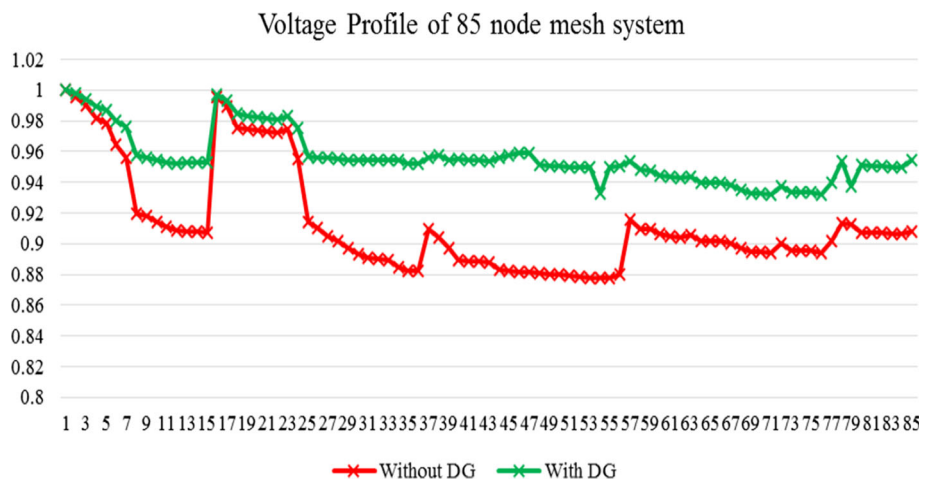


Fig. 12 VSI of 85-node MDN

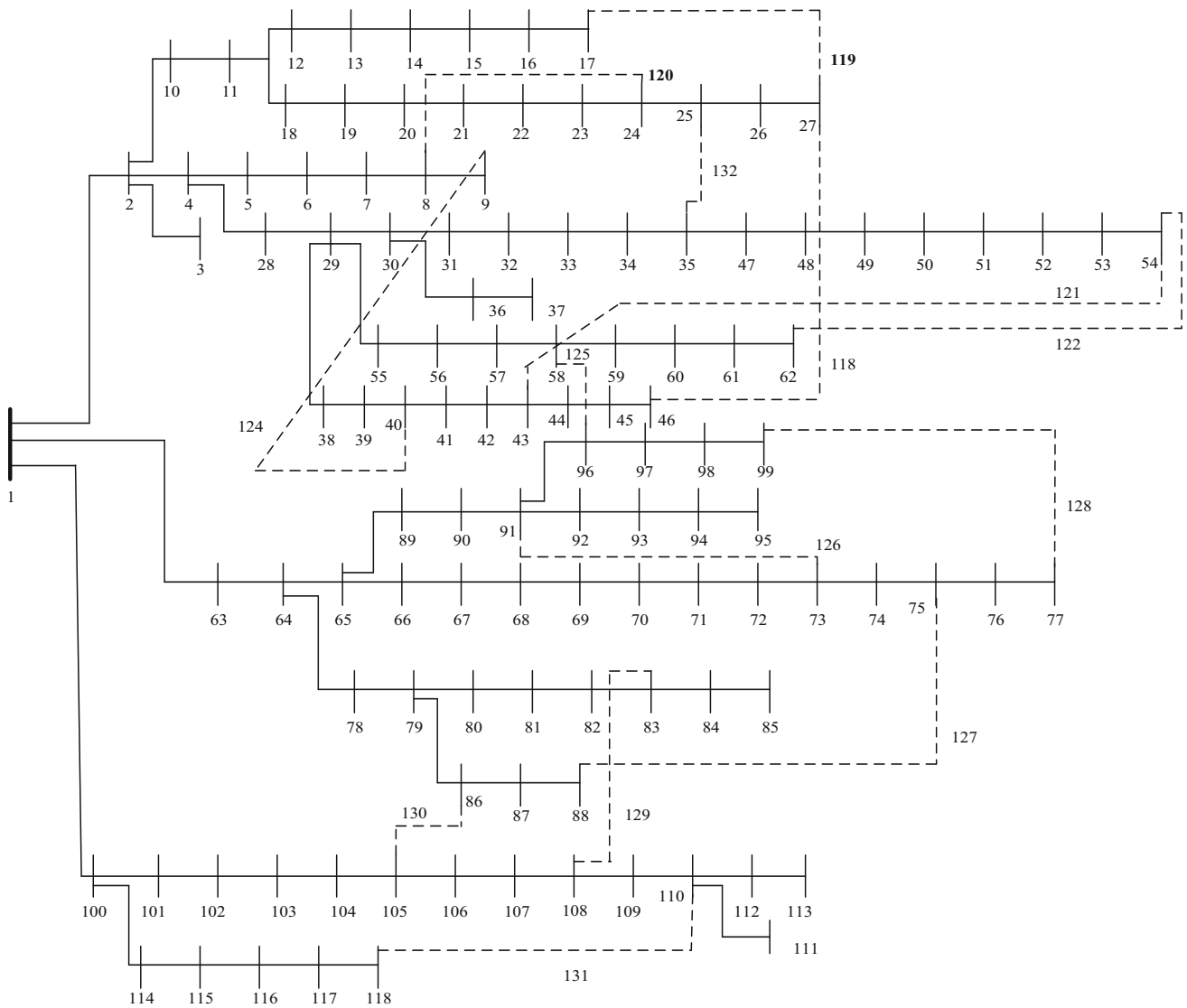
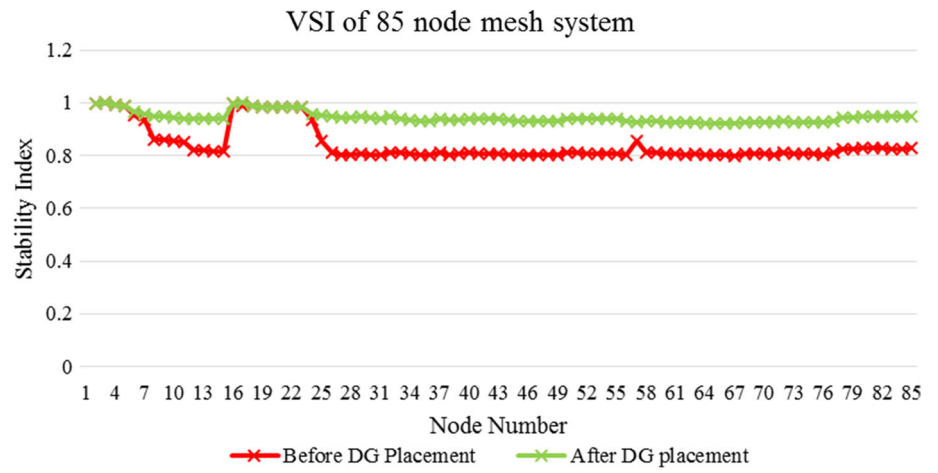


Fig. 13 119-node MDN

**Table 4** Results of 119-node MDN

Parameters	Without DG	With DG
Real power loss (kW)	1029.8	675.87
Reactive power loss (kVAr)	786.6	555.54
Minimum voltage (p.u.)	0.8615 (51)	0.9530 (51)
Number of DGs	–	3
DG location (node number)	–	21, 51, 80
DG size (MW)	–	1.3, 1.21, 1.02
DG type	–	Type 1
Power factor	–	0.89
VSI (sensitive node)	0.7829 (51)	0.9021 (51)
VSI (sensitive node) [28]	0.6478 (51)	0.8614 (51)
VSI (sensitive node) [29]	0.6384 (51)	0.8485 (51)
Cost of energy loss (\$/kWh)	541,262.88	355,237.272
Cost of DG (\$/h)	–	70.85

### 4.3 85-node MDN

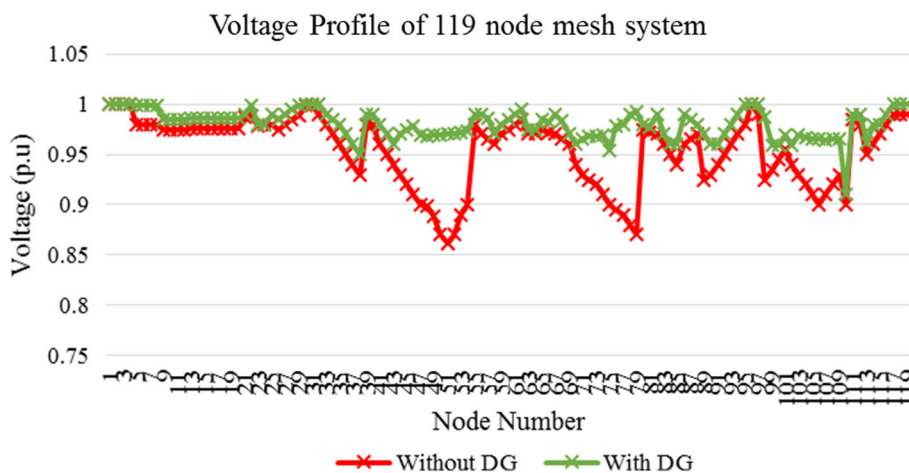
In [36], the total system data are given for 85-node MDN as shown in Fig. 10, which consists of 85 nodes and 10 meshes. The base MVA is 100, and base kV is 11. The total load of the system is  $2.57 + j2.62$  MVA.

Table 3 shows the results for cases, i.e., excluding DG and including three DG units in terms of active power loss, minimum voltage (p.u.), location and size of each DG, most sensitive node and its VSI value, price of energy loss and price of DG for 85-node MDN for normal load (100%).

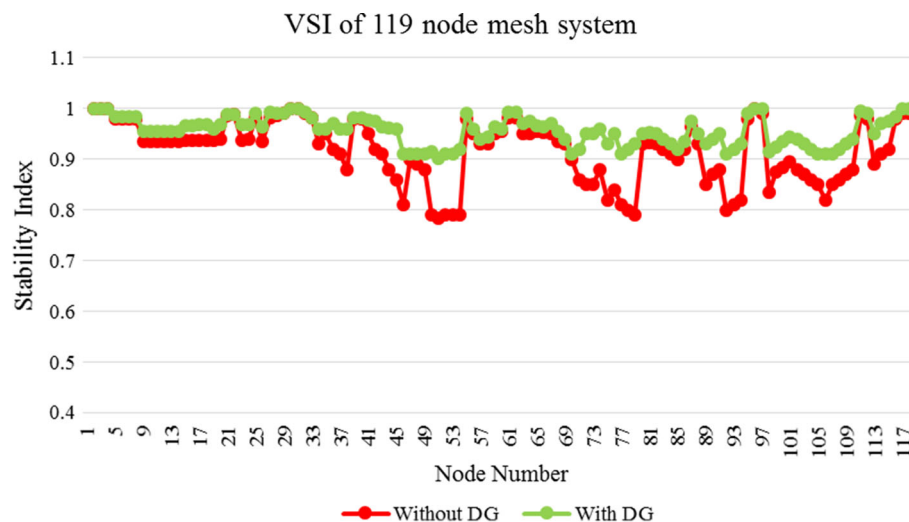
The voltage profile of 85 node MDN before and after placement 3 DG units is shown in Fig. 11 for normal load (100%).

The plot of proposed VSI vs node of 85-node MDN before and after placement of three DG units is shown in Fig. 12 for normal load (100%).

**Fig. 14** Voltage profile of 119-node MDN



**Fig. 15** VSI of 119-node MDN



**Table 5** Performance comparison for three DGs placement in 33-node and 69-node RDNs

Methods	Bus system	Real power loss (kW)	$V_{\min}$ (p.u.) & (node no.)	DG size (MW) and (location)	Relative CPU time
Proposed method	33 RDN	71.16	0.9756 (33)	0.780 (13), 0.840 (25), 1.12 (30)	1.00
	69 RDN	68.10	0.9848 (65)	0.520 (18), 1.45 (61), 0.290 (63)	<i>1.00</i>
[20]	33 RDN	89.90	0.9705 (29)	0.6521 (14), 0.1984 (18), 1.0672 (32)	1.45
	69 RDN	75.23	0.9808 (61)	0.2954 (27), 0.4476 (65), 1.3451 (61)	<i>1.78</i>
IA [23]	33 RDN	81.05	0.9715 (18)	0.900 (6), 0.900 (12), 0.720 (31)	1.65
	69 RDN	68.82	0.9779 (65)	1.700 (61), 0.510 (17), 0.340 (11)	<i>1.97</i>
[23]	33 RDN	72.79	0.9685 (33)	0.800 (13), 1.090 (24), 1.050 (30)	1.71
	69 RDN	70.08	0.9798 (65)	1.81 (61), 0.510 (17), 0.720 (50)	<i>1.99</i>
[25]	33 RDN	72.89	0.9670 (33)	0.790 (13), 1.070 (24), 1.010 (30)	1.39
	69 RDN	69.54	0.9771 (65)	0.510 (11), 0.380 (17), 1.670 (61)	<i>1.80</i>
[26]	33 RDN	71.4	0.9686 (33)	0.754 (14), 1.009 (24), 1.072(30)	1.60
	69 RDN	71.5	0.9803 (61)	0.537 (17), 1.200 (61), 0.536 (64)	<i>2.09</i>
[26] [SOS Studied]	33 RDN	77.0	0.9717 (33)	1.069 (6), 0.643 (14), 0.739 (31)	1.64
	69 RDN	74.2	0.9776 (27)	1.200 (61), 0.498 (64), 0.833 (66)	<i>2.12</i>
[27]	33 RDN	71.45	0.9686 (33)	1.07142 (30), 1.09944 (24), 0.75398 (14)	1.64
	69 RDN	69.42	0.9789 (65)	1.71912 (61), 0.38050 (18), 0.52670 (11)	<i>2.12</i>

The relative CPU time for 69 node RDN is shown in italics

#### 4.4 119-node MDN

Similarly, the method is also tested on the 119-node MDN. This system has 15 tie switches and 118 sectionalizing switches as shown in Fig. 13. The base values are 11 kV and 100 MVA. The system data are available in [37] having net load of  $22.71 + j17.01$  MVA.

Table 4 shows the results for cases, i.e., excluding DG and including three DG units in terms of active power loss, minimum voltage (p.u.), location and size of each DG, most sensitive node and its VSI value, price of energy loss and price of DG for 119-node MDN for normal load (100%).

Before and after placement of three DG units the voltage profile of 119 node MDN is shown in Fig. 14 for normal load (100%).

Before and after placement of three DG units, the plot of proposed VSI vs node of 119-node MDN is shown in Fig. 15 for normal load (100%).

The suggested method is correlated with other existing techniques [20, 23, 25–27] in terms of loss reduction and minimum voltage as shown in Table 5 for normal load.

Table 5 shows that the proposed method gives a better loss reduction as well as better improvement of minimum voltage than the other methods for 33-node and 69-node RDNs. The proposed method takes less CPU time compared to the existing methods.

#### 5 Conclusions

The proposed methodology grants the effective analysis of voltage stability, making use of Fuzzy-PSO, and does acceptably on distribution systems for simulation purposes. The most optimal size of each DG unit is illustrated via ABC–CS. The location and size of each DG unit are the principal reason in the planning and operation of energetic RDNs. The suggested implementation grants a new deterministic way that selects the optimal positions and rating for placement of each DG unit. The proposed method proves that it can save massive quantity of power and gain significant growth in voltage stability. The proposed method has been executed on 33-node and 69-node RDNs [35] as well as on 85-node [36] and 119-node MDNs [37]. The VSI value of MSN obtained by the suggested method has also been correlated with that obtained by [28, 29] using the suggested load flow. After placement of DG unit(s), the VSI values have been improved due to the reduction of losses. After placement of three DG units in 33-node as well as 69-node RDNs, the losses obtained for both 33-node and 69-node RDNs have been compared to those obtained by the methods [20, 23, 25–27]. This suggests that loss reduction by the suggested procedure is appreciable in

contrast to these methods and voltage profile and simulation time are also better than in these methods.

#### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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