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Crow Search Algorithm for Allocation of Multi-Type Distributed Generation in Unbalanced Radial Distribution System

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ABSTRACT

Optimal allocation of multiple-type distributed generators in unbalanced radial distribution systems is proposed in this article. Reduction of system total losses along with voltage profile enhancement represent the objectives of such multiple distributed generator allocation. Three types of distributed generator with different abilities to generate or consume reactive power are considered in this study. Photovoltaic based distributed generator can be synchronized with each phase independently; therefore, single-phase distribution of Photovoltaic is examined in this article. To reduce the searching effort especially with large systems, candidate locations are picked up first depending on a voltage- total real line loss index. Then, sizes of these three types of distributed generator are found by applying crow search algorithm, where a constrained optimization problem with voltage profile and loss indices as the objectives is constructed. The proposed method is applied on IEEE 13-bus, 34-bus and 123-bus unbalanced radial distribution systems. Numerical results realized by crow search algorithm are compared with those obtained by the artificial bee colony method. Analysis of the three systems indicates that the proposed allocation methods are effective in reducing total active power losses and in improving the voltage profile.

1. Introductin

The problem of optimizing the performance of distribution systems has been of much concern of many researchers and distribution system operators. Recently, the focus is towards the application of metaheuristic optimization methods on the distribution and sizing of reactive power sources, and on distributed generation (DG) allocation. The merits of these methods are the derivative-free feature, handling discrete objective functions and they can search in multi-dimension spaces. Many heuristic-based methods have been developed in the last few years, according to the no-free lunch theory; there is no method suitable for all optimization problems. Moreover, these methods differ from each other in some aspects such as the number of tuning parameters, ability to escape from local minimum, rate of convergence, and reliability. The common features of these methods are the random search, the dependence on random initial population, exploration-exploitation phases for generating new candidate solutions, and the

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uncertainty in stopping criteria.
Heuristic methods are used extensively in literatures

to allocate VAR sources and DG. Control of volt and var devices such as on-load tap changers (OLTC) and shunt capacitors affects the voltage profile and the totalpower loss in distribution networks [5]. In [1-4] the problem is formulated as a constrained optimization allocation of capacitors in radial distribution systems. Voltage/VAR optimization to enhance voltage profile and minimize system losses is discussed in [6-7]. Integration DG in distribution systems has opened a great area of research where optimal location and size are of much concern. Many articles considered the allocation of DG in balanced radial distribution systems (BRDS), in [8] a hybrid analytical-particle swarm optimization (PSO) approach is utilized to allocate DG in BRDS. PSO is applied in [9] for techno-economic DG allocation. Harmony search (HS) algorithm and particle artificial bee colony algorithm are integrated together to allocate DG and shunt capacitors in BRDS in [10]. Multiple DGs either single- or multi-type are discussed in [8, 11-12] using PSO, backtracking search algorithm, and invasive weed optimization algorithm. Many other optimization methods in this area can be found in [13-19].

Enhancement of unbalanced radial distribution systems (URDS) regarding voltage control, stability, and profile is discussed in [20-24]. In [25, 26], renewable energy-based DG allocation in URDS is discussed. Real coded genetic algorithm (GA) [27], supervised firefly algorithm [28], and other methods [29, 31] are examples of heuristic methods applied to the problem of DG allocation in URDS.

The crow search algorithm (CSA) is a recently developed optimization tool introduced in [32], where CSA outperformed three well-matured algorithms (GA, PSO and HS) regarding rate of convergence and speed of computations. Moreover, its implementation is easy since it has few tuning parameters. These features encouraged researchers to apply CSA on some engineering optimization problems [33]. To judge the performance of CSA, the well-known artificial bee colony (ABC) algorithm is also applied in this paper. It is developed in 2005 by Karaboga, many years before the development of CSA and it has some good features such as high flexibility, fast convergence, and robustness [34-38].

In this article, CSA is used to size three different types of DG either single or multiple in URDS to fulfill two objectives; reducing total voltage deviation and total losses while respecting all physical constrains. These methods are applied on three IEEE test systems; 13-bus, 34-bus and 123-bus systems. For more validation, results obtained by CSA are compared with those obtained by ABC.

2. Problem Definition

According to the ability of DGs to deliver real and reactive power, they are classified into four categories [11, 39, 40]:

- Type 1: DG is able to produce active power only such as photovoltaic and fuel cells.
- Type 2: DG is able to produce both active and reactive power such as synchronous machines.
- Type 3: DG is able to produce reactive power only such as synchronous compensators, (out of scope in our study)
- Type 4: DG is able to produce active power but consume reactive power such as induction generators used with wind farms, the consumed reactive power by an induction generator as a function in the active power can be calculated by [11]:

$$Q_{DG} = -(0.05 + 0.04\, P_{DG}^{2}) \qquad (1)$$

Among the different methods used to perform the load flow of URDS, the backward/forward sweep method is popular because of its robust convergence and the low memory requirements. The backward/forward sweep method and the modeling of the system components of the test systems used in this paper are explained in [41- 43]. The calculation of the total three-phase power loss of a line for URDS is explained in [44].

A total real line loss index (RLI_n^i) indicates the change in the total real line losses after adding DG whether positively or negatively, and it can be determined by:

$$RLI_n^i = \frac{Total\ real\ line\ loss\ with\ DG_n^i}{Total\ real\ line\ loss\ without\ DG\ (base\ case)} \qquad (2)$$

Where RLI_n^i is a total real line loss index for n^{th} DG location and i^{th} DG size; n is location of DG; and i is size of DG.

To narrow the search space, optimal location of DG can be determined first by injecting the three phase nodes (except source node) by 20% of the total feeder load as DG penetration. The voltage- total real line loss index (VRL_{index}) is determined by Eq. (3). Node with the least (VRL_{index}) is the optimal location for DG placement. For multiple DGs, the two nodes with the least two values of this index will be chosen as optimal locations for DGs placement [45, 46].

$$VRL_{index}(n) = \sqrt{\frac{\sum_{\varphi=1}^{3}\sum_{m=1}^{k}(1-V_{\varphi m})^2}{k} + \frac{RLI_n}{\sqrt{k}}} \quad (3)$$

Where $V_{\varphi m}$ is the magnitude of bus m voltage of phases a, b and c; n is DG connected node; and k is the number of total nodes.

The second step is searching for the appropriate size of DG for the candidate buses. In this stage, two goals are targeted which are minimizing total voltage deviation and total active power losses. Total voltage deviation index(VDI_n^i)can give a simple snapshot of the deviation of the voltage from its nominal value. Total voltage deviation index is the ratio between the total voltage deviation with DG and the total voltage deviation without DG (base case) for each DG size and optimal location. Since systems under study are unbalanced, which are including single and double phase circuits, (VDI_n^i)is designed only to determine the deviation of the operating phases.

$$VD\varphi_m = \begin{cases} |V\varphi_m - 1|, & V\varphi_m > 0 \\ 0, & otherwise \end{cases} \quad (4)$$

$$NVD_n^i = \sum_{m=1}^{k}\sum_{\varphi=1}^{3} VD\varphi_m \quad (5)$$

$$VDI_n^i = \frac{NVD_n^i}{NVD_{Base\ Case}} \quad (6)$$

where $VD\varphi_m$ is absolute value of voltage deviation (per unit) of φ phase at m bus; NVD_n^i is total voltage deviation for n optimal location of DG and i^{th} DG size; VDI_n^i is total voltage deviation index of the system for n optimal location of DG and i^{th} DG size; m is bus number; k is total number of buses; φ is number of phase of a conductor; n is optimal location of DG; and i is size of DG.

The multi-objective function for the optimal size of DG in URDS is designed as:

$$Min\ f = VDI_n^i + RLI_n^i \quad (7)$$

Weighting factors of the two terms representing the objective function in Eq. (7) are equal to 1, this choice is based on the fact that both terms are close in values and have the same importance in DG allocation.

The objective function in Eq. (7) is constrained by equality and inequality constraints as follows:

Power flow constraints:

$$P_{source} + P_{DG} - P_{Load} - P_{Loss} = 0 \quad (8)$$

$$Q_{source} + Q_{DG} - Q_{Load} - Q_{Loss} = 0 \quad (9)$$

Where P_{source} is the total active power of main source; P_{DG} is the total active power of DG injected into system;P_{Load} is the total active power of load demand; P_{Loss} is the total active power losses; Q_{source} is the total reactive power of main source; Q_{DG} is the total reactive power of DG injected into system; Q_{Load} is the total reactive power of load demand; and Q_{Loss} is the total reactive power losses.

DG active power constraints:

$$P_{DGmin} \le P_{nDG} \le P_{DGmax} \quad (10)$$

DG apparent power constraints:

$$S_{DGmin} \le S_{nDG} \le S_{DGmax} \quad (11)$$

Bus voltage constraints:

$$V_{min} \le |V_m| \le V_{max} \quad (12)$$

Branch current constraint:

$$I_j \le I_j^{Rated} \quad \forall j \in \{branches\ of\ the\ network\} \quad (13)$$

DG penetration level constraints:

$$DGPI_n^i \le \mu \quad (14)$$

$$DGPI_n^i = \frac{The\ total\ kVA\ of\ DG_n}{The\ total\ kVA\ of\ the\ system\ loads} \quad (15)$$

Total voltage deviation constraints:

$$VDI_n^i < 1 \quad (16)$$

Total real line loss constraints:

$$RLI_n^i < 1 \quad (17)$$

where P_{nDG} is active power of DG for n optimal location of DG; S_{nDG} is apparent power of DG for n optimal location of DG; V_{min} and V_{max} are lower (i.e.

0.90 pu) and upper (i.e. 1.05 pu) limits of bus voltage in the system, respectively; $I_j^{Rated}$is permissible branch current within safe limit of temperature; $DGPI_n^i$ is penetration level of DG for n optimal location of DG and i^{th} DG size; and μ is permissible maximum penetration level of DG.

It is worth here to mention that:

- Load flow calculations for the distribution system achieve the balance in the active and reactive power to achieve stability for system.
- DG active and apparent power boundaries are self-constrained by the used algorithm either CSA or ABC.
- Other constraints like (bus voltage limits, branch current constraint, DG penetration level, total voltage deviation, and total real line loss) are considered by penalizing the objective function when violating their limits[8, 11, 48].

3. Crow Search Algorithm

Crow search algorithm is a recent developed metaheuristic algorithm that mimics the behavior of crows in memorizing cache positions. Crows have a greedy habit that leads them to follow each other to steal food after the owner leaves. Crows take precautions to avoid being victims [3, 32]. Like other metaheuristic algorithms, CSA has a d-dimensional environment, which includes a N number of crows (flock size). The position of each crow represents a potential solution of the problem. At iteration $iter$, the position of crow i is represented as:

$$x^{i,iter} = [x_1^{i,iter}, x_2^{i,iter}, \ldots, x_d^{i,iter}] \quad (18)$$

Where$iter$ is the iteration number; and i is the crow number. It is assumed that each crow saves the position of its cache in its memory. At iteration no.$iter$, the position of the cache of crow i is called $m^{i,iter}$. This considers the best position of crow i that is found so far. Indeed, the position of the best experience of each crow has been saved in its memory. In the environment, crows move to find better food sources (caches). As mentioned earlier, Crow has a greedy habit that makes it follow the other crows to find the cache and steals their food after the owner leaves. Assume that, there are two crows $i$and j. At iteration no.$iter$, crow j intends to visit its cache $m^{j,iter}$. At this iteration, crow i wants to steal its food so crow i will follow crow j to find its cache [32]. Therefore, two cases are probable:

Case 1, crow j does not notice that it is being followed by crow i. In this case, crow i will find the cache of crow j and steals its food. Case 2, crow j notices that it is being followed by crow i. In this case, crow j will deceive crow i to protect its hiding place of theft by randomly going to another place of the search space. The expression for cases 1 and 2 is as follows:

$$x^{i,iter+1} = \begin{cases} x^{i,iter} + r_i \times fl^{i,iter} \times (m^{j,iter} - x^{i,iter}), & r_j \geq AP^{j,iter} \\ a\ random\ number, & otherwise \end{cases} \quad (19)$$

Wherer_i and $r_j$are random numbers uniformly distributed between 0 and 1; $fl^{i,iter}$ is the flight length of crow i at iteration $iter$; and $AP^{j,iter}$ is the awareness probability of crow j at iteration $iter$.

Once crow i updates its position, it will update its memory by:

$$m^{i,iter+1} = \begin{cases} x^{i,iter+1}, & f(x^{i,iter+1})\ is\ better\ than\ f(m^{i,iter}) \\ m^{i,iter}, & otherwise \end{cases} \quad (20)$$

Where$f(\cdot)$ is the value of the objective function.

In CSA, the mentioned steps that are explained above occur for all crows. The repetition of these steps depends on reaching to the predefined maximum number of iterations ($iter_{max}$). Finally, the best position of the memories is considered the optimal solution of CSA.

CSA has two specific parameters, which distinguish CSA from any other search technique; flight length (fl) and awareness probability(AP). flcalculates the step size of the movement of crow i towards the cache of crow j. If the value fl is set between 0 and 1, the new position of crow $i$will be between $x^{i,iter}$and $m^{j,iter}$ (local search), while if its value is set more than 1, the crow can reach beyond the cache (global search). APmainly controls intensification and diversification. By reducing the value of AP, the search will be on a local region and intensification will increase. On the other hand by increasing its value, crows will search on a global scale. Therefore, diversification will increase [3, 32]. CSA parameters as flock size, flight length, and awareness probability are set to 10, 2 and 0.1, respectively. A brief flow chart for the CSA method is illustrated in Figure 1.

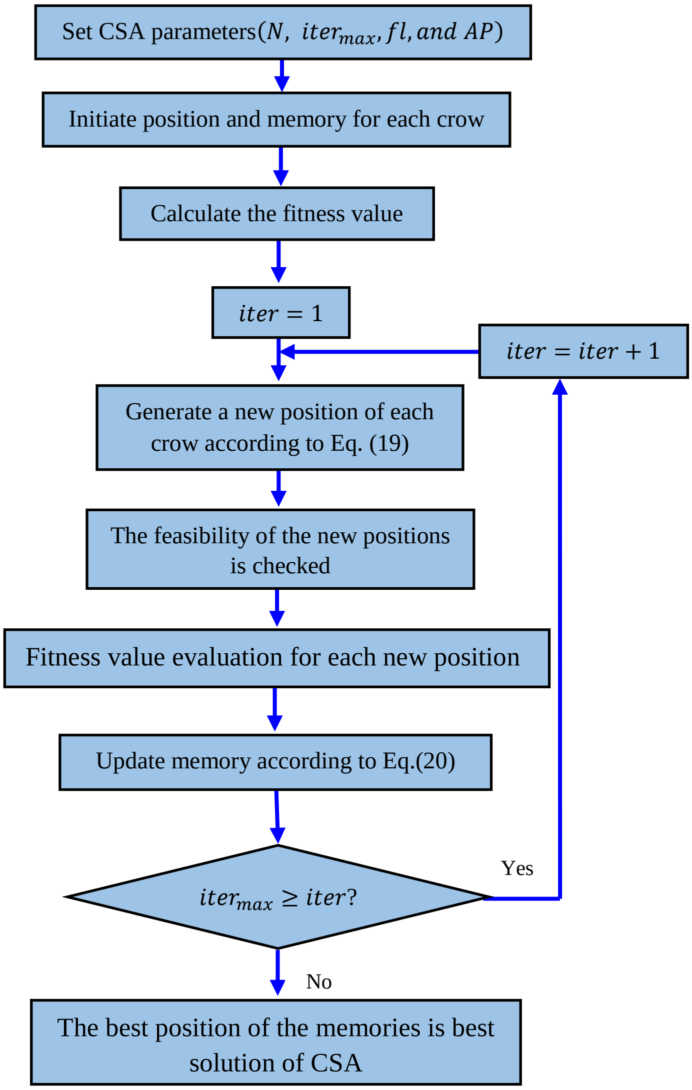
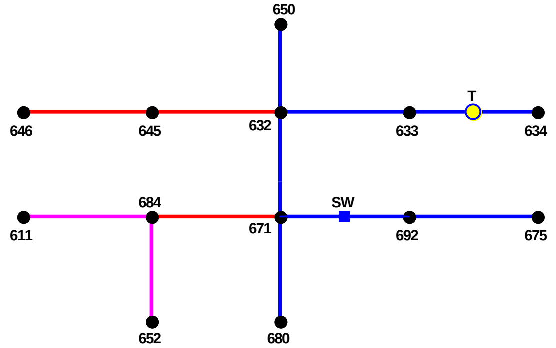


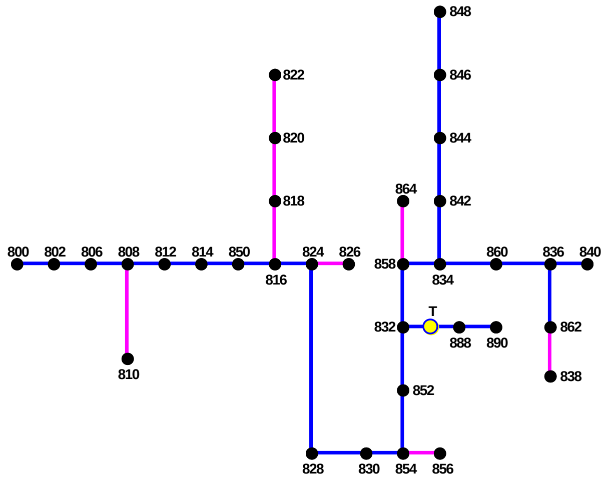
Fig. 1. Flowchart of the Proposed CSA

4. Numerical Results and Simulations

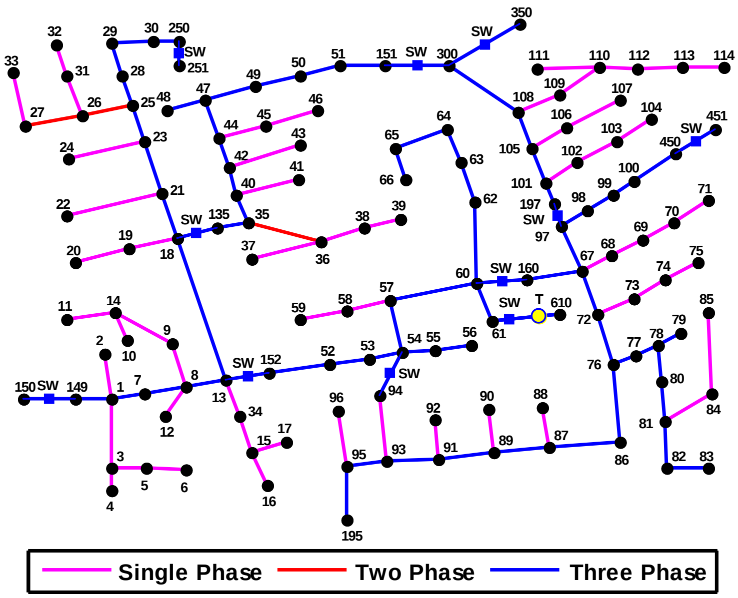
The proposed approach and optimization algorithms are carried out on the IEEE 13-bus, IEEE 34-bus and IEEE 123-bus URDS. The configuration of these systems is shown in Figure 2. (a)-(c) and data of these systems is collected from [47]. All voltage regulators are omitted from the three test systems to properly determine the effect of distributed generation solely on their performance. Numerical simulations are implemented on MATLAB R2013a version using a Dell laptop with processor Intel(R) Core (TM) i3-3217U CPU with 1.80 GHz, a 4.0 GB of RAM, and 32-bit operating system.



(a) IEEE 13-Bus System



(b) IEEE 34-Bus System



SW: Switch T:Transformer

(c) IEEE 123-Bus System

Fig. 2.Systems under Study

4.1. Base Case

Table 1 summarizes the obtained numerical results of the three systems at the base case using the backward/forward sweep method. The backward/forward sweep method is based on Kirchhoff's voltage and current laws. This method consists of two steps; backward sweep and forward sweep [42].

Table 1: Load Flow Summaries for IEEE 13-Bus, 34- Bus, and 123-Bus URDS

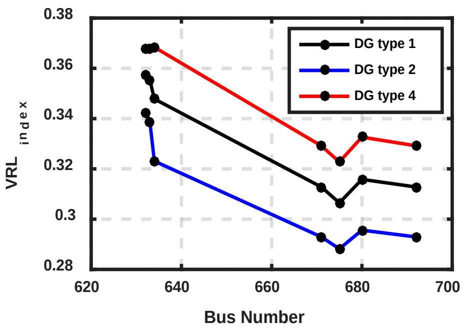
Variable	IEEE 13-Bus	IEEE 34-Bus	IEEE 123-Bus
Base kV	4.16	24.9	4.16
Total Active Power Load (kW)	3466	1769	3490
Total Reactive Power Load (kVAR)	2102	1044	1920
Total Voltage Deviation without DG (Base Case) (pu)	1.7272	4.1748	9.3414
Total Active Power Losses without DG (Base Case) (kW)	121.2054	118.5883	97.6619

4.2. Optimal Location of DG

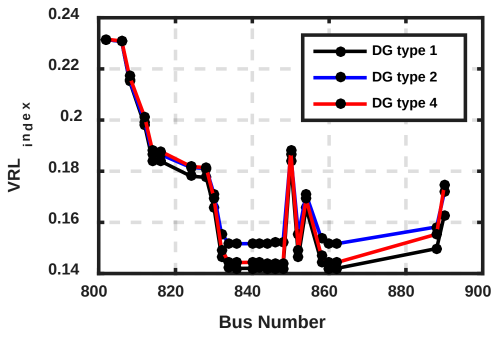
Table 2 shows the optimal location for single and multiple DGs placement of multiple types and the value of VRL_{index} for the three systems. VRL_{index} graphs for multi-type DGs for the three systems are shown in Figure 3. (a)-(c).

Table 2: Optimal Locations of Different DG Types for IEEE 13-Bus, 34- Bus, and 123-Bus URDS

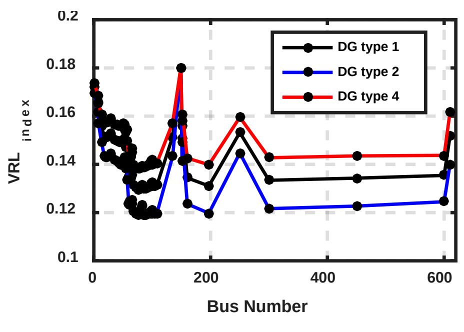
Test System	Variable	Type 1		Type 2		Type 4	
		First Location	Second Location	First Location	Second Location	First Location	Second Location
IEEE 13-Bus	Optimal Location	675	671	675	671	675	692
	VRL_{index}	0.30648	0.31279	0.28818	0.29292	0.32275	0.32917
IEEE 34-Bus	Optimal Location	844	846	860	836	848	846
	VRL_{index}	0.14186	0.14196	0.15164	0.15164	0.14370	0.14371
IEEE 123-Bus	Optimal Location	76	86	86	76	77	78
	VRL_{index}	0.12967	0.12969	0.11884	0.11886	0.13833	0.13834



(a) VRL_{index} for IEEE 13-Bus URDS



(b) VRL_{index} for IEEE 34-Bus URDS



(c) VRL_{index} for IEEE 123-Bus URDS

Fig. 3. VRL_{index} for the Studied Systems

4.3. Optimal Size of DG

Tables 3 to 8 show the obtained results of CSA algorithm and ABC for the three test systems over 20 independent runs. Best, mean and worst values of the objective function along with no. of iterations, active and reactive powers, and processing time (time) are listed in these Tables. Tables 9 to 11 summarize the test results at base case and after adding single and multiple DGs of multiple types and show the value of each part of the objective function separately.

Entries of Tables 3 and 4 show that results of CSA and ABC are very close, computation time and no. of iterations of ABC is much less that of CSA. Best objective is achieved using two DGs of type 2. This is because this type injects both active and reactive power to the system. A slight improve in the objective function resulted from distribution of type 1 DG in single-phase independently rather than using three-phase configuration. Low values of standard deviation in both methods reflect the robustness of each of them in finding the best solution along the 20 different runs.

Table 3: Results of CSA on the 13-Bus URDS over 20 Runs

Variable		Iter.	Best	Mean	Worst	Std.	Active Power (kW)	Reactive Power (kVAR)	Time, s
Type 1	Single	40	1.1265	1.1266	1.1269	9.4 × 10-4	623.13 @ 675	-	109.57
	Two	125	1.1050	1.1053	1.1080	6.29 × 10-4	311.56 @ 675 311.57 @ 671	-	334.48
	Three Single Phase	300	1.1111	1.1128	1.1200	0.0020	@ 675 Phase A: 623.13 Phase B: 513.40 Phase C: 623.11	-	785.44
	Six Single Phase	510	1.1095	1.1346	1.1798	0.0196	@ 675 Phase A: 311.56 Phase B: 204.06 Phase C: 311.52 @ 671 Phase A: 311.54 Phase B: 209.89 Phase C: 307.148	-	1289.08
Type 2	Single	60	0.9039	0.9039	0.9040	2.27 × 10-5	560.82 @ 675	271.62 @ 675	165.28
	Two	125	0.8784	0.8793	0.8869	0.0018	280.39 @ 675 280.4 @ 671	135.8 @ 675 135.8 @ 671	346.31
Type 4	Single	80	1.2250	1.2251	1.2251	1.37 × 10-5	623.14 @ 675	65.532 @ 675	214.01
	Two	125	1.2772	1.2775	1.2783	2.76 × 10-4	311.54 @ 675 311.55 @ 692	53.8823 @ 675 53.8826 @ 692	339.42

Table 4: Results of ABC Algorithm on the 13-Bus URDS over 20 Runs

Variable		Iter.	Best	Mean	Worst	Std.	Active Power (kW)	Reactive Power (kVAR)	Time (s)
Type 1	Single	10	1.1265	1.1265	1.1265	0	623.14 @ 675	-	57.23
	Two	20	1.1050	1.1050	1.1050	0	311.57 @ 675 311.57 @ 671	-	115.20
	Three Single Phase	15	1.1110	1.1116	1.1173	0.0014	@ 675 Phase A: 623.14 Phase B: 526.66 Phase C: 623.14	-	83.70
	Six Single Phase	110	1.0921	1.0922	1.0924	5.44 × 10-5	@ 675 Phase A: 311.57	-	561.37

							Phase B: 219.42 Phase C:311.57 @ 671 Phase A: 311.57 Phase B: 311.57 Phase C: 311.57		
Type 2	Single	10	0.9039	0.9039	0.9039	1.11 × 10-16	560.82 @ 675	271.62 @ 675	58.66
	Two	20	0.8784	0.8784	0.8784	4.44 × 10-16	280.41 @ 675 280.41 @ 671	135.81 @ 675 135.81 @ 671	115.17
Type 4	Single	10	1.2250	1.2250	1.2250	0	623.14 @ 675	65.53 @ 675	55.45
	Two	15	1.2772	1.2772	1.2772	2.22 × 10-16	311.57 @ 675 311.57 @ 692	53.88 @ 675 53.88 @ 692	88.19

Table 5: Results of CSA on the IEEE 34 URDS over 20 Runs

Variable		Iter.	Best	Mean	Worst	Std.	Active Power	Reactive Power	Time, s
Type 1	Single	15	1.0295	1.0295	1.0295	6.096 × 10-7	221.08 @ 844	-	163.016
	Two	35	1.0298	1.0299	1.0304	1.405 × 10-4	149.36 @ 844 70.360 @ 846	-	421.17
	Three Single Phase	85	0.8000	0.8002	0.8019	4.824 × 10-4	@ 844 Phase A:233.6 Phase B:175.6 Phase C:97.3421	-	891.004
	Six Single Phase	150	0.8010	0.8015	0.8025	3.457 × 10-4	@ 844 Phase A: 133.4 Phase B: 129.18 Phase C: 69.0934 @ 846 Phase A: 100.18 Phase B: 46.8617 Phase C: 28.3953	-	1652.013
Type 2	Single	10	1.2064	1.2064	1.2064	8.417 × 10-6	153.87 @ 860	74.524 @ 860	111.928
	Two	15	1.2064	1.2065	1.2066	6.272 × 10-5	126.74 @ 860 27.1092 @ 836	61.3806 @ 860 13.1296 @ 836	157.441
Type 4	Single	15	0.9708	0.9708	0.9708	5.187 × 10-7	239.96 @ 848	52.3033 @ 848	167.290
	Two	15	0.9448	0.9449	0.9451	7.217 × 10-5	109.65 @ 848 146.71 @ 846	50.481 @ 848 50.861 @ 846	165.333

Table 6: Results of ABC Algorithm on the IEEE 34 URDS over 20 Runs

Variable		Iter.	Best	Mean	Worst	Std.	Active Power (kW)	Reactive Power (kVAR)	Time (s)
Type 1	Single	10	1.0295	1.0295	1.0295	2.33 × 10-8	221.08 @ 844	-	198.31
	Two	15	1.0298	1.0299	1.0301	7.38 × 10-5	149.44 @ 844 70.18 @ 846	-	302.48
	Three Single Phase	50	0.8000	0.8000	0.8000	6.03 × 10-6	@ 844 Phase A: 233.55 Phase B: 175.52 Phase C: 97.30	-	1042.53

	Six Single Phase	100	0.8008	0.8012	0.8015	2.42 × 10-4	@ 844 Phase A: 149.44 Phase B: 149.44 Phase C: 70.13 @ 846 Phase A: 84.07 Phase B: 26.94 Phase C: 27.62	-	2090.96
Type 2	Single	10	1.2064	1.2064	1.2064	3.14 × 10-7	153.93 @ 860	74.55 @ 860	199.15
	Two	80	1.2064	1.2064	1.2068	9.16 × 10-5	134.30 @ 860 19.58 @ 836	65.05 @ 860 9.49 @ 836	1512.90
Type 4	Single	10	0.9708	0.9708	0.9708	9.28 × 10-8	239.96 @ 848	52.30 @ 848	212.31
	Two	30	0.9448	0.9448	0.9450	4.07 × 10-5	106.7262 @ 848 149.4387 @ 846	50.4556 @ 848 50.8933 @ 846	628.28

For the 34-bus system, CSA outperformed ABC algorithm regarding speed of computations. Objective function in all cases are almost the same using the two algorithms. Robustness of both methods is proved by examining the low values of the standard deviation. In this system, single-phase distribution of DG type 1 resulted in the lower value of the objective function and is effective than using the three phase configuration.

Table 7: Results of CSA on the IEEE 123 URDS over 20 Runs

Variable		Iter.	Best	Mean	Worst	Std.	Active Power (kW)	Reactive Power (kVAR)	Time (s)
Type 1	Single	25	0.9345	0.9390	0.9605	0.006	613.46 @76	-	561.26
	Two	115	0.9427	0.9475	0.9630	0.0052	306.7 @76 306.72 @86	-	2615.15
	Three Single Phase	220	0.9360	0.9479	0.9745	0.0113	@ 76 Phase A: 613.42 Phase B: 612.68 Phase C: 605.14	-	5137.65
	Six Single Phase	280	0.9490	1.0113	1.0539	0.0304	@ 76 Phase A: 306.69 Phase B: 263.61 Phase C: 303.6 @ 86 Phase A: 303.77 Phase B: 305.98 Phase C:296.02	-	6207.34
Type 2	Single	45	0.8429	0.8442	0.8518	0.0019	552.12 @86	267.40 @86	1008.83
	Two	65	0.7882	0.7965	0.8185	0.0074	275.45 @86 275.43 @76	133.4 @86 133.4 @76	1578.99
Type 4	Single	45	1.0810	1.0845	1.1196	0.0083	613.38 @77	65.0492 @77	1042.24
	Two	110	1.1638	1.1710	1.1985	0.0085	306.26 @77 306.45 @78	53.7518 @77 53.7566 @78	3105.24

Table 8: Results of ABC Algorithm on the IEEE 123 URDS over 20 Runs

Variable		Iter.	Best	Mean	Worst	Std.	Active Power	Reactive Power	Time, s
Type 1	Single	10	0.9344	0.9344	0.9344	1.11 × 10-16	Bus 76:613.4828	-	430.829
	Two	10	0.9426	0.9426	0.9426	3.33 × 10-16	Bus 76:306.7414 Bus 86:306.7414		448.380
	Three Single Phase	25	0.9344	0.9345	0.9349	1.07 × 10-4	Bus 76: Phase A:613.4828 Phase B:613.4828 Phase C:613.4828		1265.082
	Six Single Phase	70	0.9424	0.9424	0.9425	2.44 × 10-5	Bus 76: Phase A: 306.7414 Phase B: 306.7414 Phase C: 306.7414 Bus 86: Phase A:306.7414 Phase B:295.0967 Phase C:306.7414		2943.422
Type 2	Single	10	0.8429	0.8429	0.8429	0	Bus 86:552.1345	Bus 86: 267.4109	514.644
	Two	20	0.7874	0.7874	0.7874	3.33 × 10-16	Bus 86:276.0672 Bus 76:276.0672	Bus 86:133.7055 Bus 76:133.7055	865.252
Type 4	Single	10	1.0809	1.0809	1.0809	4.44 × 10-16	Bus 77:613.4828	Bus 77:65.0544	496.109
	Two	15	1.1633	1.1633	1.1633	0	Bus 77:306.7414 Bus 78:306.7414	Bus 77: 53.7636 Bus 78: 53.7636	714.495

Results for the 123-bus system obtained by CSA are very close to that of ABC. Nevertheless, no. of iterations and computational time are much less using ABC algorithm, and standard deviation with ABC is very small. This proves the robustness of this method over CSA method with this system. Using two DGs of type 2 resulted in the best value of the objective function. Figures 4 to 9 show the voltage profile comparison of different cases in the three phases by using the two algorithms. In most case, using two DGs of type 2 has the dominant effect on improving the voltage profile.

Table 9: Summary of Test Results at Base Case and with Single and Multiple DGs of 13-Bus System by using ABC and CSA

Variable		Total Voltage Deviation Index (VDI)		Total Real Line Loss Index (RLI)		DG Penetration Level	
		ABC	CSA	ABC	CSA	ABC	CSA
Base case		1	1	1	1	-	-
Type 1	Single	0.7276	0.7276	0.3989	0.3989	50.0000	49.9996
	Two	0.7292	0.7292	0.3758	0.3758	50.0000	49.9992
	Three Single Phase	0.7229	0.7238	0.3881	0.3873	47.4195	47.0640
	Six Single Phase	0.7234	0.7349	0.3687	0.3746	47.5353	44.2845
Type 2	Single	0.5455	0.5455	0.3584	0.3584	49.9997	49.9999
	Two	0.5481	0.5481	0.3303	0.3304	50.0000	49.9974
Type 4	Single	0.7898	0.7898	0.4353	0.4353	50.0000	50.0000
	Two	0.8386	0.8386	0.4386	0.4386	50.0000	49.9963

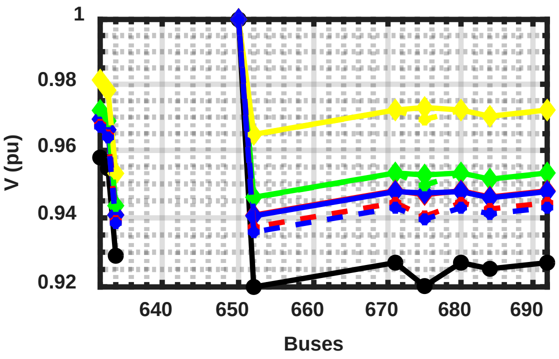
As shown in Table 9, results of CSA algorithm are close to those by using ABC. For 13-bus system, single synchronous generator presents the least value of VDI and two synchronous generators present the least value of RLI. With DG type 1 and, RLI obtained by using two DGs is smaller than that obtained by using single DG. RLI with two induction generators is the greatest due to the consumption of reactive power. For the 34-bus system, as shown in Table 10, three single phase PV present the least value of VDI and single induction generator presents the least value of RLI. In spite of using induction generator, losses are reduced in this case because in base case, this system has many buses with voltage higher than 1 pu and extra VAR in the system is absorbed by the induction generator that limited the flow of VAR toward the source and hence reduced the losses.

Table 10: Summary of Test Results at Base Case and with Single and Multiple DGs of 34-Bus System by using ABC and CSA

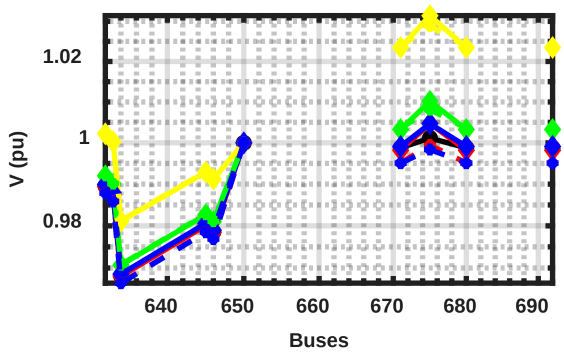
Variable		Total Voltage Deviation Index (VDI)		Total Real Line Loss Index (RLI)		DG Penetration Level	
		ABC	CSA	ABC	CSA	ABC	CSA
Base case		1	1	1	1	-	-
Type 1	Single	0.7522	0.7522	0.2773	0.2773	36.9847	36.9851
	Two	0.7497	0.7499	0.2802	0.2800	36.7408	36.7575
	Three Single Phase	0.4007	0.4008	0.3994	0.3992	28.2376	28.2469
	Six Single Phase	0.4025	0.4021	0.3982	0.3988	28.3076	28.2790
Type 2	Single	0.7153	0.7152	0.4911	0.4912	28.6136	28.6021
	Two	0.7154	0.7153	0.4910	0.4910	28.6046	28.5968
Type 4	Single	0.7244	0.7245	0.2463	0.2463	40.1438	40.1441
	Two	0.6977	0.6980	0.2471	0.2468	42.8546	42.8883

Table 11: Summary of Test Results at Base Case and with Single and Multiple DGs of 123-Bus System by using ABC and CSA

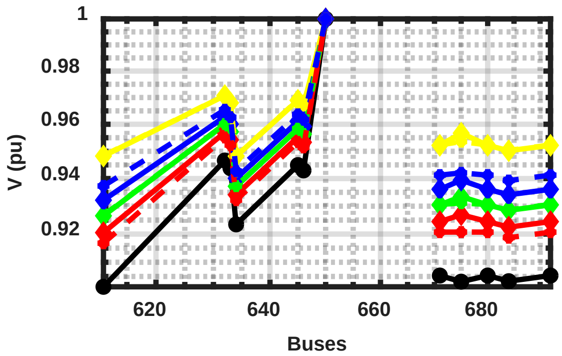
Variable		Total Voltage Deviation Index (VDI)		Total Real Line Loss Index (RLI)		DG Penetration Level	
		ABC	CSA	ABC	CSA	ABC	CSA
Base case		1	1	1	1	-	-
Type 1	Single	0.5687	0.5687	0.3657	0.3657	50.0000	49.9978
	Two	0.5674	0.5674	0.3753	0.3753	50.0000	49.9945
	Three Single Phase	0.5687	0.5699	0.3657	0.3661	50.0000	49.7497
	Six Single Phase	0.5674	0.5727	0.3750	0.3763	49.6835	48.3484
Type 2	Single	0.4060	0.4060	0.4369	0.4369	50.0000	49.9985
	Two	0.4003	0.4008	0.3870	0.3873	50.0000	49.8863
Type 4	Single	0.6516	0.6516	0.4293	0.4294	50.0000	49.9913
	Two	0.7083	0.7087	0.4550	0.4550	50.0000	49.9372



(a) Voltage Profile of Phase A



(b) Voltage Profile of Phase B



(c) Voltage Profile of Phase C

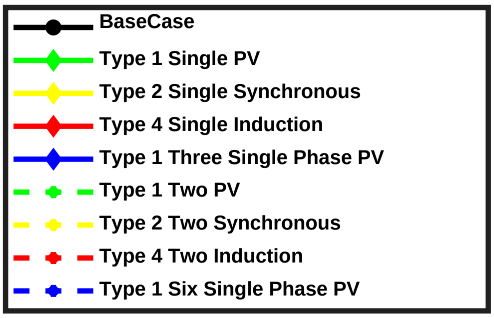
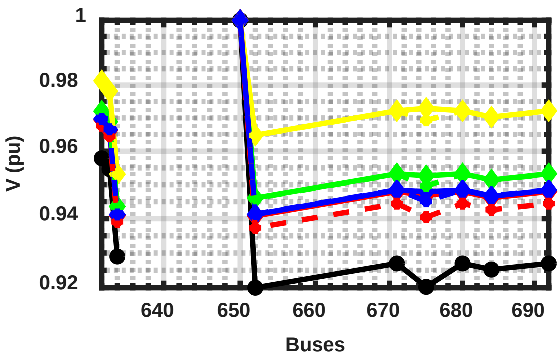
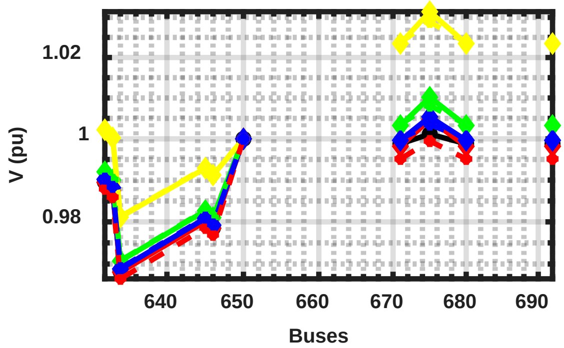


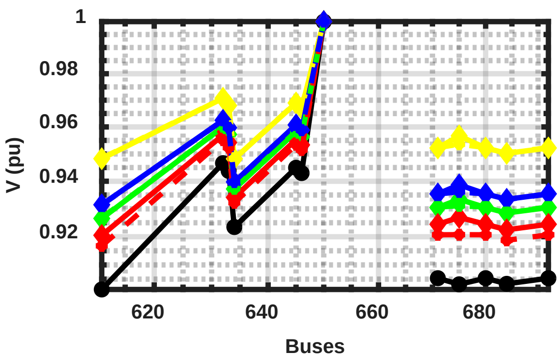
Fig. 4. Voltage Profile of Different DGs of the Three Phases for 13-Bus System by CSA



(a) Voltage Profile of Phase A



(b) Voltage Profile of Phase B



(c) Voltage Profile of Phase C

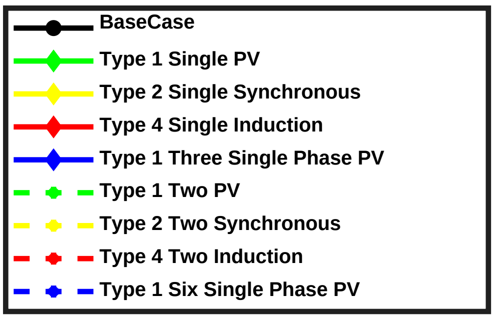
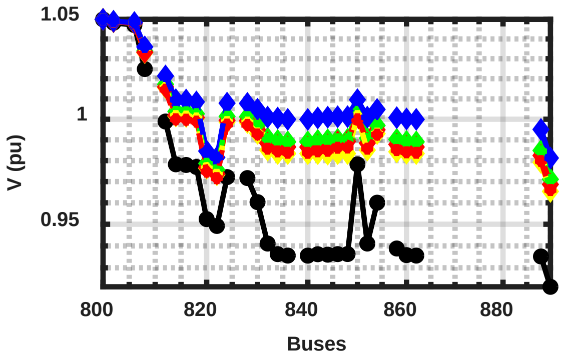
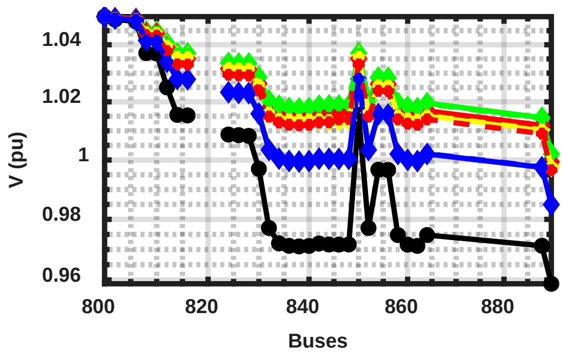


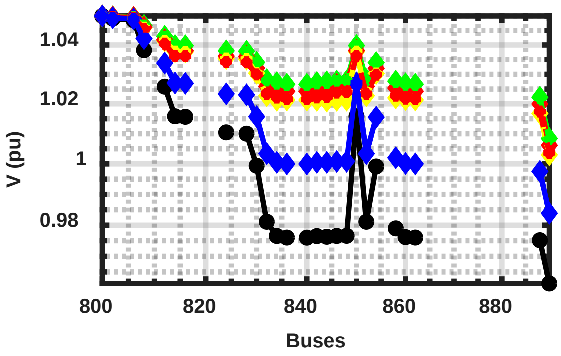
Fig. 5. Voltage Profile of Different DGs of the Three Phases for 13-Bus System by ABC



(a) Voltage Profile of Phase A



(b) Voltage Profile of Phase B



(c) Voltage Profile of Phase C

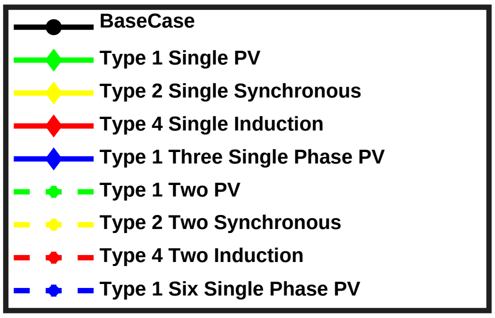
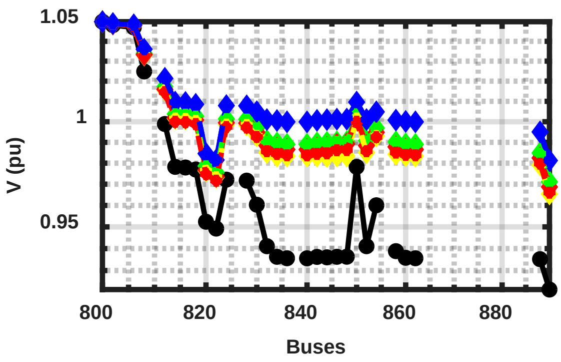
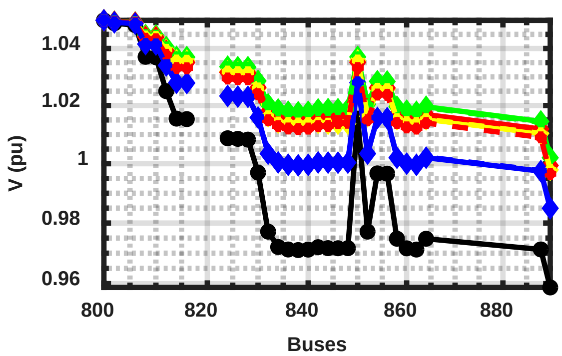


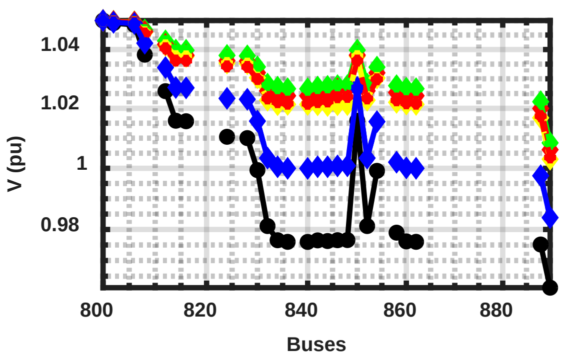
Fig. 6. Voltage Profile of Different DGs of the Three Phases for 34-Bus System by CSA



(a) Voltage Profile of Phase A



(b) Voltage Profile of Phase B



(c) Voltage Profile of Phase C

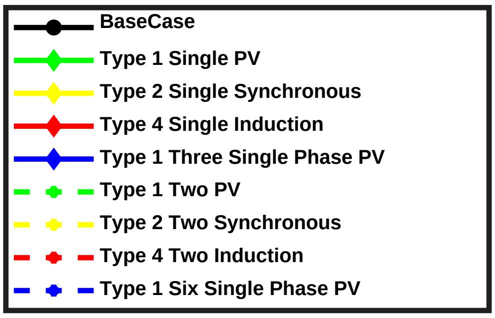
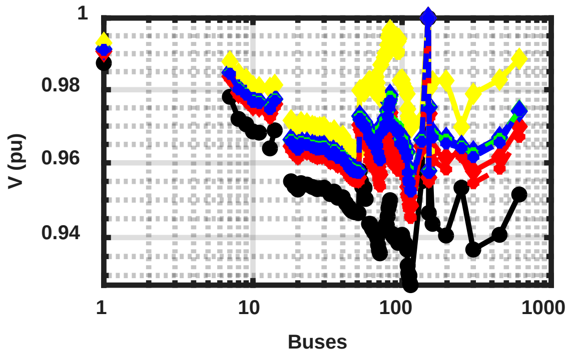
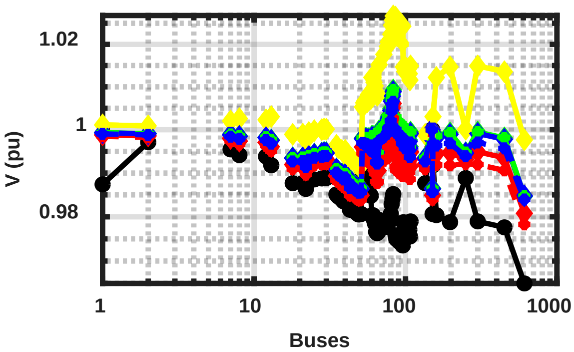


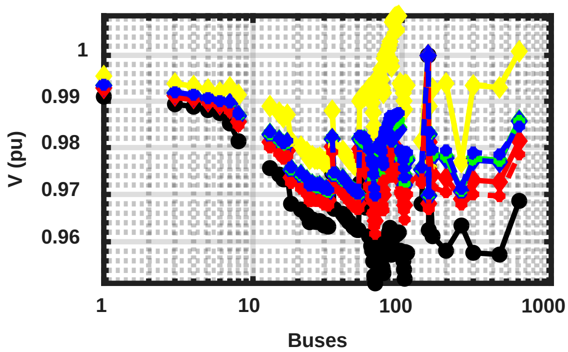
Fig. 7. Voltage Profile of Different DGs of the Three Phases for 34-Bus System by ABC



(a) Voltage Profile of Phase A



(b) Voltage Profile of Phase B



(c) Voltage Profile of Phase C

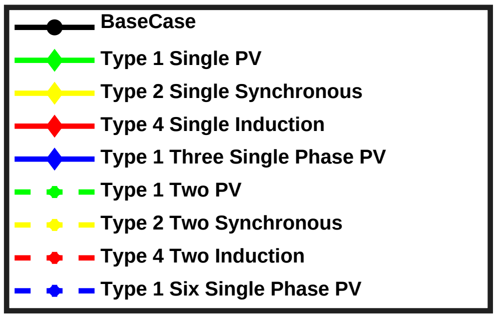
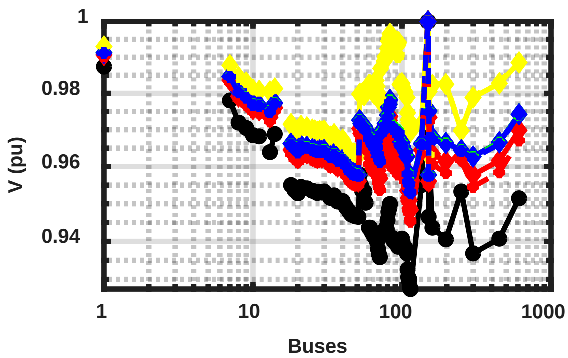
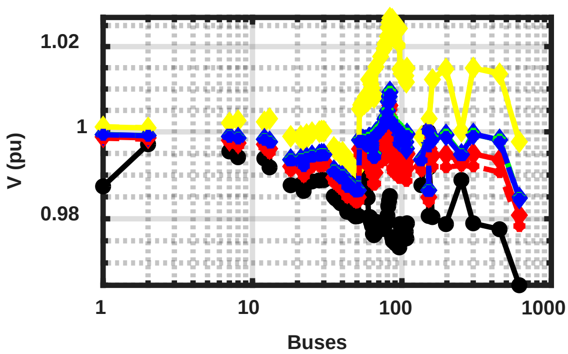


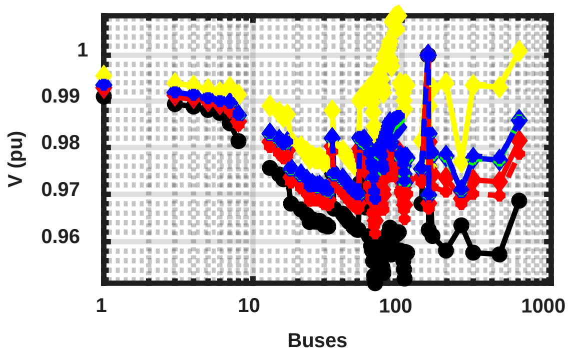
Fig. 8. Voltage Profile of Different DGs of the Three Phases for 123-Bus System by CSA



(a) Voltage Profile of Phase A



(b) Voltage Profile of Phase B



(c) Voltage Profile of Phase C

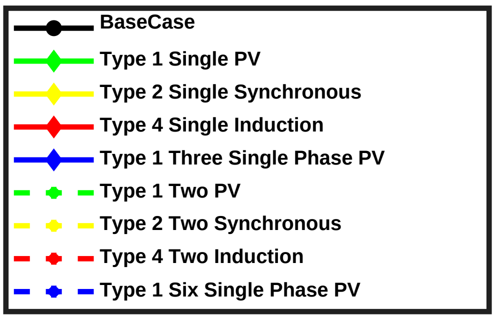


Fig. 9. Voltage Profile of Different DGs of the Three Phases for 123-Bus System by ABC

For the 123-bus system and as shown in Table 11, two synchronous generators present the least value of VDI and single PV and three single phase PV present the least value of RLI.

5. Conclusions

This paper presents a method to determine the optimal location and size of DG in unbalanced radial distribution system to minimize the total voltage deviation, and minimize the total active power losses. Searching for the optimal location and size of DG in an URDS has a huge search space. To narrow the search space, optimal location of DG is determined first depending on a combined voltage-total real line loss index. CSA and the ABC algorithm are used to determine the optimal size of single and multiple distributed generators. The proposed algorithms are applied to IEEE 13-bus, 34-bus, and 123-bus URDS. Adding single and multiple distributed generators of multiple types into these system enhance the obtained numerical results as compared to the obtained numerical results of base case.

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