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Optimal location and sizing of real power DG units to improve the voltage stability in the distribution system using ABC algorithm united with chaos

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ABSTRACT

The introduction of a Distributed Generation (DG) unit in the distribution system improves the voltage profile and reduces the system losses. Optimal placement and sizing of DG units play a major role in reducing system losses and in improving voltage profile and voltage stability. This paper presents in determination of optimal location and sizing of DG units using multi objective performance index (MOPI) for enhancing the voltage stability of the radial distribution system. The different technical issues are combined using weighting coefficients and solved under various operating constraints using a Chaotic Artificial Bee Colony (CABC) algorithm. In this paper, real power DG units and constant power load model and other voltage dependent load models such as industrial, residential, and commercial are considered. The effectiveness of the proposed algorithm is validated by testing it on a 38-node and 69-node radial distribution system.

Introduction

In general, DG can be defined as the generation of electricity within distribution networks or on the consumer side of the network. The distributed capacities minimize the requirements for over dimensioning of transmission and distribution system [1]. The various renewable and non-renewable technological options available for DG and their current status were discussed in literature [2]. The various technical based indices are used in Ref. [3] to determine the benefits of DG in terms of voltage profile improvement, line-loss and environmental impact reduction of the distribution system. The various technical issues and negative impacts of DG on the network are discussed [4,5].

To identify the most sensitive node in the radial distribution system a new voltage stability index (VSI) has been used [6,7]. In Ref. [8], the author presented the network reconfiguration using a fuzzy genetic algorithm for improvement of voltage stability in the radial distribution system. If the value of VSI is improved significantly, it is possible to operate the system away from voltage instability condition. The optimal location and sizing of DG in the distribution system using analytical methods is reported in Refs. [9,10]. If the number of DGs gets increased, finding the optimal location and sizing of DGs using analytical expressions is more complicated. Soft computing techniques can reduce such complexities raised due to increase in the number of DG units in the distribution system.

The genetic algorithm (GA) is used to obtain the optimal location and sizing of single and multiple DG units within the distribution system, considering various technical issues of impact indices in the literature [11,12]. The GA and Particle Swarm Optimization (PSO) techniques have been implemented to find the best location of DGs considering voltage stability and short circuit level in the distribution system [13,14]. Moradi and Abedini [15] proposed a hybrid GA–PSO algorithm to find the optimal location and sizing of DG units based on power loss reduction within the distribution system. Determining the optimal location and sizing of DGs in the distribution system using Kalman filter, Artificial Bee Colony (ABC) and bacterial foraging optimization algorithm have been reported in Refs. [16–18]. The authors have been presented in Refs. [19,20], the voltage stability and power losses are considered as the placement of DGs in the distribution system.

Das [21] developed a GA based fuzzy approach to determine the optimal sizes of fixed and switched capacitors to improve the voltage profile in a radial distribution system. The general discussion about the various types of load models and dynamic performances of power flow study has been reported in Ref. [22]. The distribution system is normally in unbalanced loading condition and is having a high R/X ratio. The forward and backward propagation based

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efficient load flow solution technique has been implemented in the practical radial distribution system [23].

The ABC algorithm uses less number of control parameter, and better approach for solving the multi-modal and multi-dimensional optimization problems. The ABC algorithm mimics the character of real bees in searching food sources and transfers the information with other bees. A population with different flying patterns support the algorithm to increase the diversity of solutions. This provides the effectiveness of the algorithm to maintain a suitable balance between the process of exploration and exploitation [24–28]. The basic ABC algorithm has been implemented for the constrained optimization problems, in which the convergence rate is poor. In the literature [29,30], the modified versions of ABC algorithm have been introduced and applied for solving the real world optimization problems. The PSO technique has been implemented in different real world optimization problem. The major drawback of PSO algorithm is being trapped at local optimal solution. The performance of PSO algorithm is improved by incorporating chaos in the literature [31].

In this paper, to improve the exploitation ability of ABC algorithm is integrated with chaos to construct a Chaotic Artificial Bee Colony (CABC) algorithm for solving the optimization problem. From the survey of earlier works on location and sizing of DGs, it is observed that the real power loss index, reactive power loss index, voltage profile index and MVA capacity index have been considered as the objectives for minimization. In order to improve the loading capacity of the distribution system, voltage stability index (VSI) is included as an additional objective while finding the optimal location and sizing of DGs. Various load models such as industrial, residential and commercial are considered in the problem and is solved using CABC algorithm. Simulation results show the potential of the algorithm for identifying the optimal location and sizing of DGs in the distribution system.

Load models and related impact indices

The load model in the distribution system represents the mathematical relationship between a bus voltage and power or current flowing into the load bus. The various load models considered in the distribution systems are residential, industrial and commercial. In this approach, the voltage dependent load models are used, which is mathematically expressed as,

$$P_i = P_{oi}\ V_i^{\alpha} \tag{1}$$

$$Q_i = Q_{oi}\ V_i^{\beta} \tag{2}$$

where P_i and Q_i are real and reactive power at bus i, P_{oi} and Q_{oi} are real and reactive operating points at bus i, V_i is the voltage at bus i, α and β are real and reactive power exponents. The values of α and β for constant, industrial, residential and commercial loads are given in Table 1 [11]. In this approach, several technical issues are considered that are associated to the power loss index, line flow limit index, voltage profile and voltage stability index to form the objective function. These related impact indices are defined as follows.

Table 1
Load types and exponent values.

Load type	α	β
Constant	0	0
Industrial	0.18	6.00
Residential	0.92	4.04
Commercial	1.51	3.40

Real and reactive power loss index (ILP and ILQ)

The system operates at maximum performance represent as reduces the losses. In this case, the real and reactive power loss indices are defined as [12],

$$\mathrm{ILP} = \frac{[P_{LDG}]}{[P_L]} \tag{3}$$

$$\mathrm{ILQ} = \frac{[Q_{LDG}]}{[Q_L]} \tag{4}$$

where P_{LDG} and Q_{LDG} are the total real and reactive power loss of the distribution system with DG. P_L and Q_L are the total real and reactive power loss of the distribution system without DG. The optimal location and sizing of DGs will decrease the total network losses, which means near zero values of ILP and ILQ.

Voltage stability index (VSI)

The VSI gives a significant detail about the voltage stability of the radial distribution systems. In this approach, VSI is taken as the decisive factor which variation of this value indicating the system voltage stability for the presence and absence of DGs connect to the test systems. The VSI can be defined as [6],

$$\begin{aligned}\mathrm{VSI}(m2) = |V(m1)|^4 - 4.0\ \{P(m2)\ x(jj) - Q(m2)\ r(jj)\}^2 \\ - 4.0\ \{P(m2)r(jj) + Q(m2)x(jj)\}|V(m1)|^2\end{aligned} \tag{5}$$

where NB = total number of nodes; jj = branch number; VSI($m2$) = voltage stability index of node $m2$ ($m2$ = 2, 3,…., NB); $r(jj)$ = resistance of branch jj; $x(jj)$ = reactance of branch jj; $V(m1)$ = voltage of node $m1$; $V(m2)$ = voltage of node $m2$; $P(m2)$ = real power load fed through node $m2$; $Q(m2)$ = reactive power load fed through node $m2$.

The intensity of stability can measure the distribution system using the VSI and thereby necessary action, possibly taken if the index indicates the instability condition of the system. The system operates at secure and stable condition the evaluated VSI values are greater than zero, otherwise instability occurs.

Line flow limit index (IC)

The DGs connected with the system significantly changes the power flow in various sections of the network. The acceptable limit of line flow is very important to avoid the overloading of the line. The IC index gives in detail of line flow and currents through the network concerning the maximum capacity of conductors. The value of this index less than unity indicate the acceptable limits of line flows, whereas the values higher than unity point out the violation of the limit.

$$IC = \max_{i=1}^{NL}\left(\frac{|\overline{S_{ij}}|}{|\overline{CS_{ij}}|}\right) \tag{6}$$

where $\overline{S}_{ij}$ – MVA flow in the line connecting bus i and j; $\overline{CS}_{ij}$ – MVA capacity of line i and j; NL – Number of lines.

Voltage profile index (IVD)

The DG connected to the distribution system greatly improves the voltage at each node (except first node) and better performance of the network. The voltage profile related to the IVD index can be defined as follows,

$$\mathrm{IVD} = \max_{i=2}^{NN}\left(\frac{|\overline{V}_{nominal}| - |\overline{V}_i|}{|\overline{V}_{nominal}|}\right) \tag{7}$$

where $V_{nominal}$ = 1.03 p.u. (Case (i) 38-node radial distribution system); $V_{nominal}$ = 1.00 p.u. (Case (ii) 69-node radial distribution system); NN = number of nodes.

Normally, the voltage limit ($V_{\min} \leq V_i \leq V_{\max}$) is considered as a technical constraint at a particular bus and thus the IVD value is normally small and within the permissible limits.

Problem formulation

The multi objective performance index of the distribution networks is computed taking into account the separate objective functions. The MOPI is a multiple index proposed to be optimal location and sizing of DG units and to enhance the voltage stability of the radial distribution system. The largest value of VSI is to enhance the voltage stability of the distribution system and lowest values of ILP, ILQ and IVD are to reduce the real, reactive power losses and to improve the voltage profile of the distribution systems such that all the line flows (IC) should be within their acceptable limit. For better performance of the distribution system, the separate objective functions (except VSI) are normalized between zero and one.

The separate objective function is to form a single objective (MOPI) optimization problem using the weighting factor. The Chaotic Artificial Bee Colony algorithm based multi objective performance index (MOPI) is given by,

$$\text{MOPI} = \omega_1 \cdot \text{ILP} + \omega_2 \cdot \text{ILQ} + \omega_3 \cdot \left(\frac{1}{\text{VSI}}\right) + \omega_4 \cdot IC + \omega_5 \cdot \text{IVD} \tag{8}$$

where $\sum_{P=1}^{5} \omega_P = 1.0 \; \Lambda \; \omega_P \in [0, 1]$.

The weighting factors play the important role in optimizing the multi objective problem, and the values of weighting factors are decided according to the network designer. In this approach, the

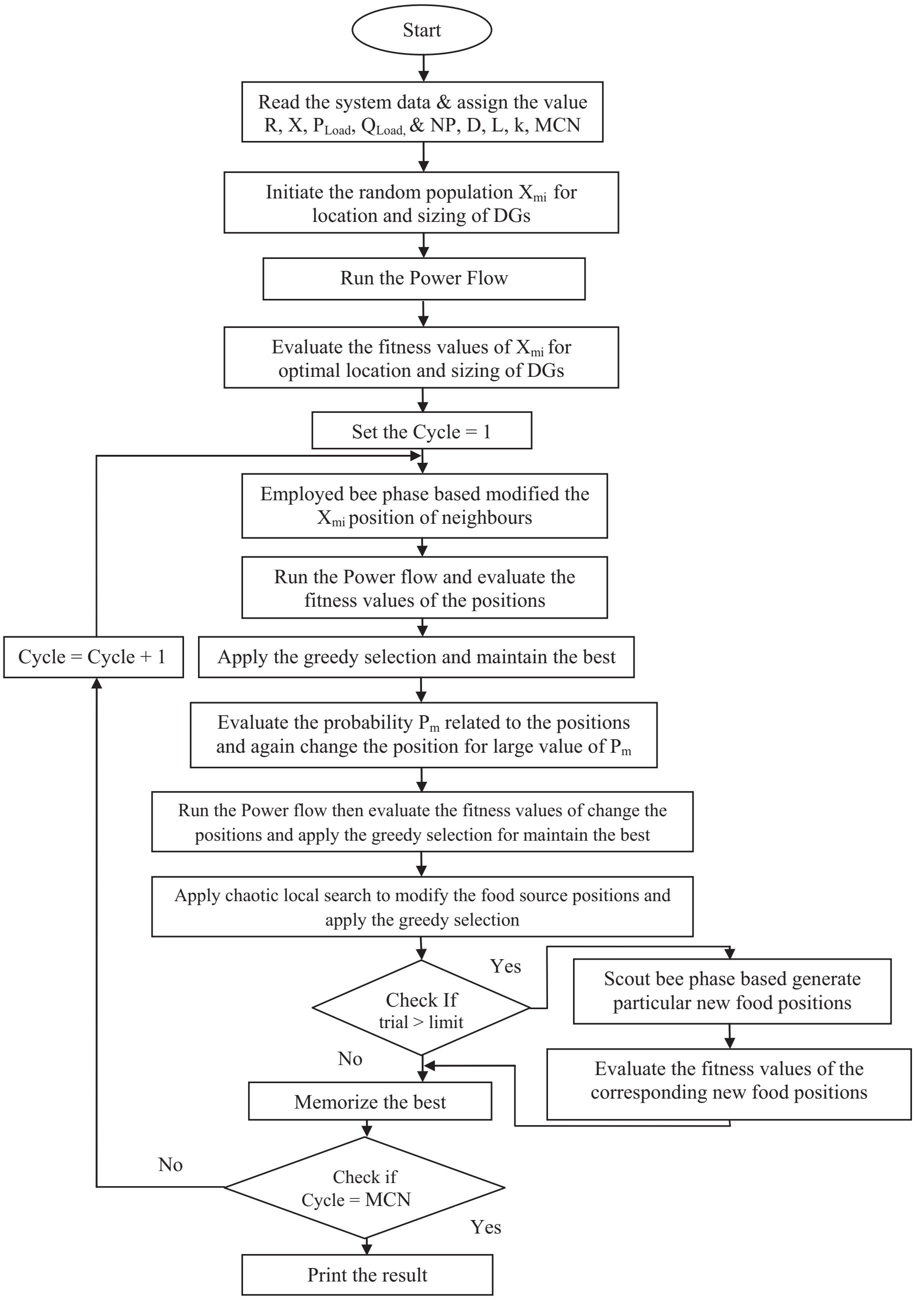


Fig. 1. A flowchart of CABC algorithm is implemented for optimal location and sizing of DGs.

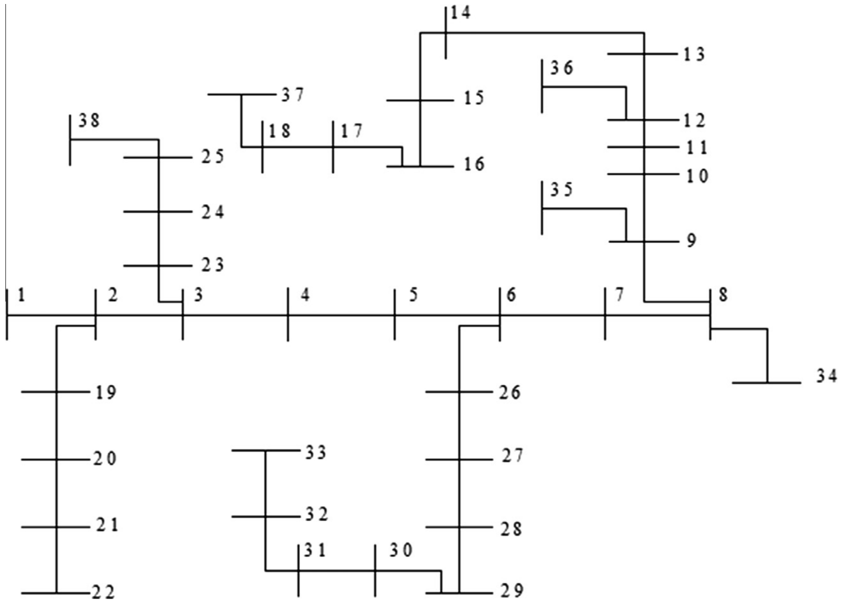


Fig. 2. 38-Node radial distribution system.

Table 2
Comparisons of related impact indices and MOPI for 38-node system with load models.

Indices	Constant	Industrial	Residential	Commercial	Mixed
ILP	0.35609	0.42294	0.41849	0.42238	0.41797
ILQ	0.37001	0.43511	0.43355	0.43833	0.43320
VSI	1.01000	0.98514	0.98414	0.98593	0.98639
IC	0.98543	0.98132	0.98120	0.97983	0.98279
IVD	0.02671	0.03274	0.03300	0.03256	0.03245
Min MOPI	0.52951	0.56504	0.56336	0.56485	0.56321
Optimal location-size (p.u.) pairs	14 @ 0.75466	13 @ 0.72956	13 @ 0.69604	13 @ 0.68632	13 @ 0.70491
	24 @ 1.08786	24 @ 1.05144	24 @ 1.04097	24 @ 1.04308	24 @ 1.04173
	30 @ 1.16206	31 @ 0.81340	30 @ 0.98879	30 @ 1.00703	30 @ 1.00314

real power loss index is the first part of the objective function inward a significant weight factor of 0.35. The second part of the objective function is the reactive power loss index receives 0.15 as weight factor. The inverse of VSI receives 0.10, gives a detail of whether the system operates away from the voltage collapse point. The IC index receives 0.25 gives the information on line upgrading. The IVD index receives a weight factor of 0.15 due to voltage profile on the system. The CABC algorithm has to be simulated so that the bees can move over the feasible region and limit in the search space. In the problem formulation, the objective is to minimize the multi objective functions while satisfying the various constraints. These constraints are discussed as follows.

Power – conservation limits

The algebraic sum of all receiving and sending powers including line losses over the complete distribution network and power produced from the DG unit should be equal to zero.

$$P_{SS}(i,V)=\sum_{i=2}^{NB}P_D(i,V)+\sum_{j=1}^{NL}P_{loss}(j,V)-\sum_{k=1}^{NDG}P_{DG}(k,V) \tag{9}$$

where P_D – total system real power demand (MW); P_{loss} – total system real power loss (MW); P_{DG} – total real power generated by Distributed Generation (MW); NDG – number of DG.

DG real power generation limits

The real power generated by each DG (P_{DG}) is limited by its lower and upper limits as,

$$P_{DG}^{\min}\le P_{DG}\le P_{DG}^{\max} \tag{10}$$

Voltage profile limits

The voltage magnitude of each node in the radial distribution system is defined as,

$$V_i^{\min}\le V_i\le V_i^{\max} \tag{11}$$

$$0.95\le V_i\le 1.03\ (Case\ (i))$$

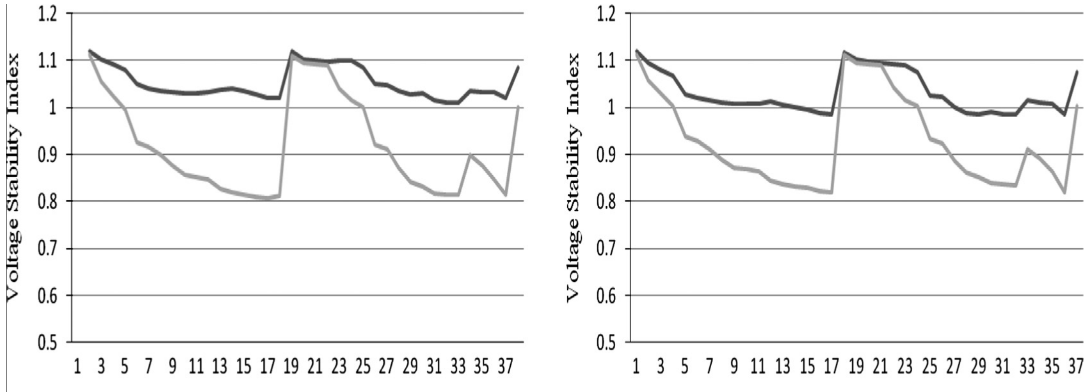
$$0.90\le V_i\le 1.00\ (Case\ (ii))$$

The voltage at each node of the distribution system should be maintained within limits.

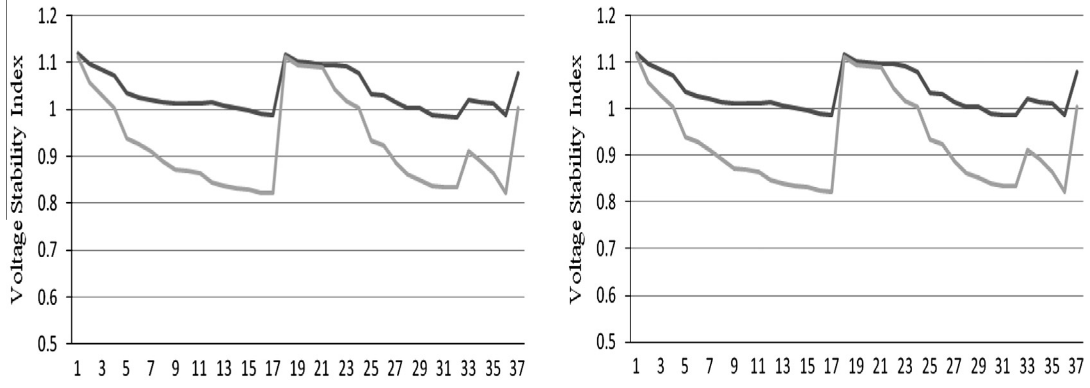
Line thermal limits

The distribution of power is done through the feeder in the radial distribution system, and the feeder should not exceed the thermal capacity of the line.

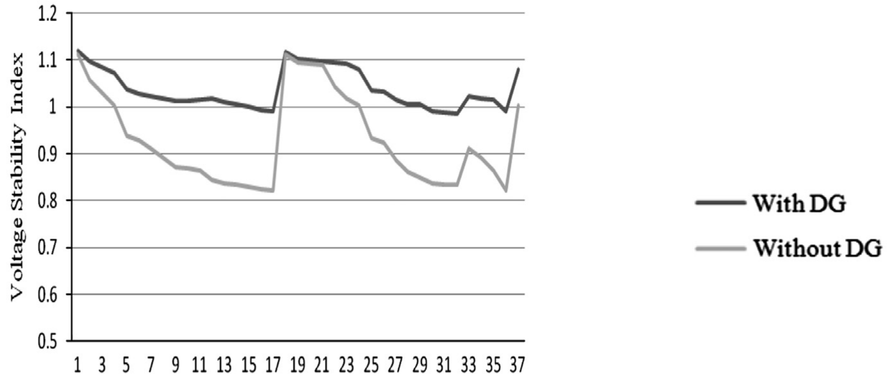
$$S_{(i,j)}\le S_{(i,j)}^{\max} \tag{12}$$



(a) Constant load (b) Industrial load



(c) Residential load (d) Commercial load



(e) Mixed load

Fig. 3. Comparison of voltage stability indices between with and without DG of 38-node system for different load models.

The inequality constraints of voltage and line flow limits are satisfied under certain size-location pairs, allow the pairs for next generation population. It is not satisfied reject the size-location pairs in the next generation. Evaluate the size-location pairs for minimum MOPI.

Artificial Bee Colony (ABC) algorithm

The Artificial Bee Colony (ABC) algorithm is developed based on the foraging behavior of honey bees. This colony contains three groups of bees namely employed bees, onlooker bees and scout bees. The employed bees are searching with specific food sources and presented to the dance area. The onlooker bees are waiting on the dance area for making the decision to select a food source. If a particular food source is not converged for some cycles, bees search for food sources randomly called scout. Both onlooker and scouts bees are called as unemployed bees. The important steps of the ABC algorithm are as follows:

Step 1: Initialize the random population of food source, limit and maximum cycle number.
Step 2: Apply the employed bee procedure to modify the food source and evaluate the fitness function.
Step 3: Modify the food source based on onlooker bees procedure and evaluate the fitness function.
Step 4: The particular food source of the solution is abandoned, it is replaced by applying the scout bees.

Table 3
Comparisons of related impact indices and MOPI for 69-node system with load models.

Indices	Constant	Industrial	Residential	Commercial	Mixed
ILP	0.31866	0.33126	0.36428	0.38503	0.38018
ILQ	0.35155	0.37264	0.40375	0.42406	0.41935
VSI	0.92892	0.91569	0.92064	0.92069	0.92030
IC	0.80002	0.79928	0.79934	0.79928	0.79933
IVD	0.01824	0.02178	0.02046	0.02042	0.02054
Min MOPI	0.47465	0.48413	0.49958	0.50986	0.50753
Optimal location-size (MW) pairs	17 @ 0.56272	17 @ 0.50470	17 @ 0.51507	17 @ 0.52029	17 @ 0.51019
	61 @ 1.2	61 @ 1.2	61 @ 1.2	61 @ 1.2	61 @ 1.2
	64 @ 0.57335	64 @ 0.41853	64 @ 0.47094	64 @ 0.47751	64 @ 0.47620

Table 4
Comparisons of power losses and minimum VSI of without DG condition of 38-node system with load models.

Load model	P_{LDG} (p.u.)	P_L (p.u.)	Q_{LDG} (p.u.)	Q_L (p.u.)	$\text{VSI}_{\min}$ (without DG)
Constant	0.06723	0.18880	0.04658	0.12589	0.80782
Industrial	0.07022	0.16603	0.04801	0.11034	0.82044
Residential	0.06962	0.16636	0.04792	0.11053	0.82084
Commercial	0.06952	0.16459	0.04791	0.10930	0.82309
Mixed	0.06950	0.16628	0.04786	0.11048	0.82132

Table 5
Comparisons of power losses and minimum VSI of without DG condition of 69-node system with load models.

Load model	P_{LDG} (KW)	P_L (KW)	Q_{LDG} (KVAR)	Q_L (KVAR)	$\text{VSI}_{\min}$ (without DG)
Constant	71.69	224.97	35.90	102.12	0.68332
Industrial	58.00	175.09	30.05	80.64	0.71252
Residential	62.23	170.83	31.84	78.86	0.71741
Commercial	63.55	165.05	32.39	76.38	0.72332
Mixed	63.02	165.76	32.16	76.69	0.72251

Chaotic local search

The chaos theory is used to improve the searching behavior and to avoid the solutions caught in local optima. The chaotic local search based on two well known maps such as logistic map and tent map. The chaotic local search can be defined as the following logistic equation [31],

$$cx_i^{k+1} = 4cx_i^k(1 - cx_i^k) \qquad i = 1, 2, \ldots, n \tag{13}$$

where k is the maximum number of iteration or 300.

The important steps of the chaotic local search are as follows:

Step 1: The decision variables x_i^k is converted into chaotic variables cx_i^k using the equation

$$cx_i^k = \frac{x_i^k - lb_i}{ub_i - lb_i} \qquad i = 1, 2, \ldots, n \tag{14}$$

where lb_i and ub_i are the lower and upper bound of the x.

Step 2: The chaotic variables cx_i^{k+1} are determined for the next iteration using Eq. (13).

Step 3: The chaotic variables cx_i^{k+1} is converted into decision variables x_i^{k+1} using the following equation,

$$x_i^{k+1} = lb_i + cx_i^{k+1}(ub_i - lb_i) \qquad i = 1, 2, \ldots, n \tag{15}$$

Step 4: Calculate the fitness of new solution with decision variables x_i^{k+1}.

Step 5: Update the new solution if it has better fitness when compared to old one.

Chaotic Artificial Bee Colony (CABC) algorithm

The ABC algorithm proposed by Karaboga attracts much attention in the recent past because of its flexibility and robustness in solving optimization problems. The main drawback of ABC algorithm is it requires more number of cycles to reach the optimal solution of the problem. Due to this drawback, the computational time gets increased. To overcome the above mentioned problem, the ABC algorithm is combined with chaos theory such that the exploitation capability of the ABC algorithm is increased known as Chaotic Artificial Bee Colony (CABC) algorithm. Thus, with a CABC algorithm, to reduce the number of cycles and hence results in best solution with reasonable computational time. The CABC algorithm has been proposed for finding the optimal location and capacity of DGs in the test systems.

The explanation of the CABC algorithm as follows:

In the initialization phase, each vector of the population of food sources $\vec{x}_m$ $(m = 1, 2, \ldots, CS)$ are initialized by scout bees and control parameters are set, where CS (Colony Size) represents the size of the population. In this optimization problem, the solution of the vector $\vec{x}_m$ in each food source and holds n variables $(\vec{x}_{mi,}\ i = 1, 2, \ldots n)$, which are to be optimized so as to optimize the objective function.

$$x_{mi} = lb_i + rand[0, 1] * (ub_i - lb_i) \tag{16}$$

The employed bees search for new food source $\vec{v}_m$ having much nectar within the neighborhood of the food source $\vec{x}_m$ in the memory. The new food source is calculated by

$$v_{mi} = x_{mi} + rand[-1, 1] * (x_{mi} - x_{ki}) \tag{17}$$

where x_k is a randomly selected food source, i is a randomly chosen parameter index. After producing the new food source $\vec{v}_m$, its fitness is calculated. If the fitness value of $\vec{v}_m$ dominates the previous food source solution, and then it will be replaced by the new food source vector. If it is not dominated, the particular source vector was ineffective and trial value is incremented by one. For each cycle, the employed bees optimized their food source by considering the

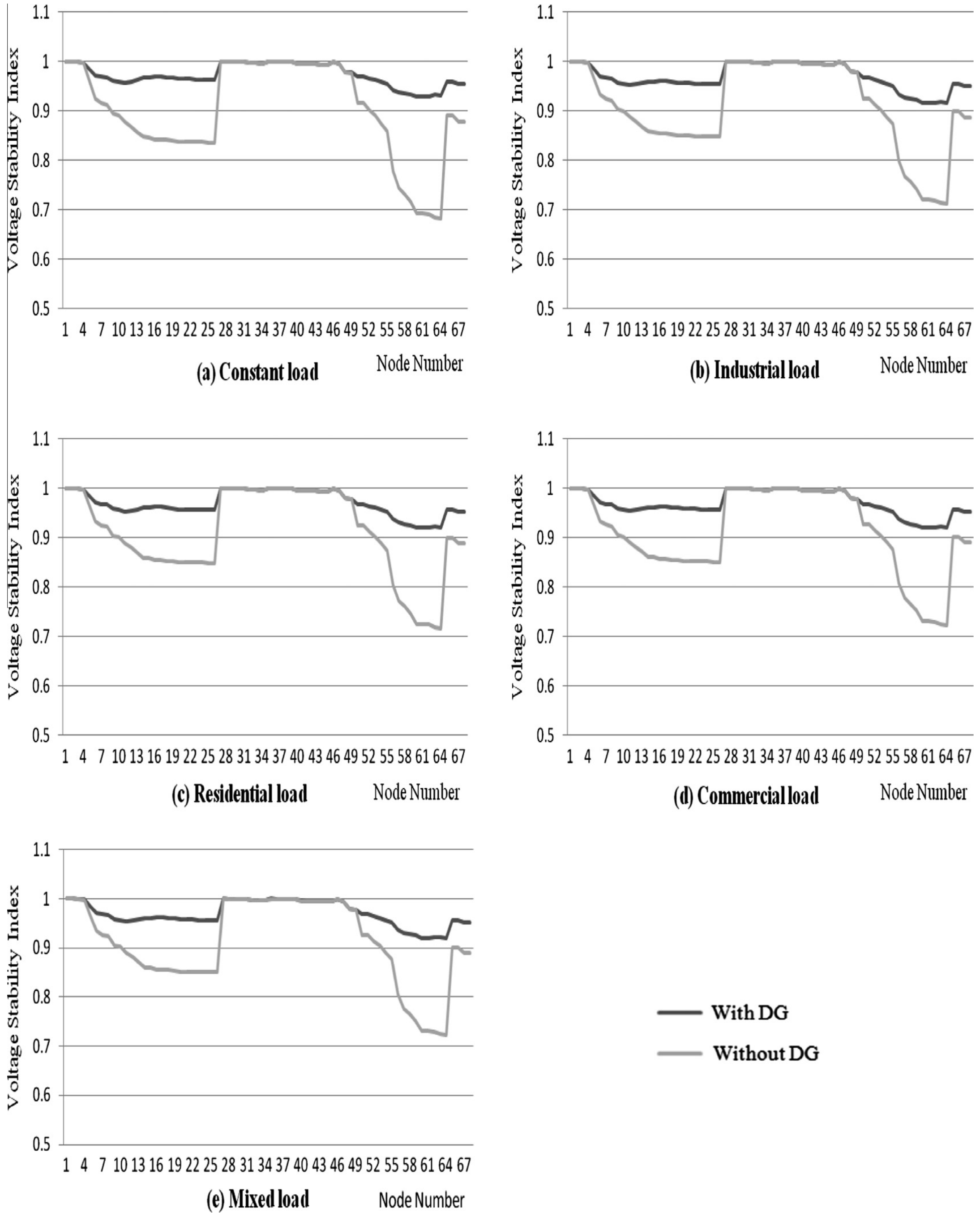


Fig. 4. Comparison of voltage stability indices between with and without DG of 69-node system for different load models.

information with onlooker bees waiting in the hive and then onlooker bees probabilistically select their food sources related to this information. The probability for each food source m advertised by the corresponding employed bee will be determined as follows,

$$p_m = \frac{fit(\vec{x}_m)}{\sum_{m=1}^{SN} fit(\vec{x}_m)} \tag{18}$$

After a food source $\vec{x}_m$ for an onlooker bee is probabilistically chosen, a neighborhood source $\vec{v}_m$ is determined by using Eq. (17), and its fitness value is computed. In this solution could dominates the previous food source solution, and then it will be replaced by the old food source vector. If it is not dominated, the particular food source vector is ineffective, retain the previous food source solution and trial value is incremented by one.

ABC approach is hybridized with chaotic local search by sorting the onlooker bee results of the objective function. Formulate the half of ascending order in the food number. Implemented the chaos theory using Eqs. (13)–(15) for best food source. Results significant represent that updating the food source of bees. Apply the greedy selection in order to obtain the best food source vector. Then, decrease the search space in the food source according to the specified limit. In each cycle of process the new fitness solution better than old one, trial value will be reset to zero. Otherwise, trial value is incremented by one. This process will be continued, the trial value should reach their maximum value and it is significant that the solution cannot be improved and abandoned. Then, the scouts start to search for new solutions, randomly using the equation as,

$$v_{mi} = lb_i + rand[0,1] * (ub_i - lb_i) \tag{19}$$

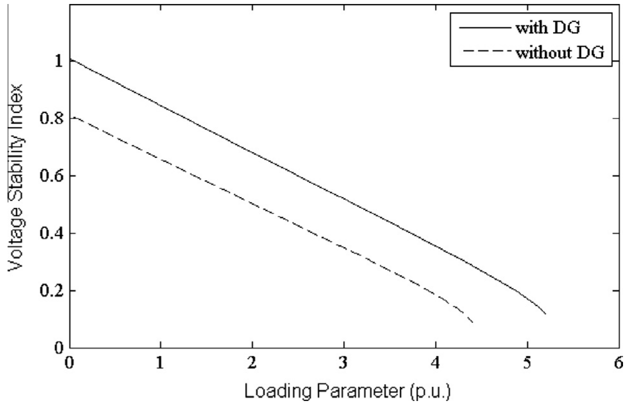


Fig. 5a. VSI curve of node-33 for 38-node system (constant type).

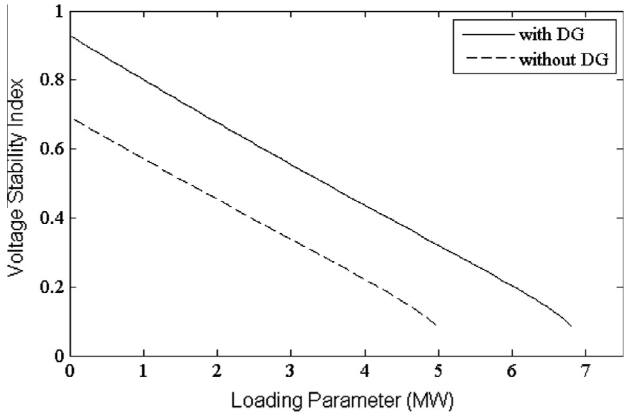


Fig. 5b. VSI curve of node-61 for 69-node system (constant type).

In this manner, for generating v_{mi} of each candidate and then determined by the artificial bee, its performance is compared with old one. If new one dominated the old one, it is stored in the memory. Otherwise retain the old.

Implementation of CABC algorithm for optimal location and sizing of DGs in the systems

The optimal location and sizing of DGs in the distribution system evaluated using an Artificial Bee Colony algorithm combined with chaos is described as follows,

1. Initialization: set the colony size (*CS*) and D-dimensional parameter vectors in the chaotic Artificial Bee Colony algorithm

   $$x_{mi}; \qquad m = 1, 2, \ldots, CS \tag{20}$$

   The generation *m* with *CS* should be constant over the complete process of the optimization. The population vectors depending on size and location of DG units are generated randomly and within the limits. Initialize the control parameter such as food number (*CS*/2), limit (*L*), *k* and maximum cycle number (MCN).
2. Create the random population vector using Eq. (16) and maintain the limit as,

   $$x_{mi} = (x_{m1},\ x_{m2}, \ldots, x_{mN}) \quad i = 1, 2, \ldots, N \tag{21}$$

   where *N* is the number of control variables. In this approach, the location of the DG units is considered as the integer variable of the food source. The CABC algorithm handles the integer variables, regarding the rounding off food source position to the nearest integer.
3. Calculate the fitness value of the objective function by using

   $$fitness = \frac{1}{1 + objective\ function} \tag{22}$$

4. Set cycle = 1.
5. Employed bee phase: create the new solutions v_m for the employed bees by using (17) and determined them. The new solution is called the modified neighbor of food source and maintaining the permissible limit. Using this parameter applied the objective function and should be satisfied the constraints. Further, evaluates the fitness value, and then applied the greedy selection between the current solutions and its perturbed.
6. Evaluate the probability values p_m for the solutions $\vec{x}_m$ by using Eq. (18).
7. Onlooker bee phase: generate the new solutions v_m for modified food source depending on probability p_m and evaluate them. Using these food source to apply the objective function and should be satisfied the constraints. Further, evaluates the fitness value, and then applied the greedy selection between the current solutions and its perturbed.
8. Apply the chaotic local search to enrich the exploitation process and update the food source vector. After that, calculate the fitness value and apply the greedy selection between the current and previous solutions.
9. Scout bee phase: if the trial counters greater than the assigned limit value, newly created the random solution v_m by using (19) and maintaining the limits of the problem.
10. Memorize the best solution achieved so far.
11. Cycle = cycle + 1
12. If the cycle is smaller than MCN, go to step 5, otherwise go to step 13.
13. STOP and print the result.

The complete flow chart for optimal location and sizing of DGs using CABC algorithm is represented in Fig. 1. The proposed method has been implemented using MATLAB 2009 running on core i3 computer and reasonable computational time.

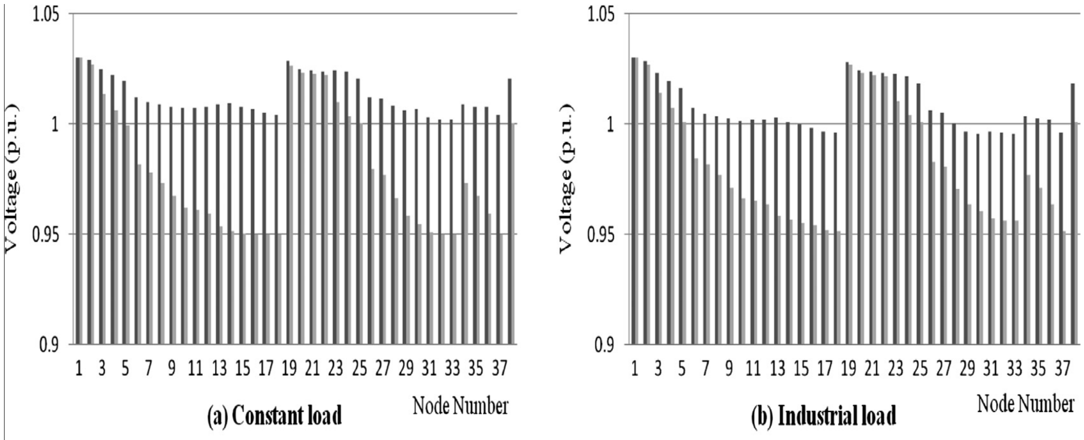
Numerical results

Test systems

The proposed approach has been implemented on the 38-node and 69-node radial distribution system consisting of base values used are 100 MVA and 23 kV for case (i), 12.66 kV for the case (ii). The size of the DG unit is considered in a practical range of 0–1.2 p.u. and unity *p.f.* for 38-node system. The system and load data of the 38-node system is taken from Ref. [12]. In 69-node test system, total demand for real power is 3.8021 MW, and reactive power is 2.6945 MVAr. The size of the DG unit is selected for in this case a practical range of 0–1.2 MW and unity *p.f.* The system and load data of the 69-node is given in Appendix A. In this approach, the three DG units are operated at unity power factor for both cases, which leads to maximum benefits from the system. One-line diagram of the 38-node system having 38 bus and 37 branches are shown in Fig. 2.

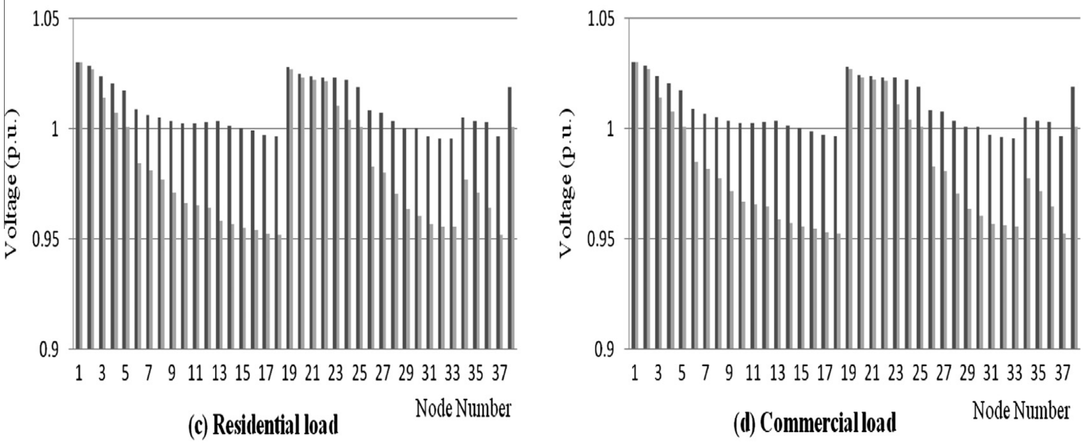
Initialisation

The assessment of several impact indices based on separate objective function listed in Section ‘Load models and related impact indices’ and are used to evaluate the MOPI aimed at



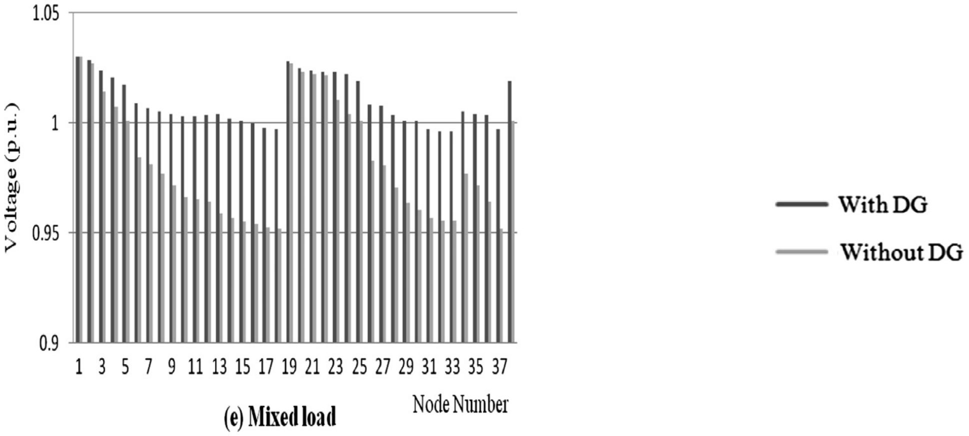
(a) Constant load

(b) Industrial load



(c) Residential load

(d) Commercial load



(e) Mixed load

Fig. 6. Voltage profile of 38-node system with load models.

location and sizing of DG units in the test systems. After implementation of DGs, the voltage stability of the system is improved and the results are compared without DG has been demonstrated. In CABC algorithm, the control parameters are selected as, $CS = 50$, $MCN = 200$, $k = 300$ and $L = 0.5 \times CS \times D$ for both cases.

Case (i) 38-node radial distribution system

The various impact indices, MOPI, optimal location and sizing of DGs for constant, industrial, residential, commercial and mixed load models obtained by a CABC algorithm are listed in Table 2. The result of MOPI satisfies all the constraints related to the problem. The introduction of DGs in the distribution system effects that reduction of power losses and system operates in the maximum profit manner. In constant type load model, the real power loss of the system without DG is 0.18880 p.u. as given in Table 4.

In this approach, the three DG units that are connected to the nodes 14, 24 and 30. Thus the real power loss is reduced to 0.06723 p.u. consequent that 64.39% of saving the real power loss. Related to the reactive power loss in the system, without DG it is 0.12589 p.u. and with DG it is 0.04658 p.u. resultant that the reactive power loss is reduced to 63% compared to without DG. Further, the real and reactive power loss indices of all types of load model are greatly reduced with presences of DGs.

The VSI value of each node (except substation) of the system for various types of load model is shown in Fig. 3(a–e). It is clearly

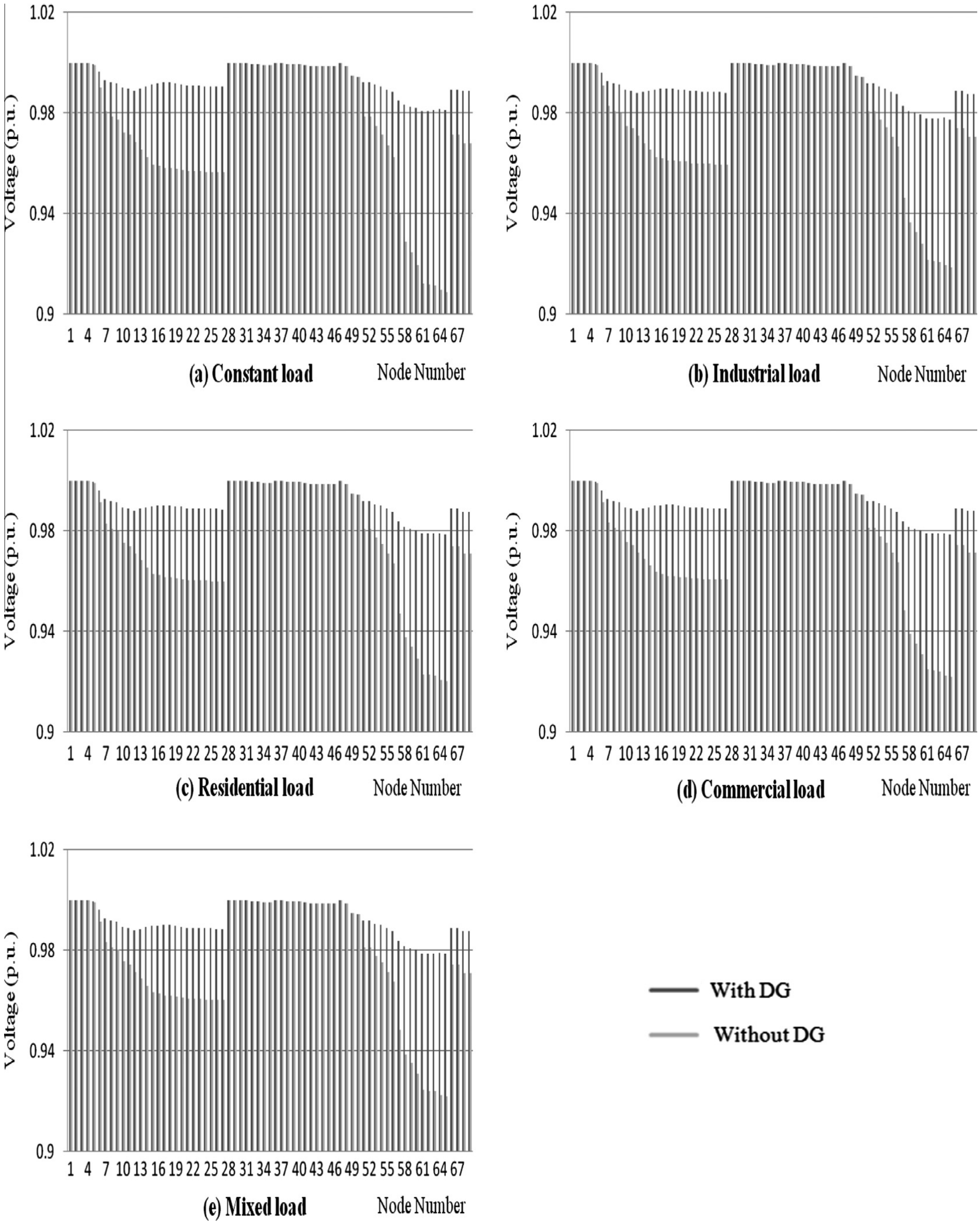


Fig. 7. Voltage profile of 69-node system with load models.

seen that VSI values of the nodes are improved due to the presence of DGs compared with absence. The value of minimum VSI node in the constant load model with DG is 1.01 as listed in Table 2 and that corresponding to the absence of DG is 0.80782 as listed in Table 4. From the above results it is clear that the value of VSI increases when DGs are introduced and thus the voltage stability of the system gets improved. After placement of DGs, the most sensitive node of the system is identified as 33 (VSI_{min}). In this node, the real power load is uniformly increased as shown in Fig. 5a, illustrating the improvement of voltage stability of the system and the nose point is extended greatly in the presence of DG when compared to its absence. The IC index is always less than unity for all types of load model as indicated in Table 2. Further, it can be seen from Table 2 that all the line flows are within their limit. The voltage profile improvement indicates that the value of IVD is always nearby zero as shown in Table 2. The voltage profile for different types of load model in the 38-node radial distribution system is shown in Fig. 6(a–e). The voltage at each node is increased, and within a limit due to the presence of DGs compared to the absence has been adopted.

Case (ii) 69-node radial distribution system

The various related impact indices, MOPI, optimal location and sizing of DGs for all types of load model for the 69-node system are listed in Table 3. The base case result of the constant type load model considered that the real power loss in the system without DG is 224.97 KW is listed in Table 5. Application of DGs are connected to the nodes 17, 61 and 64 with optimal size, which effects that the real power loss is 71.69 KW, consequent that the real

Table A1
Line and nominal load data for 69-radial distribution system.

F	*T*	*R* (p.u.)	*X* (p.u.)	*P* (MW)	*Q* (MVAr)	L_T
1	2	0.0003	0.0007	0	0	
2	3	0.0003	0.0007	0	0	
3	4	0.0009	0.0022	0	0	
4	5	0.0157	0.0183	0	0	
5	6	0.2284	0.1163	0.0026	0.0022	*R*
6	7	0.2378	0.1211	0.0404	0.0300	*I*
7	8	0.0575	0.0293	0.0750	0.0540	*I*
8	9	0.0308	0.0157	0.0300	0.0220	*I*
9	10	0.5110	0.1689	0.0280	0.0190	*I*
10	11	0.1168	0.0386	0.1450	0.1040	*C*
11	12	0.4438	0.1467	0.1450	0.1040	*C*
12	13	0.6426	0.2121	0.0080	0.0055	*R*
13	14	0.6514	0.2152	0.0080	0.0055	*R*
14	15	0.6601	0.2181	0	0	
15	16	0.1227	0.0406	0.0455	0.0300	*I*
16	17	0.2336	0.0772	0.0600	0.0350	*I*
17	18	0.0029	0.0010	0.0600	0.0350	*I*
18	19	0.2044	0.0676	0	0	
19	20	0.1314	0.0434	0.0010	0.0006	*R*
20	21	0.2131	0.0704	0.1140	0.0810	*C*
21	22	0.0087	0.0029	0.0053	0.0035	*R*
22	23	0.0993	0.0328	0	0	
23	24	0.2161	0.0714	0.0280	0.0200	*I*
24	25	0.4672	0.1544	0	0	
25	26	0.1927	0.0637	0.0140	0.0100	*R*
26	27	0.1081	0.0357	0.0140	0.0100	*R*
3	28	0.0027	0.0067	0.0260	0.0185	*I*
28	29	0.0399	0.0976	0.0260	0.0185	*I*
29	30	0.2482	0.0820	0	0	
30	31	0.0438	0.0145	0	0	
31	32	0.2190	0.0724	0	0	
32	33	0.5235	0.1757	0.0140	0.0100	*R*
33	34	1.0656	0.3523	0.0195	0.0140	*R*
34	35	0.9196	0.3040	0.0060	0.0040	*R*
3	36	0.0027	0.0067	0.0260	0.0186	*I*
36	37	0.0399	0.0976	0.0260	0.0186	*I*
37	38	0.0657	0.0767	0	0	
38	39	0.0190	0.0221	0.0240	0.0170	*I*
39	40	0.0011	0.0013	0.0240	0.0170	*I*
40	41	0.4544	0.5309	0.0012	0.0010	*R*
41	42	0.1934	0.2260	0	0	
42	43	0.0256	0.0298	0.0060	0.0043	*R*
43	44	0.0057	0.0072	0	0	
44	45	0.0679	0.0857	0.0392	0.0263	*I*
45	46	0.0006	0.0007	0.0392	0.0263	*I*
4	47	0.0021	0.0052	0	0	
47	48	0.0531	0.1300	0.0790	0.0564	*I*
48	49	0.1808	0.4424	0.3847	0.2745	*C*
49	50	0.0513	0.1255	0.3847	0.2745	*C*
8	51	0.0579	0.0295	0.0405	0.0283	*I*
51	52	0.2071	0.0695	0.0036	0.0027	*R*
9	53	0.1086	0.0553	0.0043	0.0035	*R*
53	54	0.1267	0.0645	0.0264	0.0190	*I*
54	55	0.1773	0.0903	0.0240	0.0172	*I*
55	56	0.1755	0.0894	0	0	
56	57	0.9920	0.3330	0	0	
57	58	0.4890	0.1641	0	0	
58	59	0.1898	0.0628	0.1	0.0720	*C*
59	60	0.2409	0.0731	0	0	
60	61	0.3166	0.1613	1.2440	0.8880	*C*
61	62	0.0608	0.0309	0.0320	0.0230	*I*
62	63	0.0905	0.0460	0	0	
63	64	0.4433	0.2258	0.2270	0.1620	*C*
64	65	0.6495	0.3308	0.0590	0.0420	*I*
11	66	0.1255	0.0381	0.0180	0.0130	*R*
66	67	0.0029	0.0009	0.0180	0.0130	*R*
12	68	0.4613	0.1525	0.0280	0.0200	*I*
68	69	0.0029	0.0010	0.0280	0.0200	*I*

F = from node, *T* = to node, *P* = real MW load, *Q* = reactive MVAR load, L_T = load type, *R* = residential, *I* = industrial, *C* = commercial.

power loss is reduced to 68.13% compared to without DG. As well as the reactive power loss is 102.12 KW for without DG condition and with DG is 35.90 KW is listed in Table 5. Ensuring that reactive power loss is reduced to 64.85% compared to without DG. The real and reactive power losses are reduced with presence of DGs, effects that decrease the value of ILP and ILQ for all types of load model is listed in Table 3. For constant type load model, the minimum value of VSI listed in Table 3 is 0.92892 for with DG condition and without DG is 0.68332 in Table 5. The VSI in each node of the 69-node system for various type load model is shown in Fig. 4(a–e).

Voltage stability analysis is concerned with the calculation of how far the system is operating from the voltage collapse point using repeated load flow solutions. With the DGs connected, the weakest node of the system is identified as 61 ($\mathrm{VSI}_{\mathrm{min}}$) which effects that the load factor is greatly increased with the presence of DGs as shown in Fig. 5b. In this way, the system is improved in the voltage stability and operates distant from the voltage instability condition. The line flow of the system should be controlled which indicates that the value of IC is nearby zero has listed in Table 3. The value of voltage profile index is reduced, which effects that the voltage deviation of the system is considerably reduced and it is improving the voltage profile as shown in Fig. 7(a–e). It is demonstrated that the voltage profile improvement of the test system and quality of supply to customer terminals.

Conclusion

In this paper, multi objective performance index is used for finding the optimal location of real power DG units and their capacities. The various impact indices such as a power loss index, line flow limit index, voltage profile index and voltage stability index are considered and are combined using weighting coefficients. The multi objective problem is solved using CABC algorithm for various types of load models. From the results, it can be concluded that the presence of DGs in optimal location reduces the real and reactive power losses and improves the voltage profile of the system. Moreover, the power flows on all the lines are within their specified limit.

The graphical representation of VSI results shows the presence of DG enhances the voltage stability of the system. From the results obtained, it is observed that with lesser number of cycles itself, CABC has the ability to find the optimal solution. This shows that there is a considerable increase in speed of convergence in solving DG size – location planning problem using Chaotic Artificial Bee Colony algorithm.

Appendix A

See Table A1.

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