Optimal Location and Sizing of Multiple DGs to Enhance the Voltage Stability in the Distribution System using a Chaotic ABC Algorithm

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ABSTRACT
Electric power is one of the inherent things in the modern world. Recently, the renewable and non-renewable energy based Distributed Generator (DG) units are used for generation of electric power to satisfy the local load of the distribution system. This paper proposes a chaotic artificial bee colony (CABC) algorithm based optimal placement and sizing of various categories of DGs that are simultaneously placed in the distribution system according to their technical benefits and planning aspects. Four different types of DGs, such as capable of supplying real power only, capable of supplying reactive power only, capable of supplying real and reactive power, capable of supplying real power and absorbing reactive power has been considered in this approach. The objective is to reduce the resource cost and network loss in such a way that line flows should be within limit and to improve the voltage profile and stability of the system. The Voltage Stability Index (VSI) is used to identify the most sensitive node in the system. The constant power and other voltage dependent load models such as industrial, residential and commercial are considered for this work. The efficiency of the proposed method is tested on 38-node and 69-node radial distribution systems.

Keywords
Chaotic artificial bee colony, load models, distributed generation, distribution system, cost, voltage stability.

1. INTRODUCTION
Distributed Generation is defined as the generation of electricity that has been used to support the distribution network in case of power demand. The definition of various terms such as distributed generation, distributed resources, distributed capacity and distributed utility are discussed in literature [1]. The survey of different categories of DGs, their technologies and operational constraints have been listed in the report [2]. The distribution systems are radial and have a high R/X ratio compared to transmission systems, which results incomparably high voltage drops and power losses in the distribution feeders. The power loss reduction and voltage profile improvement are one of the challenging tasks in distribution systems. In [3, 4], the various impact indices related to the power loss, voltage profile and line flow limits are explained and the penetration of DG unit in the distribution systems is discussed. The voltage stability of the distribution system can be improved with the inclusion of DG in it. A newly formed voltage stability index is used to calculate the level of stability in the distribution system [5, 6].

In [7], a fuzzy genetic approach is proposed for reconfiguration of radial distribution network as a result of improving the voltage stability. The definition as a load model related to the mathematical equation and various types of load models is discussed in the literature [8, 9]. The analytical expression is formed to determine the optimal allocation of size and power factor of various categories of DGs for minimizing the power loss in the primary distribution systems [10, 11]. Adaptive weight particle swarm optimization and imperialist competitive algorithm based optimal location and capacity of various categories of DG units for minimization of real power loss and improved voltage profile of the distribution system have been proposed in the literature [12, 13]. The combination of GA and PSO algorithm based optimal location and capacity of real power DG units in the distribution system has been discussed in the literature [14]. In [15], two categories of DG units (supplying real power only, supplying real and reactive power) have been considered and their location and sizing are obtained through the Simulated Annealing (SA) techniques for minimization of real power loss in the distribution systems.

The discussion about simultaneous placement of DG unit and capacitor in the radial distribution system with time varying load is given in the report [16, 17]. In [18], the voltage and reactive power control over the distribution systems in the presence of synchronous machine based DG unit is presented. In [19], the author developed a Power Stability Index (PSI) based location and sizing of the DG unit for reduction of network losses in the distribution systems. The power exceeding limits and losses is considered as the objective function of placing the DG unit in the system [20].

In [21], the author proposed method to identify the different constraints of the system and minimizes the necessary changes that should be performed after placing of DG units. In [22], the author proposed a sensitivity matrix for power flow calculations in distribution networks with a presence of DGs. The voltage stability index is analyzed and quantified due to impacts of DGs on the system. The planning procedure based optimization problem is proposed the impacts on voltage security, active power losses and cost of resources in the system [23]. The various costs of power resources are presented in the literature [24]. The IEEE standard 1547 gives the importance of distributed resources (DR) are installed on radial primary and secondary distribution systems [25, 26]. The forward and backward propagation based power flow algorithm has been implemented for the radial distribution system and concluded that the results thus obtained have better convergence [27]. The ABC algorithm is a new population based meta-heuristic approach and is used for solving the various optimization problems. The ABC algorithm has been carried out the exploration and exploitation processes. Onlookers and employed bees perform the exploitation process in the search space. The scout bee controls the exploration process. To improve the convergence rate of the algorithm, the modified ABC algorithm is introduced at a modification rate (MR) as another control parameter [28-33]. While solving an optimization problem using ABC algorithm, there is a higher possibility of trapping at local optimum value. It is necessary to improve the exploitation ability and the convergence rate of ABC algorithm. The local search ability of a particle swarm optimization (PSO) algorithm is enhanced by integrating chaos theory is reported in [34]. In this paper, the artificial bee colony algorithm is combined with chaos theory and is proposed to improve the performance during an exploitation process of this algorithm. To find the optimal location and sizing of different type of DG units in order to minimize the power losses, cost of resources and to improve the voltage profile of the radial distribution systems, the proposed algorithm is used.

2. LOAD MODELS AND IMPACT INDICES

A load model is a mathematical representation of the relationship between a bus voltage and power or current flowing through the bus load [8]. The optimal location and sizing of various categories of DG units under constant power and other voltage dependent load models, i.e., industrial, residential, and commercial has been adopted to improve the voltage stability of the system. The voltage dependent load models can be mathematically expressed as [4],

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

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

where, P_i and Q_i are the real and reactive power at bus i, P_{oi} and Q_{oi} are the 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 [4]. In this approach, four different categories of DG units are simultaneously placed in different locations on the test systems. The advantages of renewable energy based DGs are free from raw material cost and pollution. The proposed approach gives the importance of sharing the power in the distribution system according to the real power injects; reactive power injects and absorbs based DGs. The technical issues and planning aspects of how DGs are connected to the distribution system and voltage stability is the significant factor of power injects and absorbs of DGs. The several impact indices are expressed as based on technical and planning issues such as power loss, line flow capacity, voltage profile, voltage stability and cost of resources on the distribution system. The different indices are defined as follows,

2.1 Real and Reactive Power Loss Index (ILP and ILQ)

The real and reactive power loss indices are defined as [4],

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

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

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. Obtaining the value of these indices nearby to zero indicates the minimization of system power losses.

2.2 Voltage Stability Index (VSI)

The VSI can be defined as [5],

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

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.

In the distribution system, the value of VSI of all the nodes (except first node) should be evaluated. If these values are greater than zero, which indicates that the system operates away from voltage instability issue.

2.3 Line Flow Limit Index (IC)

The renewable and non-renewable source of energy is converted into an electric energy using different type of DG unit and is then connected to the distribution system. There is a maximum line flow limit having for each distribution line of the system. In case, the power flow in a particular distribution line exceeds its maximum limit, then the thermal oriented problem will be occured. If the value of this index is less than unity, which indicates that the line flows are within limits. The IC index is defined as [4],

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

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.

2.4 Voltage Profile Index (IVD)

The voltage profile related to the IVD index can be defined as follows,

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

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.

If the value of this index is nearby to zero, which reduce the deviation of voltage and improve the voltage profile of the system.

2.5 DG power resources cost index (CI)

The costs incurred due to the installation and maintenance of DG power resources should be minimized. This index can be described as,

$$CI = \left(\frac{DG_{\cos t,i}}{DG_{\cos t,\max}}\right) \tag{8}$$

$$DG_{\cos t} = \sum_{i=1}^{N}(C_{fi} + C_{vi}\,DG_i + 8760\,C_{Mi}\,DG_i) \tag{9}$$

C_{fi} - Installation cost of DG resource at bus *i*

C_{vi} - Investment cost of DG resource at bus *i*

DG_i - Capacity of distributed generation unit at bus *i*

C_{Mi} - Maintenance cost of DG resource at bus *i*

N - Total number of various categories of DG units.

$DG_{cost,i}$ - The value of cost objective function in population *i*

$DG_{cost,max}$ - The value of cost objective function in maximum value of population.

If the value of this index is nearby to zero, which indicating the cost of distributed power resources should be minimized.

3. PROBLEM FORMULATION

The several impact indices are combined with weighting factors to form the multi-objective performance index (MOPI) of the optimization problem. The MOPI is a complex index proposed to quantify the optimal location and sizing of DG category and used to improve the voltage stability of the distribution system. The performance of impact indices (except VSI) should be normalized between zero and one. The multi-objective performance index is given by,

$$MOPI = \omega_1.ILP + \omega_2.ILQ + \omega_3.\left(\frac{1}{VSI}\right) + \omega_4.IC + \omega_5.IVD + \omega_6.CI \tag{10}$$

where, $\sum_{P=1}^{6}\omega_P = 1.0 \;\; \Lambda \;\; \omega_P \in [0,1]$

The values of weighting factors are decided according to the planner concerns. For this analysis, the first ILP index receives a weight factor (0.30) and reactive power loss index receives a weight factor (0.10), both indices should be minimized in order to reduce the power loss of the system. The inverse of VSI receives a weight factor (0.10) used to indicate whether the system operates in stable or unstable condition. The fourth index inward a weight factor (0.20) and is used to avoid overloading of the line. The fifth index weight factor (0.10) gives the performance of the voltage profile of the system. Finally, the latter index inward a weight factor (0.20) and it is used to reduce the cost of power resources. In this approach, there are several operational constraints have been adopted and to be satisfied to get the feasible solution of the problem. These constraints are discussed as follows.

3.1 Power Balance Constraints

The algebraic sum of all receiving power is equal to the sum of all sending power plus line loss over the complete distribution network and power generated from DG unit.

$$P_{SS} = \sum_{i=2}^{NB}P_D(i) + \sum_{j=1}^{NL}P_{loss}(j) - \sum_{k=1}^{NDG}P_{DG}(k) \tag{11}$$

$$Q_{SS} = \sum_{i=2}^{NB}Q_D(i) + \sum_{j=1}^{NL}Q_{loss}(j) \pm \sum_{k=1}^{NDG}Q_{DG}(k) \tag{12}$$

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)

Q_D - Total system reactive power demand (MVAr)

Q_{loss} - Total system reactive power loss (MVAr)

Q_{DG} - Total reactive power generated by Distributed Generation (MVAr)

NDG - Number of DG.

3.2 DG Real and Reactive Power Generation Limits

The real and reactive power generation of DG is controlled by its lower and upper limits as follows,

$$P_{DG}^{\min} \le P_{DG} \le P_{DG}^{\max} \tag{13}$$

$$Q_{DG}^{\min} \le Q_{DG} \le Q_{DG}^{\max} \tag{14}$$

3.3 Voltage Profile Limits

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

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{15}$$

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

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

3.4 Line Thermal Limits

The power carrying capacity of feeders should not exceed the thermal limit of the lines (S).

$$S_{(i,j)} \le S_{(i,j)}^{\max} \quad (16)$$

4. CATEGORY OF DG

Based on delivering the real and reactive power capabilities, DG can be classified into four categories as follows,

4.1 Category I

This category of DG (e.g., Photovoltaic, fuel cells and micro turbines) is having the capability of supplying real power only and operates at unity power factor.

$$P_i = P_{DGi} - P_{Di} \quad (17)$$

where,

P_i - the net real power injection at node i

P_{DGi} - the real power generation of DG at node i

P_{Di} - the real power demand at node i.

4.2 Category II

This category of DG (e.g., Synchronous Compensators) is having the capability of supplying reactive power alone and is having the zero power factors.

$$Q_i = Q_{DGi} - Q_{Di} \quad (18)$$

where,

Q_i - the net reactive power injection at node i

Q_{DGi} - the reactive power generation of DG at node i

Q_{Di} - the reactive power demand at node i.

4.3 Category III

The DG in this category (e.g., Gas turbine) is having the capability of delivering both real and reactive power. In this approach, the power factor is fixed at 0.85 leading. By considering $a = (sign)\ \tan(\cos^{-1}(PF_{DG}))$ as in [10], the reactive power output of DG is expressed as,

$$Q_{DGi} = aP_{DGi} \quad (19)$$

In this category, $a = (+1)\tan(\cos^{-1}(PF_{DG}))$.

In which,

Sign = +1; DG is supplying reactive power.

Sign = –1; DG is absorbing reactive power.

PF_{DG} - Power Factor of DG.

4.4 Category IV

This category of DG (e.g., Wind farm) is having the capability of delivering real power and absorbing reactive power. The power factor is fixed at 0.85 lagging.

In this category, $a = (-1)\tan(\cos^{-1}(PF_{DG}))$.

5. ARTIFICIAL BEE COLONY (ABC) ALGORITHM

The ABC algorithm is an optimization algorithm based on the clever performance of honey bee swarm [28]. In this algorithm, the position of a food source indicating a possible solution and the nectar amount of a food source represents a feasible solution of the optimization problem. The colony of artificial bees can be classified as employed, onlookers and scout bees. It generates a random population of food source solution and D-dimensional vectors where D is the number of optimized parameters. The ABC algorithm can be explained as follows,

Initialization: Set the population vector of food sources $\vec{x}_m$ *(m = 1, 2,…., CS)* and corresponding solution of the vector $\vec{x}_m$ holds n variables, ($\vec{x}_{mi}$, *i=1,2,…, n),* where, x_{mi} is randomly generated in the search space $\{x_i^{\min}, x_i^{\max}\}$ of the problem.

Set the cycle = 1.

Employed bee phase: In this phase, the new food source $\vec{v}_m$ is generated from distributing the neighbourhood of the food source $\vec{x}_m$ in the memory. After finding the food source, then evaluate the corresponding fitness value and apply the greedy selection.

$$v_{mi} = x_{mi} + rand\,[-1,1] * (x_{mi} - x_{ki}) \quad (20)$$

where, x_k is a randomly selected food source, i is a randomly chosen parameter index.*Onlooker bee phase*: It is also finding the food source $\vec{v}_m$ based on the probabilityusing the equation (21) and according to the neighbourhood source using the equation (20). Further, evaluate the fitness value and apply the greedy selection.

$$p_m = \frac{fit\ (\vec{x}_m)}{\sum_{m=1}^{SN} fit\ (\vec{x}_m)} \quad (21)$$

Scout bee phase: The food source in the specific nectar is abandoned by the bees when the trial number exceeds theirlimit, then it is replaced in the scouts phase. In this bee v_{mi} is randomly generated in the search space $\{x_i^{\min}, x_i^{\max}\}$.

The cycle is updated: cycle = cycle + 1

The number of cycle reaches at maximum cycle number (MCN) of the algorithm, print the best results of the problem.

5.1 Chaotic Local Search

The chaos theory is used to improve the searching behaviour and to avoid the solutions trapped in a local optimum. The chaotic local search considers as a two well known map such as logistic map and tent map. The chaotic local search can be defined as the following logistic equation as,

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

(22)

where, k is the maximum number of iterations or 300.

The chaotic local search has the following procedure.

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

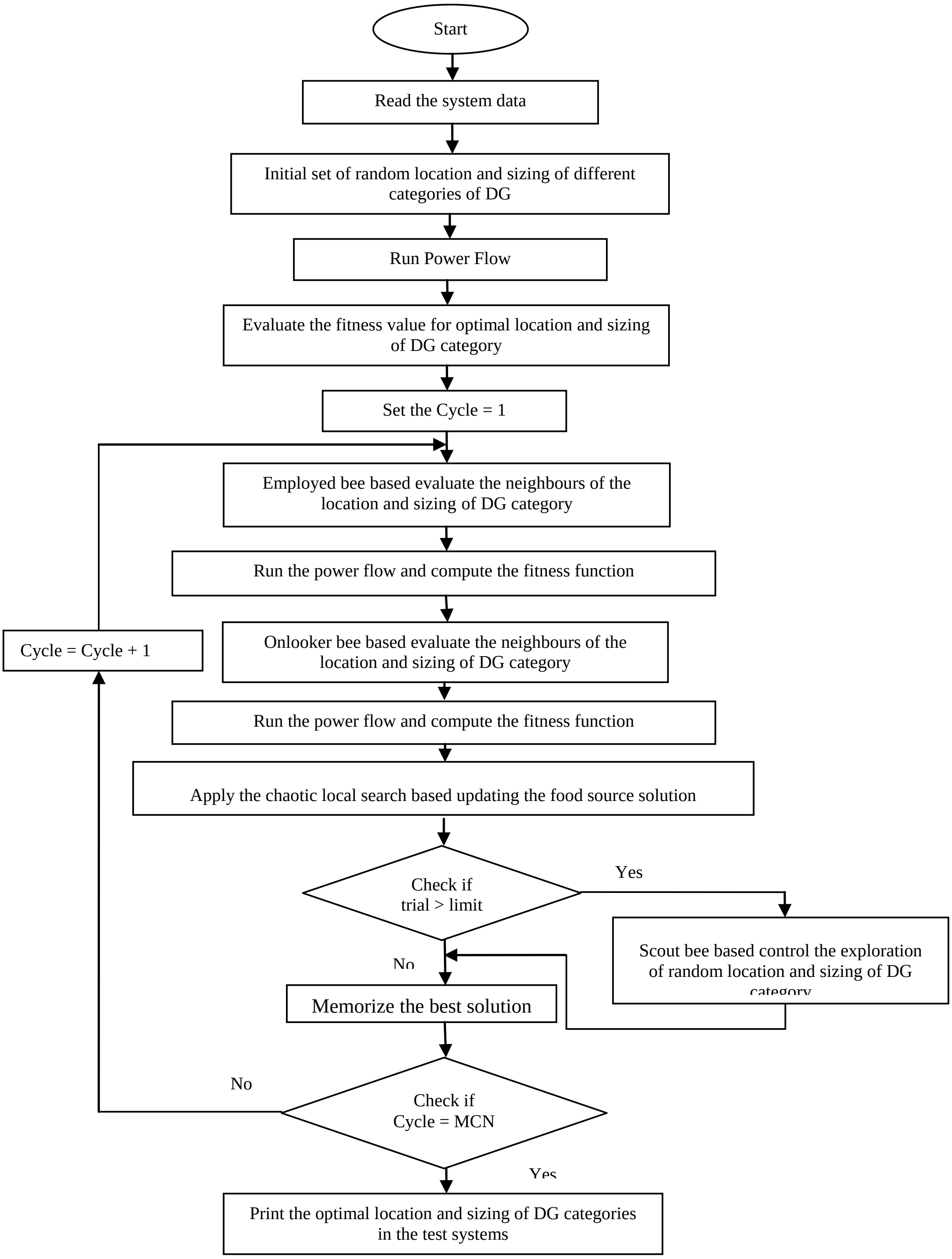

Fig. 1. The CABC algorithm is implemented for Optimal location and sizing of DG category

$$cx_i^k = \frac{x_i^k - lb_i}{ub_i - lb_i} \qquad i = 1, 2, \ldots, n \tag{23}$$

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

Determine the chaotic variables cx_i^{k+1} using the equation (22) for the next iteration.

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

$$x_i^{k+1} = lb_i + cx_i^{k+1}(ub_i - lb_i) \qquad i = 1, 2, \ldots, n \tag{24}$$

Calculate the new solution with decision variables x_i^{k+1}. Update the new solution if it has better fitness when compared to old one.

5.2 Chaotic Artificial Bee Colony (CABC) algorithm

The ABC algorithm is used for the exploration process of updating the food source of the bees and combined with chaos theory is used in the exploitation process to modify the finest food source resulted by ABC.

The CABC algorithm has the following steps:

Step 1: Initialize the random population, limit, *k* and MCN.

Step 2: Generate the initial population x_{mi} using the equation as,

$$x_{mi} = lb_i + rand\,[0,1] * (ub_i - lb_i) \tag{25}$$

Step 3: set the cycle = 1.

Step 4: Apply the employed bee procedure for modifying the food source $\vec{v}_m$ using the equation (20) and evaluate the fitness value. If the new food source vector could dominate the old one, it will be replaced by the old.

Step 5: Apply the onlooker bee procedure for modifying the food source $\vec{v}_m$ using the equations (21), (20) and evaluate the fitness value. If the new food source vector could not dominate the old one, the particular vector is ineffective and retains the old.

Step 6: Modify the food source that is obtained from the onlooker bee phase based on chaotic local search procedure using the equations (22), (23), (24) and evaluate the fitness value. Apply the greedy selection in order to obtain the best food source vector.

Step 7: After the above steps, if there is no improvement in food source solution, then scout bee procedure is applied using the equation,

$$v_{mi} = lb_i + rand\,[0,1] * (ub_i - lb_i) \tag{26}$$

Step 8: Update the cycle.

Step 9: If the number of cycle reaches at MCN, Print the best result.

5.3 The Implementation Of CABC Algorithm For Objective Function

There are two variable parameters in the problem such as location and sizing of DG in the distribution system. In this paper, there are four different types of DG are considered such that a total of eight variables is there in the problem considered. The location of various categories of DGs is represented as the integer variable of the optimization problem. In this case, the CABC algorithm can be reformulated by rounding off the food source position to the nearest integer. The optimal location and sizing of DG units to improve the voltage stability of the radial distribution system using CABC algorithm is explained as follows,

Set the colony size, limit, *k* and MCN. The location and sizing of DGs consist on random population $\vec{x}_m$ to generate within limits and evaluate the fitness value of the objective function.

Set cycle:

Cycle = 1.

Employed bee phase: Choose a random food source from the initial population, and by using equation (20) find the new food source v_{mi} . The fitness value is evaluated and applied the greedy selection between $\vec{v}_m$ and $\vec{x}_m$.

Onlooker bee phase: Here, the onlooker bee probabilistically chooses the food source from the employed bee foodsources.Equation (20) finds the new food source v_{mi} . Further, calculate the fitness value of the new food source and apply the greedy selection between new and old food source.*Chaotic local search*: The food source obtained after the onlooker bee phase is updated based on chaos theory for better exploitation.*Scout bee phase*: If the trial count exceeds the assigned limit, the food source is abandoned. It is replaced by the scouts using equation (26).

Cycle updating:

Update the cycle = cycle + 1.

Stopping criterion: If the cycle reaches MCN, the algorithm stops and gives the corresponding location and sizing of various categories of DG units.The entire implementation of the CABC algorithm is illustrated in the flow chart as shown in figure 1.

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

6. NUMERICAL RESULTS AND DISCUSSION

The CABC program has been developed using a MATLAB 2009 Intel core i3 processor. The proposed approach has been demonstrated on the 38-node and 69-node radial distribution system consisting of base values of 100 MVA for both the cases and 23 KV for case (i), 12.66 KV for case (ii). The

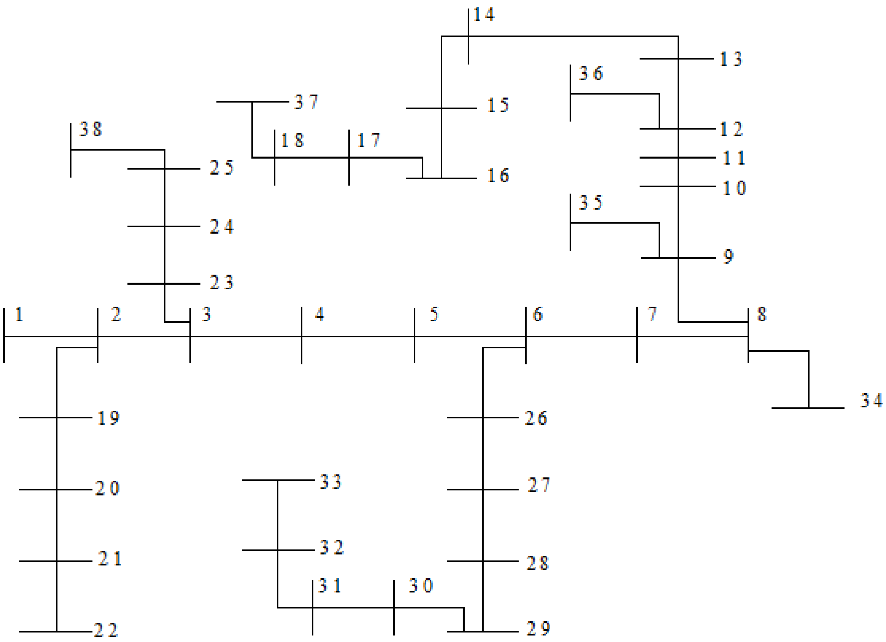

Fig. 2. 38-node Radial Distribution System

Table 2. The various cost of distributed generation power resources

Cost component	**DG type**			
	Photovoltaic $/KW	**Synchronous compensator $/KVAR**	**Gas turbine $/KW**	**Wind farm $/KW**
Investment cost (C_v)	2000	30	1387	1800
Maintenance cost (C_M) **(in case hour)**	0.03	0.01	0.005	0.05

system and load data for the 38-node system is taken from the reference [4], and the 69-node system is given in appendix. The following controlling parameters are initialized as, CS = 50, MCN = 200, k = 300 and L = 0.5 × CS × D for both cases. The various cost of DG type is presented in table 2. The installation cost C_f is considered to be five times of C_v. One-line diagram of the 38-node system having 38 bus and 37 branches is shown in figure 2.

The minimization of MOPI is associated with several impact indices, and it is used to obtain the optimal location and sizing of DGs in order to improve the system voltage stability. The different impact indices, MOPI, optimal location and sizing of various categories of DGs for various load models are obtained by CABC algorithm, and the results are presented in tables 3 and 4.

6.1 Case (i) 38-node radial distribution system

Constant load model: From table 5, it can be observed that the real and reactive power losses of the system which does not have any DG is 0.18880 *p.u.* and 0.12589 *p.u.* The placing of various categories of DGs, the real and reactive power losses are reduced to 0.03638 *p.u.* and 0.02518 *p.u.* respectively. The DGs are placed in the optimal nodes of the system according to categories 14, 18, 30 and 25 with optimal

sizes are presented in table 3. The values of ILP, ILQ, IC, IVD and CI are lying between zero and one as shown in table 3. The value of VSI in the presence of DGs is 1.03572 which is higher than that of the absence. The value of MOPI is 0.45171 lower than the other type load model.

Industrial load model: In this model, the real and reactive power losses of without DG condition is 0.16603 *p.u.* and 0.11034 *p.u.* On the other hand, when the DG categories are placed in the optimal nodes 14, 18, 30 and 25 respectively, the

real and reactive power losses are reduced to 0.03924 *p.u.* and 0.02703 *p.u.* The obtained results of these impact indices IVD < ILP < ILQ < CI < IC are normalized between 0 and 1. The value of VSI with DG condition is 1.02727 greater than that of the absence. In this model, the optimal result of MOPI is 0.47379.*Residential load model*: For this model, the real and reactive power losses of the system without DG condition is 0.16636 *p.u.* and 0.11053 *p.u.* respectively. The DGs are connected to the optimal nodes of the system correspondingly 14, 18, 30 and 25. As a result of this, the real and reactive power losses of this model get reduced to 0.03883 *p.u.* and

0.02681 *p.u.* respectively. The value of VSI in the presence of DG is 1.03035 higher than without DG. In this model, the minimization of MOPI is 0.47331 as listed in table 3.

Commercial load model: It is observed from table 5 of this model, the real and reactive power losses of the system without DG is 0.16459 *p.u.* and 0.10930 *p.u.* There is a significant reduction in real and reactive losses of the system when placing of DGs in the nodes 14, 18, 30 and 25 respectively. The various technical and planning impact indices such as ILP, ILQ, IC, IVD and CI are nearby to zero and it is presented in table 3. The VSI of this model with DG is 1.03169 and without DG is 0.82309. The optimal result of MOPI is 0.47600 higher than the other type load model.

Table 3. Comparisons of Related Impact Indices, MOPI and placing of DG categories for 38-node System with Load Models

Indices	Constant	Industrial	Residential	Commercial	Mixed
ILP	0.19269	0.23634	0.23340	0.23671	0.24188
ILQ	0.20002	0.24497	0.24255	0.24639	0.25072
VSI	1.03572	1.02727	1.03035	1.03169	1.02014
IC	0.94314	0.96648	0.97124	0.97943	0.96867
IVD	0.02057	0.02257	0.02184	0.02152	0.02427
CI	0.43330	0.42744	0.42773	0.42693	0.40839
min MOPI	0.45171	0.47379	0.47331	0.47600	0.47350
Opti. loc-size (*p. u.*) pairs of category					
Category 1	14 @ 0.67998	14 @ 0.64954	14 @ 0.65971	14 @ 0.66375	15 @ 0.55600
Category 2	18 @ 0.06810	18 @ 0.07348	18 @ 0.07383	18 @ 0.07504	18 @ 0.07449
Category 3	30 @ 1.2 + j 0.74364	30 @ 1.2 + j 0.74364	30 @ 1.2 + j 0.74364	30 @ 1.19985 + j 0.74355	30 @ 1.2 + j 0.74364
Category 4	25 @ 0.08988 - j 0.05570	25 @ 0.08353 - j 0.05176	25 @ 0.07419 - j 0.04598	25 @ 0.06450 - j 0.03997	25 @ 0.08400 - j 0.05205

Mixed load model: In this model, the optimal location of DG categories are placed in the nodes of the system correspondingly 15, 18, 30 and 25 with sizing has listed in table 3. The reduction of real and reactive power losses are 0.04022 *p.u.* and 0.02770 *p.u.* respectively for placing of DGs in the test system, and it is listed in table 5. The improved VSI of this model is 1.02014. The finest result of MOPI is 0.47350 presented in table 3.

6.2 Case (ii) 69-node radial distribution system

Constant load model: From the table 6, the real and reactive power losses of without DG is 224.97 KW and 102.12 KVAR respectively. The different category of DGs are placed in the system resultant that reducing the network losses such as 28.26 KW and 17.69 KVAR. The values of ILP, ILQ, IC and IVD are nearby zero as shown in table 4. The value of VSI in the presence of DG is 0.90248 which is higher than an absence. The value of MOPI is 0.40744 smaller than the other type load model.

Industrial load model: In this model, the real and reactive power losses of without DG is 175.09 KW and 80.64 KVAR.

Further, the real and reactive power losses are reduced to 26.57 KW and 16.82 KVAR while placing of DGs in the

system. The obtained results of these impact indices IVD < ILP < ILQ < CI < IC are normalized between 0 and 1. The value of the VSI in with DG is 0.90760 greater than that absence. In this model, the optimal value of MOPI is 0.41509.

Residential load model: For this model, the real and reactive power losses of without DG is 170.83 KW and 78.86 KVAR respectively. The placing of DG categories in the system with effect that significantly reduced to the real and reactive power losses are 24.89 KW and 16.03 KVAR. The impact indices of this load model are nearby zero and it is listed in table 4. The value of VSI in the presence of DG is 0.92082 higher than absence is 0.71741. In this model, the minimization of MOPI is 0.41858.

Commercial load model: It is observed that the table 4, the real and reactive power losses of without DG is 165.05 KW and 76.38 KVAR. These losses are significantly gets reduced to 22.81 KW and 15.13 KVAR while various categories of DGs placed in the system. The technical and planning based impact indices ILP, ILQ, IC, IVD and CI are nearby zero and it is presented in table 4. The VSI of this model with DG is 0.91624 larger than that the without condition. In this model, the optimal result of MOPI is 0.42020 and it is larger than the other type load model.

Mixed load model: In this model to form the combination of constant, industrial, residential and commercial load models. In this model, the simultaneous placement of various categories of DGs in the system which reduces the real and reactive power losses are 22.26 KW and 14.90 KVAR respectively. The value of indices ILP, ILQ, IC, IVD and CI are reduced to placing of DG categories has presented in table 4. The improved VSI of this model is 0.91786. The finest result of MOPI is 0.41845 listed in table 4.

Table 4. Comparisons of Related Impact Indices, MOPI and placing of DG categories for 69-node System with Load Models

Indices	Constant	Industrial	Residential	Commercial	Mixed
ILP	0.12562	0.15175	0.14570	0.13820	0.13429
ILQ	0.17323	0.20858	0.20327	0.19809	0.19429
VSI	0.90248	0.90760	0.92082	0.91624	0.91786
IC	0.80002	0.79929	0.79936	0.79929	0.79936
IVD	0.02533	0.02395	0.02041	0.02163	0.02120
CI	0.39545	0.38137	0.42016	0.43884	0.43901
min MOPI	0.40744	0.41509	0.41858	0.42020	0.41845
Opti. loc-size (MW±jMVAr) pairs of category					
Category 1	21 @ 0.30840	18 @ 0.34455	64 @ 0.31237	18 @ 0.35595	19 @ 0.33926
Category 2	64 @ 0.17452	65 @ 0.09092	21 @ 0.18196	64 @ 0.24350	63 @ 0.24782
Category 3	61 @ 1.2 + j 0.74364	61 @ 1.2 + j 0.74364	61 @ 1.2 + j 0.74364	61 @ 1.2 + j 0.74364	61 @ 1.2 + j 0.74364
Category 4	63 @ 0.09964 - j 0.06175	64 @ 0.13078 - j 0.08104	20 @ 0.20266 - j 0.12559	63 @ 0.14958 - j 0.09269	64 @ 0.16008 - j 0.09920

Table 5. Comparisons of Power Losses and Minimum VSI of without DG condition for 38-node System with Load Models

Load Model	P_{LDG} p.u.	P_L p.u.	Q_{LDG} p.u.	Q_L p.u.	VSI_{min} (without DG)
Constant	0.03638	0.18880	0.02518	0.12589	0.80782
Industrial	0.03924	0.16603	0.02703	0.11034	0.82044
Residential	0.03883	0.16636	0.02681	0.11053	0.82084
Commercial	0.03896	0.16459	0.02693	0.10930	0.82309
Mixed	0.04022	0.16628	0.02770	0.11048	0.82132

Table 6. Comparisons of Power Losses and Minimum VSI of without DG condition for 69-node System with Load Models

Load Model	P_{LDG} KW	P_L KW	Q_{LDG} KVAR	Q_L KVAR	VSI_{min} (without DG)
Constant	28.26	224.97	17.69	102.12	0.68332

Industrial	26.57	175.09	16.82	80.64	0.71252
Residential	24.89	170.83	16.03	78.86	0.71741
Commercial	22.81	165.05	15.13	76.38	0.72332
Mixed	22.26	165.76	14.90	76.69	0.72251

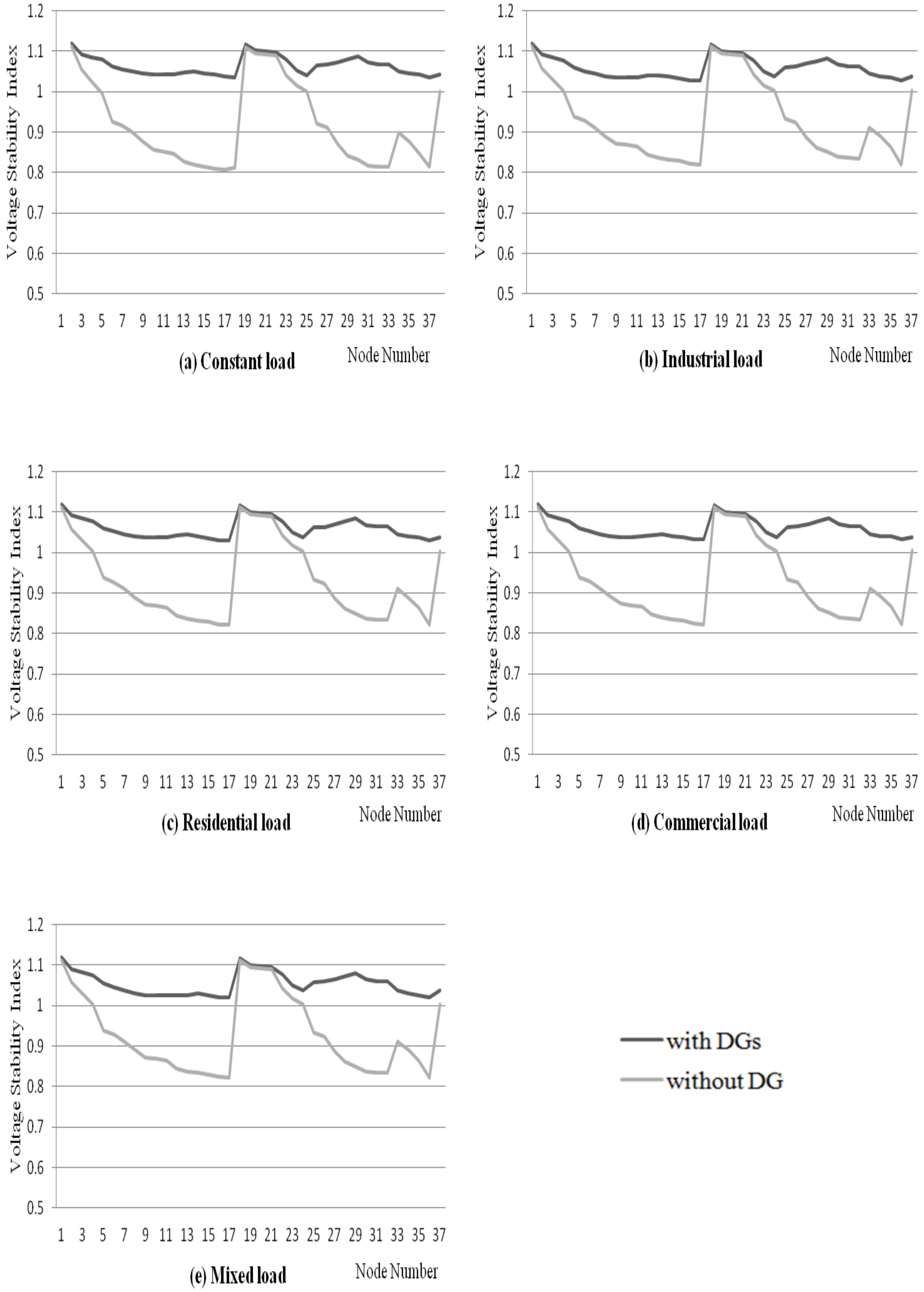

Fig. 3. Comparison of Voltage Stability Indices between with various categories of DG and without DG of 38-node system for different Load Models

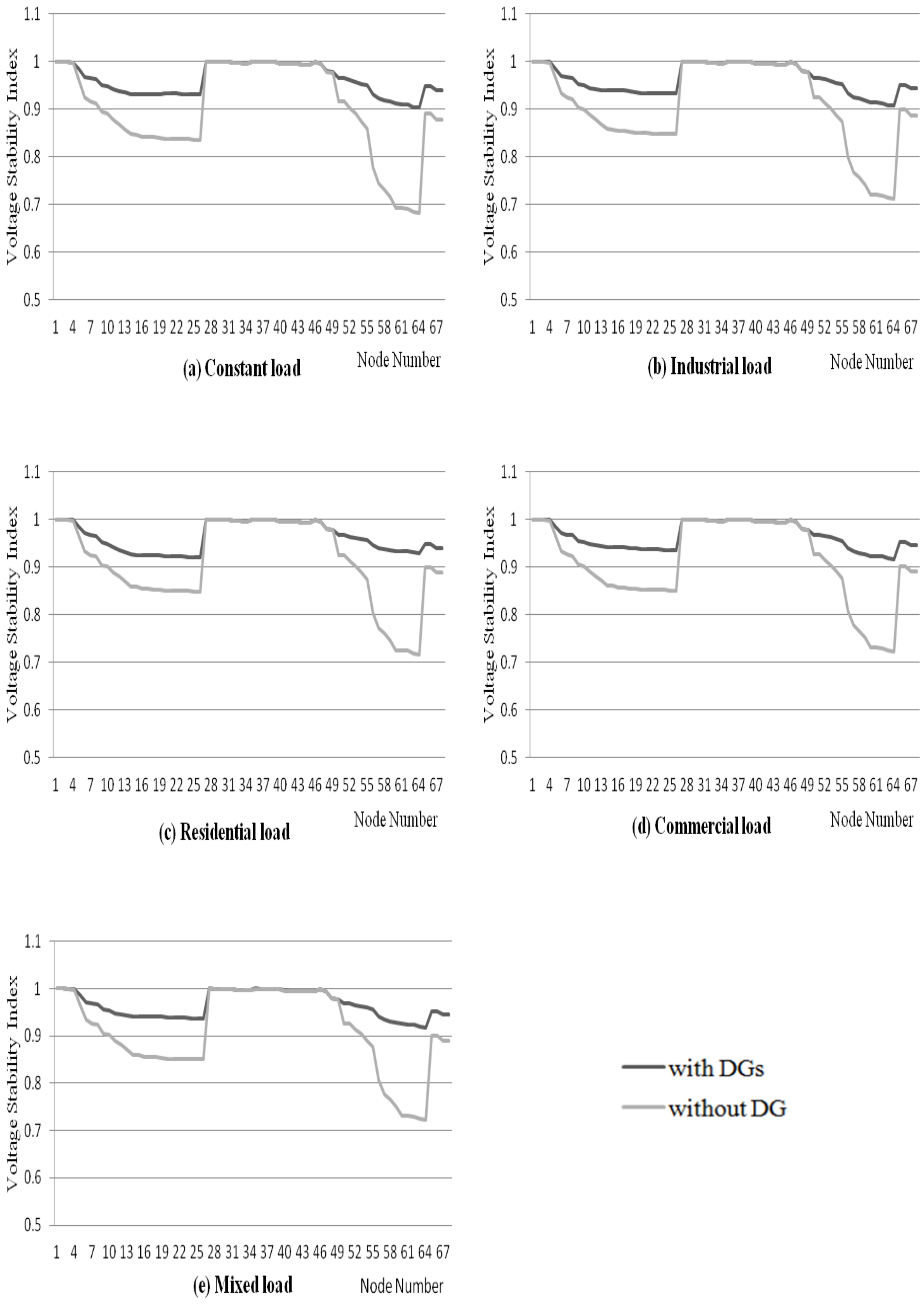

Fig. 4. Comparison of Voltage Stability Indices between with various categories of DG and without DG of 69-node system for different Load Models

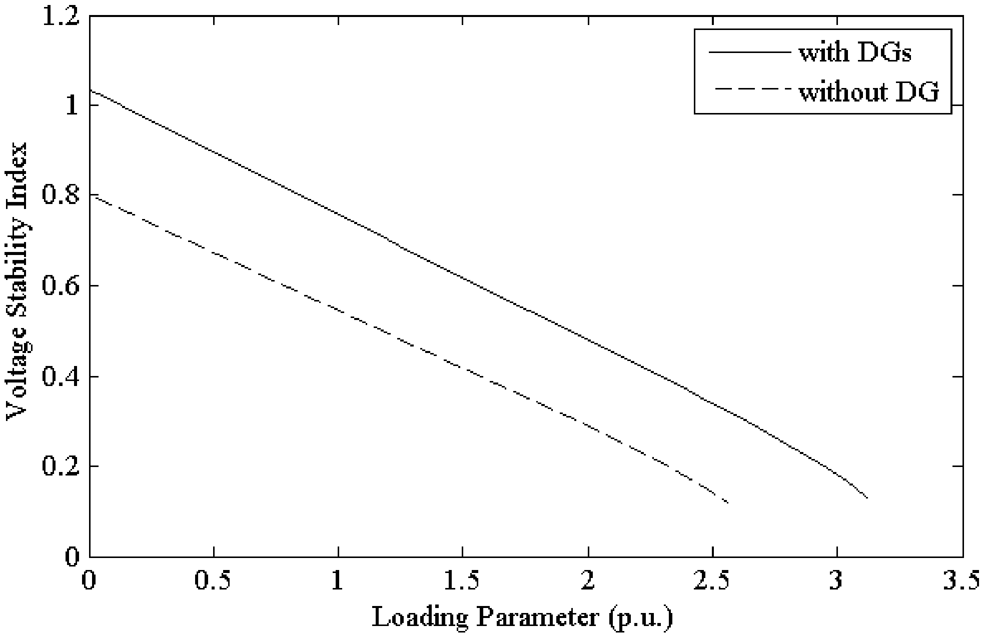

Fig. 5 (a). VSI curve of node–18 in 38–node system (constant type)

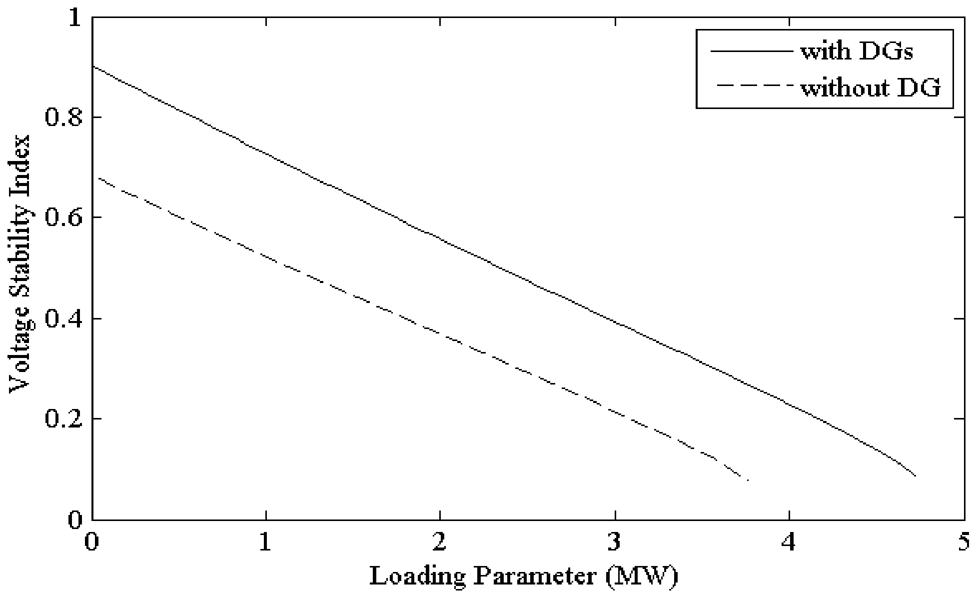

Fig. 5 (b). VSI curve of node–65 in 69–node system (constant type)

6.3 Discussion

The minimization of the objective function (MOPI) is achieved by satisfying all the constraints mentioned in section 3. Generally, the location of DGs in the distribution system gives more attention to voltage profile, overloading of the line, network losses and cost. In this approach, the impact indices mentioned above are considered for achieving the best result of optimization problem. The optimal location and sizing of DGs in the test system which results are greatly reducing the real and reactive power losses of the system for the entire load model. As a result of these loss indices is nearby zero, in which the system operates in an efficient manner. The VSI value of each node of the test systems considered that the entire load model is shown in figure 3 (a-e) for case (i) and figure 4 (a-e) for the case (ii). The graphical representation of the results indicates that the VSI values are greatly improved when the presence of DGs in the system. For constant type load model is considered that the optimal placing of various categories of DGs which results in the most sensitive node is 18 (VSI_{min}) for case (i) and 65 (VSI_{min}) for case (ii). The load abilities of case (i) and case (ii) are verified by increasing the real power load uniformly, as shown in figure 5 (a) and 5 (b) respectively. Figure 5 illustrates that the system loading ability and voltage stability is enhanced by the presence of DGs when compared to absences. To avoid overloading of the line, the power flow in each and every line should be maintained within limits. The result of IC index for the entire load model is less than unity, which represents that the line flows are permissible limits and

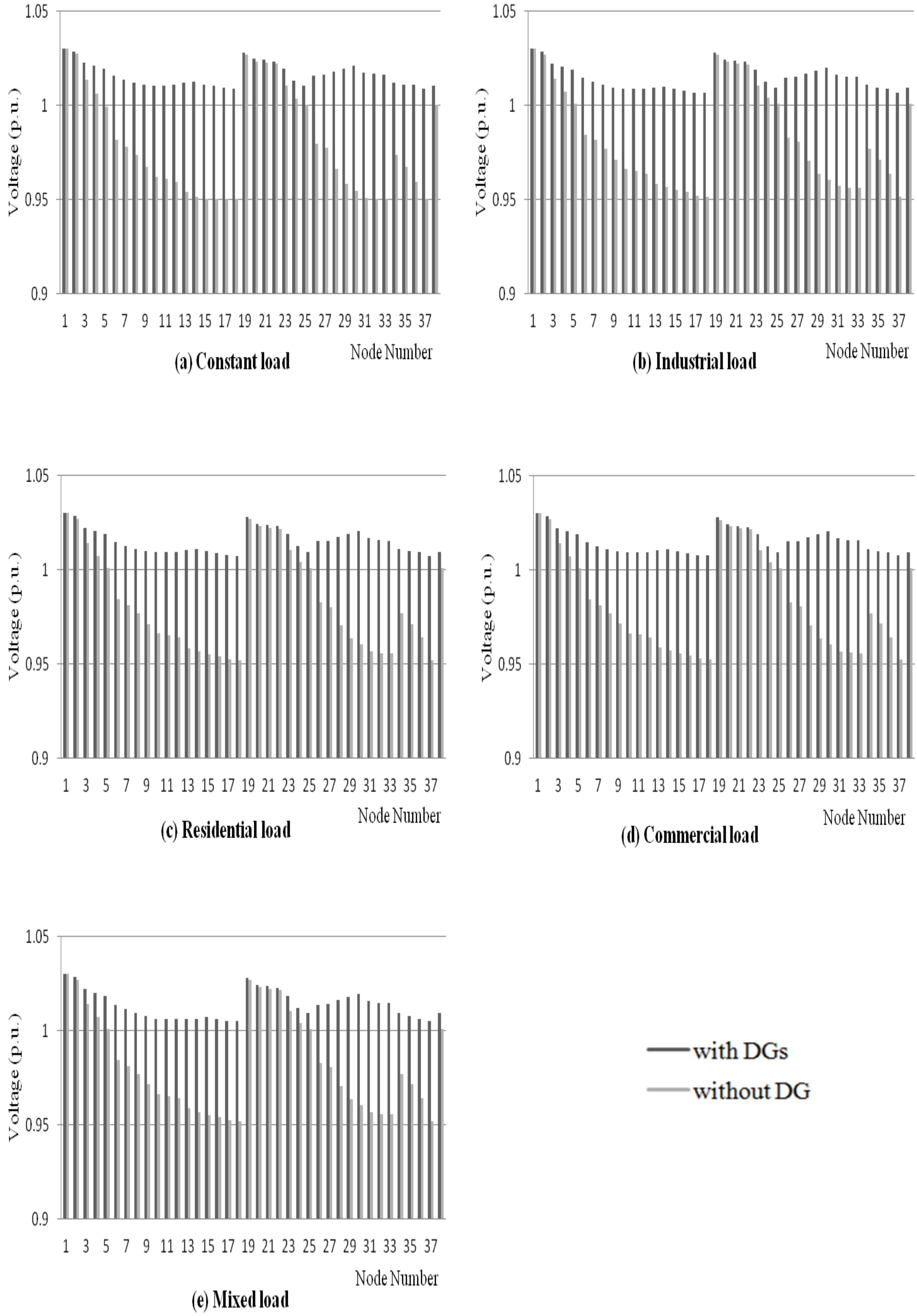

Fig. 6. Voltage profile of 38-node system with load models

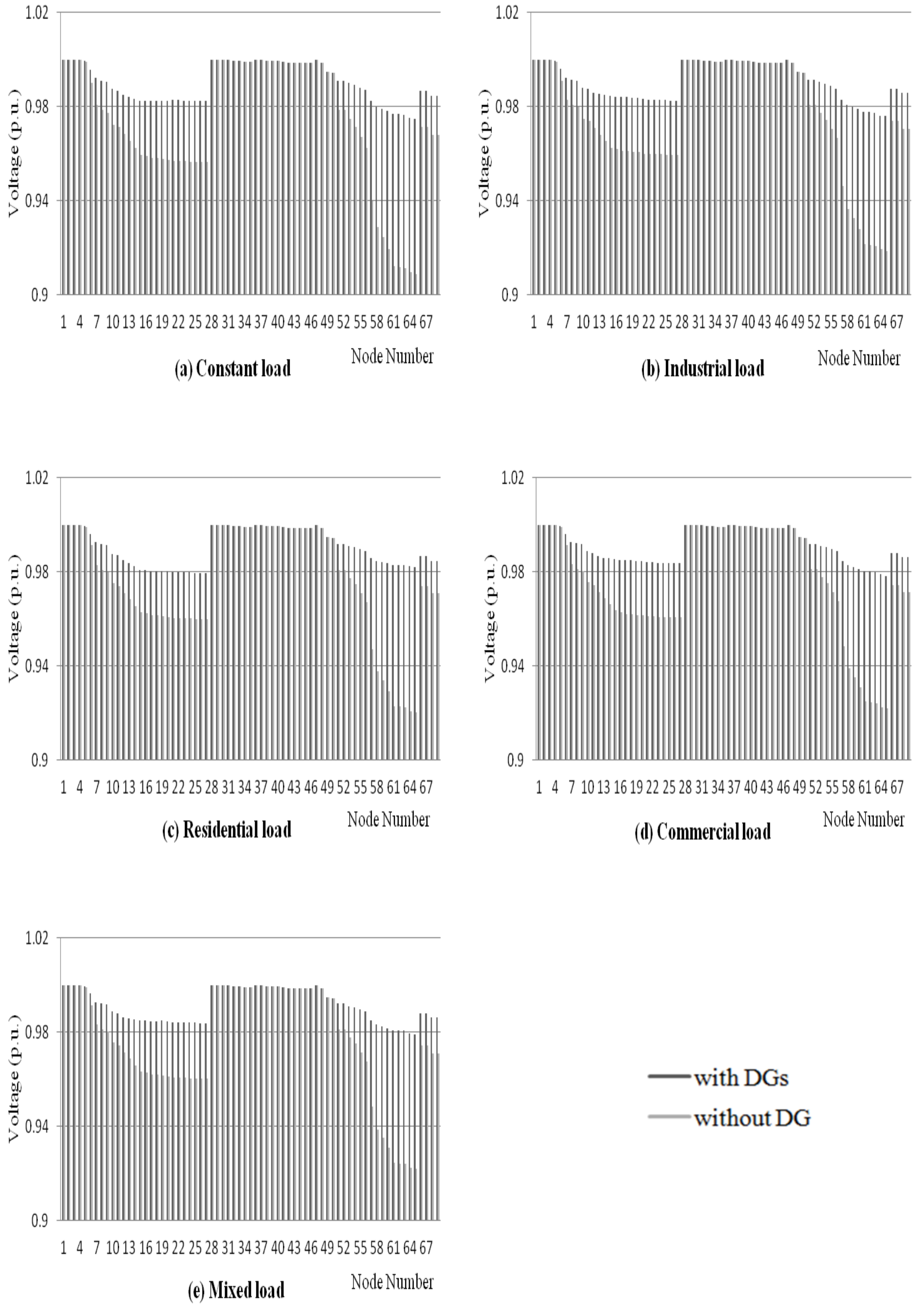

Fig. 7. Voltage profile of 69-node system with load models

extend the upgradation of the system. The voltage profile of the test systems considered in the entire load model as shown in figure 6 (a-e) for the case (i) and figure 7 (a-e) for the case (ii). From the graphical representations, it is indicated that the voltage at each node of the system is increased within their limit with the presence of DGs. The voltage profile index (IVD) is greatly reduced with effect of decreased the deviation of voltages in the test systems.

The cost factor is one of the major issues of placing the DGs in the test system. The value of power resources index (CI) is reduced with effect of minimizing the cost of installation and maintenance of the power resources in the distributed generation of the test systems.

7. CONCLUSION

The proposed optimization approach has been demonstrated the benefits of DG using CABC algorithm for optimal location and sizing of various categories of DGs. The algorithm is able to find the optimal solution of MOPI with various operating constraints of the problem. Technically, the lot of factors has influenced the combination of various categories of DGs is placed in the distribution system. This paper accounts the different technical and planning issues are considered for placing of various categories of DGs in the test systems. The numerical results indicate that there is a huge impact on the distribution system with the existence of DGs, which are real and reactive power loss index (ILP & ILQ), voltage stability index (VSI), line flow limit index (IC), voltage profile index (IVD) and cost index (CI). The graphical representations have proven that the voltage profile and voltage stability indices are greatly improved in the presence of DGs in the test systems. The future scope of this work is to inclusion of reliability based index for improved the reliability and quality of power supply and search the direction of our approach is to implement the possibilities of restructured power systems.

8. ACKNOWLEDGMENT

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10. APPENDIX

Table A. 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