

## Enhancing active radial distribution networks by optimal sizing and placement of DGs using modified crow search algorithm

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### Article Info

#### Article history:

Received, Apr 13 2019

Revised Jun 15, 2019

Accepted Jul 2, 2019

#### Keywords:

Crow search algorithm  
Distributed generation  
Multi-objective optimization  
Sizing of DGs  
Total harmonic distortion

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### ABSTRACT

Incorporating many Distributed Generators (DGs) technologies in power system networks has grown rapidly in recent years. Distributed generation (DG) plays a key role in reducing power loss and enhancing the voltage profile in radial distribution networks. However, inappropriate DGs site or size may cut network efficiency; moreover, injecting harmonics is one of the integration concerns of inverter-based DGs. Two-procedure based approach is introduced in this paper. The first procedure solves the DGs siting and sizing problem, as a multi-objective one by improving the voltage profile of the whole distribution network and also reducing its power loss. A weighted sum method is presented to create the Pareto optimal front in this procedure and get the compromised solution by applying a novel metaheuristic optimizer, named Crow Search Algorithm (CSA). A modification on CSA is also proposed and applied to improve its performance. The achieved solution for inverter-based DGs placement and size is checked in the second procedure to make sure the accepted voltage THD at all buses by implementing detailed simulation for the tested system using Matlab/Simulink. The proposed approach has been tested on IEEE 33-bus radial distribution system with photovoltaic DGs. To confirm the superiority of the modified CSA algorithm in terms of quality of solution, its achieved results are compared with the results offered by the original CSA algorithm and published results of some other nature-inspired algorithms.

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## 1. INTRODUCTION

Radial distribution systems (RDS) are commonly implemented in rural or suburban areas for their simplest structure and low initial installation cost as they are fed from utility grid at only one end. However, they suffer from several disadvantages. Their main disadvantages are the heavy loaded distributor at its end near to the substation, the customers at the distant end of the distributor face serious voltage fluctuation problem and in addition that distributor faults will cause interruption in supply to large number of consumers connected to that distributor. Actually, the overall power losses within the transmission and distribution systems limit the capability of the radial distribution system. In fact, distribution power loss accounts for the greatest amount of loss as 13% of the generated energy, which is dissipated as a heat within conducting materials [1]. This non-negligible quantity of losses results in a direct economic impact and also affects the overall capability of RDS.

DGs at the distribution side of the network are projected to play a significant role in satisfying the rapidly increasing world's electricity demand. DGs differ with respect to purpose, voltage level, size, technology and others [2]. In general, DG size ranges from some kW to hundreds of MW. It can be classified by micro DG for less than 5 kW; small DG from 5 kW to less than 5 MW; medium DG from 5 MW to less

than 50 MW and finally large distributed generation from 50 MW to less than 300 MW [3]. Based on technology and connection with distribution network, DG can also be classified as reciprocating engines, micro-turbines, combustion gas turbines, fuel cells, photovoltaic systems, small hydro turbines and wind turbines [4]. The main advantageous applications of DG can be summarized as less expensive standby generation instead of grid extension and improving system performance. Besides, DG units using renewable energy resources offer environmentally friendly solutions than the traditional generation by avoiding the large measure of CO<sub>2</sub> emissions. On the other hand, most DG technologies use power electronic converters to manage the ability of these generators. Such converters negatively affect the grid harmonics level that need to be carefully monitored to guarantee the allowable limits and ensure satisfactory operation of the system [5].

Determining the suitable place and size of DG is vital to get greatest benefits from integrating DG with distribution systems. Inappropriate sitting may scale back the advantages and drive to overall poor system performance [6]. Several approaches are proposed and developed in literature to decide the right site and size of DG units achieving one or several goals with or without network reconfiguration. The analytical and improved analytical methodologies for minimizing power loss have been introduced in [6-7]. A power stability index is employed in [8] to decide the more sensitive bus for DG unit placement, and an exploration rule was introduced for getting the optimum size to reduce power loss. Several researchers have also applied different metaheuristic techniques for getting the optimum location and size of DG units. In [9], the genetic algorithm (GA) is primarily used for solving multi-objective optimization for the most effective size and allocation of DG units with multi-system constraints whereas in [10-11], the particle swarm optimization (PSO) has been implemented to select the optimum size and placement of one DG unit. Both GA and PSO are joined in [12] to improve their performance for determining the DG optimum size and placement.

In recent years, there has been an increasing amount of literature on applying very recent developed optimization tools for optimally DG allocation such as cuckoo search, bacterial foraging optimization algorithm, flower pollination algorithm, backtracking search optimization, ant colony optimization and teaching learning-based optimization [13-18]. During most of these optimization approaches, the generation, constraints of bus voltage and branch loading are incorporated in the fitness function as penalty factors to meet a valid solution such that all optimal power flow variables stay within their permissible limits.

In the recent decade, the new Crow Search Algorithm (CSA) is applied in several research studies to get the optimal size and site of DGs [19-23]. The simultaneous optimal placement of DGs and capacitor units in RDS is studied in [20]. Reducing the power loss and improving the voltage profile of the RDS using multiple DGs were the goals of [21, 23], while maximizing the overall saving and reducing the network losses were the main objectives of [22]. Obtaining the optimal size and site of DG and DSTATCOM in practical distribution system, to reduce the distribution system loss, is fully introduced in [19].

In present work; modified CSA is implemented to formulate multi-objective function for getting optimal DG size and allocation. It is applied for single DG or multiple DGs units to reduce the active power losses and improve the voltage profile in RDS. The proposed technique will be tested on IEEE 33-bus test radial system. This paper will be organized as follows: problem formulation is presented in Section 2, while in Section 3 the metaheuristic CSA is introduced with the proposed changes. In Section 4, detailed simulation results are discussed. CSA algorithm and the modified one are compared against some other nature inspired algorithms in Section 5; and finally the conclusions are drawn in Section 6.

## 2. OPTIMAL PLACEMENT AND SIZING PROBLEM FORMULATION

This section will discuss briefly the applied method for load flow analysis while the mathematical formulation of the objective function for optimum DGs placement and sizing will be introduced in details.

### 2.1. Load Flow Analysis

The simple forward-backward sweep method introduced in [24] is applied here to solve the RDS load flow analysis and calculate the overall power loss and bus voltages at all buses. It begins at the end bus and precedes backwards the source node. The convergence is checked using the node voltage calculated in backward sweep. If the obtained voltage has less difference than the convergence criterion, the process will end, but if the voltage does not meet convergence limit, forward sweep begins to compute the voltages at each bus starting from the feeder source bus.

According to the small sample network shown in Figure 1, the current in the branch section line  $I_x$  and the voltage  $V_y$  at node 'y' are computed according to (1), known the load active and reactive powers ( $P_{1x}$ ,  $Q_{1x}$ ) at node 'x' & the branch resistance and reactance ( $R_x$ ,  $X_x$ ) respectively and the voltage  $V_x$  at node 'x'. Real power loss in the branch section connecting nodes x and y is expressed in (2):

$$I_x = \left( \frac{P_{1x} + jQ_{1x}}{V_x} \right) V_y = V_x - I_x(R_x + jX_x) \tag{1}$$

$$P_{\text{loss}(x,y)} = \left( \frac{P_x^2 + Q_x^2}{|V_x|^2} \right) \times R_x \tag{2}$$

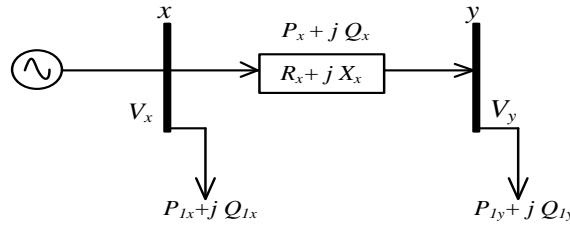


Figure 1. Sampled distribution system for load flow analysis

**2.2. Mathematical Problem Formulation**

**2.2.1 Multi-Objective Approach for Optimal DG Sizing and Placement**

As a matter of fact, the bus voltage of a typical RDS often experiences fluctuations and may collapse under some critical loading conditions with increased load demand. Therefore, the main purpose of the present work is to get the optimal location and size of multiple added DGs in RDS while achieving minimum real network loss and improved voltage profile. Accordingly, the objective function can be divided into two parts: power loss minimization and voltage deviation minimization. These two single objective functions are merged to form a multi-objective optimization problem, whose (OF) is the cost function. As given in (3), the overall multi-objective function is expressed using a linear combination of the two objectives OF<sub>1</sub> and OF<sub>2</sub> via the weighted sum method, where w<sub>1</sub>, w<sub>2</sub> are the weighting factors for OF<sub>1</sub> and OF<sub>2</sub> respectively.

$$OF = w_1 \times OF_1 + w_2 \times OF_2 \tag{3}$$

Assuming that the studied RDS that has a rated network voltage V<sub>rated</sub> (equals 1.0 pu), consists of number of buses equals No\_b and number of branch lines is No\_lines. Each branch j connecting two buses has a branch resistance R<sub>j</sub>, carries a current with the value I<sub>j</sub> and the voltage at the i<sub>th</sub> bus is denoted by V<sub>i</sub>. Therefore the two objectives OF<sub>1</sub> and OF<sub>2</sub> are expressed by (4) and (5). As clearly shown, the total active power loss of the system (P<sub>T\_loss</sub>) can be calculated based on the summation of the power loss in all RDS branches, while the overall voltage deviation (VD<sub>T</sub>) is calculated based on the summation of the square value of bus voltage deviation (VD<sub>i</sub>) at all buses.

$$OF_1 = \text{minimizing total active power loss } (P_{T\_loss}) = \min \sum_{j=1}^{No\_lines} I_j^2 R_j \tag{4}$$

$$OF_2 = \text{minimizing overall voltage deviation } (VD_T) = \min \sum_{i=1}^{No\_b} VD_i = \min \sum_{i=1}^{No\_b} (V_i - V_{rated})^2 \tag{5}$$

In fact, the weighted sum method is applied here to create the Pareto optimal front. This might be noted that each objective functions in (3) is normalized via dividing it by its base value which makes the objective function dimensionless and normalized and that prevents any scaling problem as discussed in [25].

**2.2.2 Constraints**

The applied formulation as a multi-objective function is subjected several constraints: network operating constraints and DG constraints. The operating constraints define the voltage limits at all network buses, line capacity limits of different lines and the active power balance equations as follows:

$$V_{min} \leq V_i \leq V_{max} \text{ for } i = 1 \text{ to } No\_b \tag{6}$$

$$I_j \leq I_{max}(j) \text{ for } j = 1 \text{ to } No\_lines \tag{7}$$

$$P_{\text{supply}} + \sum_{k=1}^N P_{\text{DG},k} = P_{\text{load}} + P_{\text{T,loss}} \quad (8)$$

Where:

$V_{\text{min}}$  and  $V_{\text{max}}$  are the smallest and the greatest allowable voltage  $V_i$  at each bus  $i$ . Such limits are expressed according to [26] by  $\pm 5\%$  of the rated network voltage  $V_{\text{rated}}$  for all network buses.

$I_{\text{max}}(j)$  is the maximum current carrying capacity [26-27], the current  $I_j$  flowing in the line  $j$  should be less than  $I_{\text{max}}(j)$ .

$P_{\text{supply}}$  is the active power supplied by the grid as the original primary source, while  $P_{\text{load}}$  is the total active load of the system.  $P_{\text{DG},k}$  is the active power penetrated by  $k_{\text{th}}$  DG unit for  $N$  no. of DG units.

On the other hand, some constraints about the size of each added DG at  $k_{\text{th}}$  bus ( $P_{\text{DG},k}$ ) and the overall DG penetration should also be considered as follows:

$$P_{\text{DG},\text{min}} \leq P_{\text{DG},k} \leq P_{\text{DG},\text{max}} \quad (9)$$

$$P_{\text{T,DG},\text{min}} \leq \sum_{k=1}^N P_{\text{DG},k} \leq P_{\text{T,DG},\text{max}} \quad (10)$$

Where:

$P_{\text{DG},\text{min}}$  and  $P_{\text{DG},\text{max}}$  denote the minimum and maximum allowed output active power of  $k_{\text{th}}$  DG unit respectively,

$P_{\text{T,DG},\text{min}}$  and  $P_{\text{T,DG},\text{max}}$  are the total minimum and maximum allowed output of all added DG units ( $N$  units), assuming that all DG units generate active power only.

### 2.2.3 Ensuring the voltage THD<sub>v</sub> at All Buses

Distorted currents absorbed by harmonic-producing loads also distort the supply voltage as they pass through system impedance. Therefore, a distorted voltage can be presented to other end users. The power quality industry has developed certain indices to assess service quality related to distortions caused by harmonics. The total harmonic distortion is one of the most commonly used indices for measuring the overall waveform harmonic content taken into account the contribution of all harmonics components [28]. IEEE Std. 519™-2014 is developed for utilities and customers to limit the harmonic content, the boundaries on the

total harmonic distortion on the output voltage ( $\text{THD}_v = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{\text{Fundamental voltage}}$ ) are listed in Table 1 for distribution networks levels.

In the second procedure of the proposed approach, the impact of DGs on harmonics is investigated. The achieved former solution for DGs placement and size is tested to check  $\text{THD}_v$  at all buses by simulating the RDS using Matlab/Simulink where the installed DGs type is assumed inverter-based. When the limits are still confirmed, the achieved solution is accepted. However, if the limits are violated, another solution is selected or inserting a mitigation filter is suggested.

Table 1. Voltage Distortion Limits in Distribution Networks According to IEEE Std. 519™-2014

Bus voltage V at point of common coupling	Individual Harmonic (%)	Total Harmonic Distortion (%)
$V \leq 1.0 \text{ kV}$	5.0	8.0
$1 \text{ kV} < V \leq 69 \text{ kV}$	3.0	5.0

### 3. MODIFIED CROW SEARCH ALGORITHM (CSA) OPTIMIZER

Crow search algorithm is a recent metaheuristic algorithm developed by Askarzadeh [29], inspired on the intelligence behavior conducted by crows of hiding their excess food in a place and get it back when needed. CSA has been applied for different problems with different constraints. As an algorithm based on population, the size of the flock is confirmed by  $N_c$  individuals (crows) which are of  $n$  – dimensional where  $n$  denotes the problem dimensions. Each crow (individual) is assumed to have the capability of remember the best visited location to hide food. The position is then modified according to Pursuit & Evasion behaviors. Pursuit: a crow  $j$  follows crow  $i$  with the purpose to discover its hidden place. The crow  $i$  does not notice the presence of the other crow, as consequence the purpose of crow  $j$  is achieved. Evasion: the crow  $i$  knows about the presence of crow  $j$  and in order to protect its food, crow  $i$  intentionally takes a random trajectory. This behavior is simulated in CSA through the implementation of a random movement. The type of behavior considered by each crow  $i$  is determined by an awareness probability (AP). The flight length (FL) parameter

indicates the magnitude of movement from crow position towards the best position of crow  $j$  [30-31]. In fact, CSA consumes less time than other metaheuristic methods as it has fewer parameters to adjust: AP and FL, so it is easy to be implemented. To offer a good balance between diversification and intensification in CSA, the AP can control both factors. When AP decreases, the algorithm tends to search in local optima therefore, the intensification increases. When AP increases, the algorithm tends to search in global optima therefore, the diversification increases.

In [19-23], the original CSA is applied to get the optimal size and site of DGs where the variable represents the position of the crows in the space is assumed randomly based on lower ( $L_B$ ) and upper ( $U_B$ ) bounds of the variable. A modified CSA is proposed in this article, where the CSA variable is calculated depending on Gaussian and Cauchy density functions [32], which are shown in Figure 2.

- a) The Gaussian function or the normal distribution is defined as a continuous function that approximates exact binomial distribution for the events. It provides probability for some real observations to fall between any two predefined real numbers or limits as the function tends to zero on either side. Its curve resembles the shape of a bell, thus it is informally known as the bell curve. For the mean or expectation of the distribution ( $\mu$ ) and the variance ( $\sigma^2$ ), the probability density of the normal distribution is expressed by  $F(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$ . In paper work, the variance is assumed to be unity (*i.e.*  $\sigma^2=1$ ).
- b) The Cauchy distribution is a continuous probability distribution known as Cauchy–Lorentz distribution or Breit–Wigner distribution. It is expressed by:  $F(x) = \frac{1}{\pi} \frac{t}{t^2+x^2}$  for  $t > 0$  as a scale parameter.

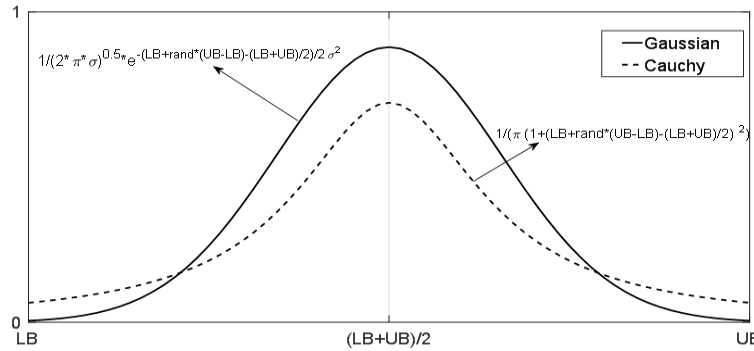


Figure 2. Gaussian and Cauchy distribution functions

In order to check the performance of the modified CSA on larger-scale optimization problems, four well-known benchmark functions, discussed in [33], are solved in 10 dimensions using CSA (original algorithm), CSA-G (based on Gaussian distribution), and CSA-C (based on Cauchy distribution). The obtained results are summarized in Table 2. As shown, CSA-G outperforms the other methods.

Table 2. Performance of Modified CSA for Benchmark Test Functions

Function Name	Function Formulation	Search Space	Optimal Value	CSA	CSA-G	CSA-C
Sphere Function	$\sum_{i=1}^n X_i^2$	[-100,100]	0	9.54 e-13	1.39 e-36	2.69 e-35
Rosenbrock Function	$\sum_{i=1}^n (100(x_{i+1} - X_i^2)^2 + (x_i - 1)^2)$	[-30,30]	0	1.52	0.75	0.77
Griewank function	$\frac{1}{4000} \sum_{i=1}^n (X_i)^2 - \prod_{i=1}^n \cos(\frac{x_i}{\sqrt{i}}) + 1$	[-600,600]	0	0.0099	0.0059	0.229
Schwefel function	$\sum_{i=1}^n  x_i  - \prod_{i=1}^n  x_i $	[-10,10]	0	9.37 e-6	3.29 e-18	1.13 e-17

#### 4. TEST SYSTEM AND SIMULATION RESULTS

The system under study is IEEE 33-bus radial distribution network shown in Figure 3. Without DG installation, it has a total load of 3.72 MW, 2.3 MVAR and real power loss of 211 kW. All system buses are not within the limits  $\pm 5\%$  of the rated network voltage and the least voltage is 0.9037 pu at bus 18 [34].

In this paper, two-procedure based approach is introduced. The first one solves the DG siting and sizing problem as a multi-objective one by improving the voltage profile of RDS and reducing its power loss

as two conflicting functions using a modified CSA-G. Then the solution is checked in the second procedure to ensure accepted  $THD_V$  at all buses. In the following sections, achieved results are introduced. The results for solving optimal DG placement and sizing problem using multi-objective optimization approach are introduced in first part. The impact of DG on  $THD_V$  is investigated in the second one.

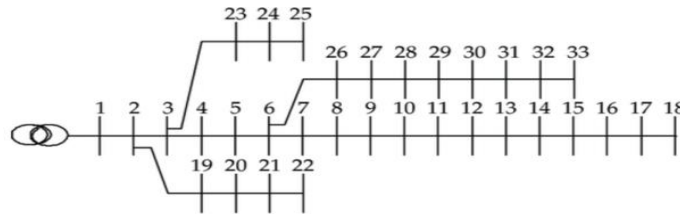


Figure 3. IEEE 33-bus radial distribution network

#### 4.1. Results of Optimal DG Sizing and Placement

Installation of single and multiple DGs are considered in the tests, which ended with a comparative study of all cases.

##### 4.1.1 Case 1: Installing Single DG

In this case, a single DG unit is assumed to be integrated to the 33-bus RDS. By applying different values for weighting factors  $w_1$ ,  $w_2$ , sets of solutions are achieved using CSA-G. Figure 4-a) shows the solutions set or the Pareto front which consists of 10 trade-off solutions (values of  $w_1$ ,  $w_2$ , change from 0.1 to 0.9 with a step of 0.1). The point of intersection of the two curves denotes the compromised solution. The Pareto front for such optimal solution ensures that a DG size of 3114.5 kW can be installed at bus 7 to give the least voltage deviation of 0.02342 pu, and lowest reduction in real power loss from 211 kW without DG installation to 118.5 kW with a reduction of about 43.83% at weighting factors of 0.47 & 0.53.

##### 4.1.2 Case 2: Installing Multiple DG units

In this case, the multi-objective optimization problem is resolved by installing two DG units simultaneously to the tested RDS and three simultaneous DG units. The Pareto front curves using the modified CSA-G are shown in Figure 4-b) and Figure 4-c).

- Point B represents the compromised solution for adding two DG units of size 1344.7 and 1161.3 kW at bus 12 and 30 respectively to provide the minimum voltage deviation at 0.007107 pu, and real power has reduced to 94.18 kW (55.36% reduction without DG installation) at weighting factors 0.52 & 0.48.
- Point C characterizes the compromised solution for adding three DG units of 846.2, 931.6 and 1296.2 kW to be installed at buses 13, 24 and 31. Such sizes ensure the minimum voltage deviation at 0.0066 pu, and reduction of about 62.5% in real power loss (79 kW). The weighting factors  $w_1$ ,  $w_2$  are 0.58 & 0.42 respectively in this case.

From the quick comparison of the Figure 4 graphs, it can be concluded that multiple DG installations will reduce the real power losses more than using a single DG unit and also the voltage deviation is decreased significantly. Actually, the size of the added DGs regarding the reduced loss reduction can be economically evaluated by a simple economical index. Besides, the effect of adding DGs on the voltage of all buses can be assessed using the index of the average voltage deviation.

For further evaluate the proposed changes on CSA, the three compromised solutions A, B and C, are fully summarized for all applied methods of CSA (original CSA, CSA-G, and CSA-C) in Table 3 according to such proposed indices:

$$\text{Economical Index} = \frac{\sum_{k=1}^N P_{DG,k}}{P_{T,loss_{without DG}} - P_{T,loss_{with DG}}} \quad (11)$$

$$\text{Voltage Index (p. u)} = \text{Average deviation per bus} = \sqrt{\frac{\sum_{i=1}^{No_b} (V_{rated} - V_i \text{ with DG})^2}{No_b}} \quad (12)$$

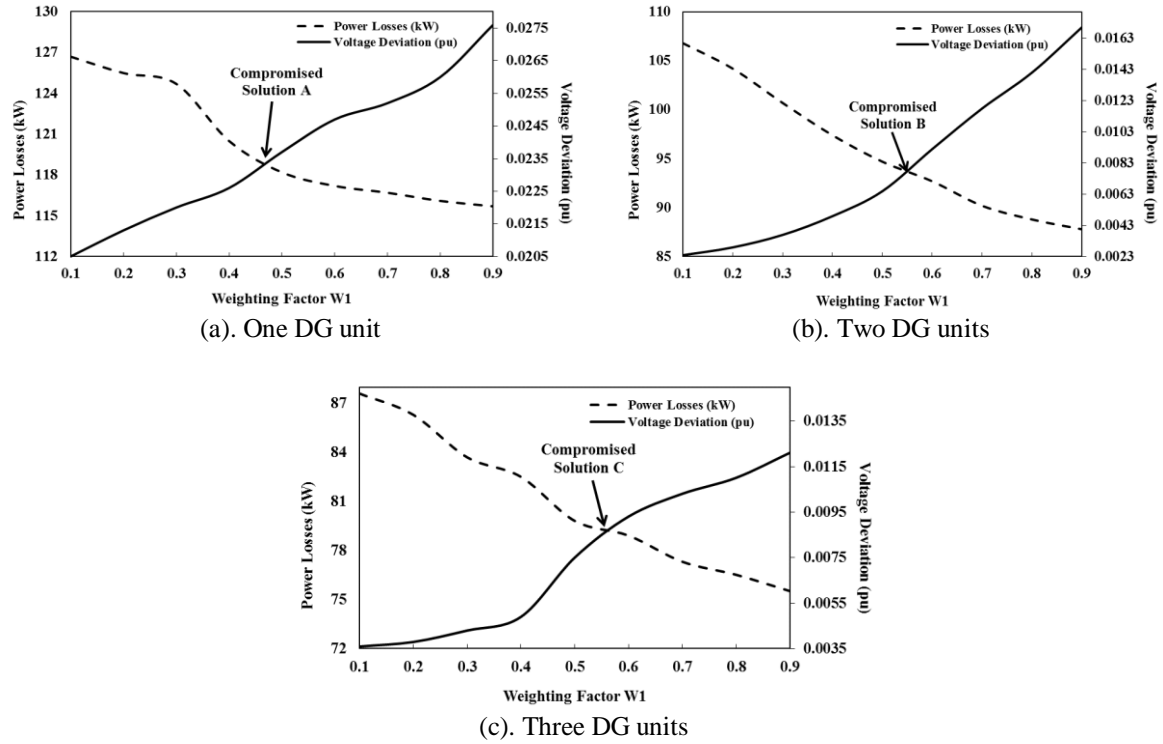


Figure 4. Compromised solutions using modified CSA-G

Table 3. Comparison of the Three Compromised Solutions (A, B And C) for Single and Multiple DG Units

No. of DG units	Applied Algorithm	DG Size (kW)	@ Bus	$w_1, w_2$	$P_{T,loss}$ (kW)	Ec. Index	Voltage Index (pu)	Lowest bus voltage (pu @ bus)
One	CSA	2534.7	8	0.42, 0.58	132.1	32.3	0.022804	0.9532 @ bus 18
	CSA-G	3114.5	7	0.47, 0.53	118.5	33.6	0.02664	0.9534 @ bus 18
	CSA-C	2579.3	6	0.61, 0.39	153.3	44.7	0.02009	0.9534 @ bus 33
Two	CSA	1073.5, 1326.2	16,26	0.48, 0.52	103.9	22.4	0.021105	0.9537 @ bus 33
	CSA-G	1344.7, 1161.3	12,30	0.52, 0.48	94.18	21.45	0.01468	0.9752 @ bus 33
	CSA-C	2494.3, 811.7	28,16	0.35, 0.65	121	36.73	0.00798	0.982 @ bus 25
Three	CSA	1251.3, 1271.9, 611.6	14,24,30	0.38, 0.62	87	25.28	0.01834	0.9601 @ bus 33
	CSA-G	1296.2, 931.6, 846.2	31,24,13	0.58, 0.42	79	23.29	0.01655	0.9736 @ bus 18
	CSA-C	1061.3, 1215.1, 1047.2	14,26,31	0.47, 0.53	99.6	29.83	0.00644	0.9823 @ bus 25

4.2. Results Of Investigating THD<sub>v</sub>

The aim of this section is to investigate the impact of adding the previous optimal calculated DG units to the RDS with the assumption that all added units are inverter-based PV units to get the worst condition of THD<sub>v</sub>. Detailed Simulink model of the studied RDS (IEEE-33 bus) is developed in phasor mode as it calculates the node and the branch voltage representing sinusoidal voltages and currents at a particular frequency. Firstly, the system is simulated without connecting any DG units, and without the presence of any harmonic-producing loads which ensures 0 % for THD<sub>v</sub> as expected at all buses. Then three other scenarios are investigated as illustrated in Figure 5. Such cases represent the three compromised solutions A, B and C using the modified CSA-G:

- a) 1<sup>st</sup> scenario: 3114.5 kW PV unit is connected at bus 7. As shown the voltage at all buses is distorted within the permissible limit.
- b) 2<sup>nd</sup> scenario: 1344.7 kW PV unit is connected at bus 12 and 1164.25 kW PV unit is installed at bus 30; the results ensure that all buses are contaminated with harmonics within the permissible boundaries.
- c) 3<sup>rd</sup> scenario: 1296.2 kW PV unit is added at bus 31, 931.6 kW PV unit is added at bus 24 while 846.2 kW PV unit is connected to bus 13. As illustrated all buses voltage are distorted within accepted limit.

As clearly shown, that the bus where an inverter-based PV system as a DG unit is installed has almost the highest THD<sub>v</sub> in most of the simulated cases. Besides, the distortion on other neighboring buses also increases, which means that neighboring buses are significantly affected; however the actual number of affected buses depends on the location of DG within the RDS. The THD<sub>v</sub> of the worst bus condition in all

studied scenarios results has increased to almost 1.97 % compared with the original case before DG addition, however it is still satisfying the limits of 3% according to the IEEE Std. 519™- 2014. Therefore, the achieved size and place of added DG units for the sake of improving the voltage profile and reducing the overall power system loss are accepted on the power quality issue of injected harmonics.

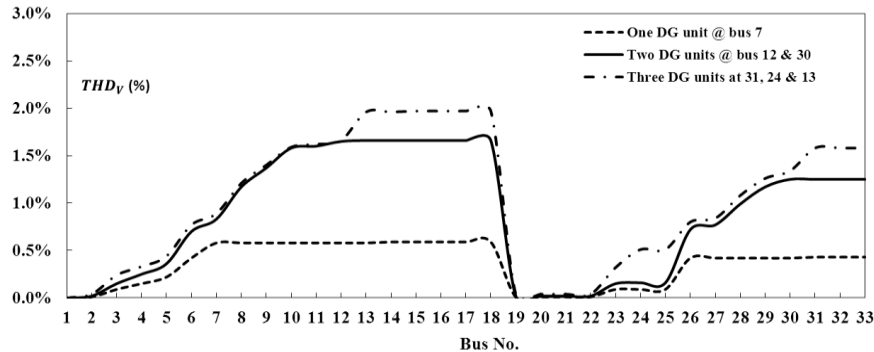


Figure 5. Impact of installing PV-based DGs (based on CSA-G) on  $THD_V$

## 5. EXAMINING PROPOSED MODIFICATION FOR CSA

To confirm the superiority of the proposed CSA-G and CSA-C algorithms over other algorithms in terms of quality of solution, the results of the original CSA algorithm and the modified one are compared against the results offered by other nature-inspired algorithms [35-36]. Such comparison is carried out to meet the goal of simultaneously minimize real power loss and improve voltage profile over IEEE 33 bus system using three DG units. The results are tabulated in Table 4, in which the performance of CSA, CSA-G and CSA-C and are compared with the documented results of PSO in [36], GA in [36], GA-PSO in [36] and TLBO in [35]. From Table 4, it may be noted that the proposed CSA-G offers a minimum value of power loss among all the algorithms referred there in. The voltage deviation obtained by the proposed CSA-G is not better than the original CSA but is better than the GA and PSO variants and the overall voltage profile of the system also gets improved, also CSA-G has the best economical index among all other algorithms.

Table 4. Investigating Modified CSA Performance Over Other Methods

Algorithm Ref.	Optimal DG		Loss reduction evaluation			Voltage improvement	
	Size (MW)	@ Bus	Loss (pu)	Reduction (%)	Ec. Index	Voltage Index (pu)	Lowest bus voltage (pu @ bus)
TLBO in [35]	1.1826, 1.1913, 1.1863	12,28,30	0.1246	40.90%	41.20	0.005773	0.9829 @ bus 25
GA in [36]	1.5, 0.4228, 1.0714	11,29,30	0.1063	49.62%	28.68	0.03511	0.9810 @ bus 25
PSO in [36]	1.1768, 0.9816, 0.8297	8,13,32	0.1053	50.09%	28.26	0.03186	0.9806 @ bus 30
GA-PSO in [36]	0.925, 0.863, 1.2	11,16,32	0.1034	50.99%	27.66	0.01938	0.9808 @ bus 25
CSA	1.251, 1.271, 0.611	14,24,30	0.087	58.76%	25.28	0.01834	0.961 @ bus 33
CSA-G	0.846, 0.931, 1.296	13,24,31	0.079	62.55%	23.29	0.01655	0.9736 @ bus 18
CSA-C	1.061, 1.215, 1.047	14,26,31	0.0996	53.08%	28.83	0.00644	0.9823 @ bus 25

## 6. CONCLUSION

In this paper, a multi-objective optimization was applied to search for the optimal DG sizing and placing. DG is added in distribution networks for improving the voltage profile and reducing system loss keeping the injected harmonics values within accepted limits as a main power quality issue. The optimization problem is formulated from two conflicted goals, the total real power loss and the overall voltage deviation. A weighted sum method is presented to create the Pareto front and get the best compromised solution. The considered optimization problem is solved using modified CSA algorithm based on Gaussian distribution (CSA-G) for IEEE 33-bus radial distribution network in case of adding one or multiple DG units. Proposed economical and voltage indices are applied to check the achieved solutions of single, two or three DG units. A comparative study for CSA and the modified CSA-G and CSA-C for mathematical benchmark test functions depicts the better performance of the proposed CSA-G in terms of accuracy. It ensures that CSA-G is capable of enhancing the original CSA performance. Regarding the optimal DG sizing and location, it can be observed that the proposed method is able to find out the optimal location and size of DG, while, at the



same time, it reduces the real power loss and improves the voltage profile of the system. Upon achieving the compromised solution, the tested system is investigated for satisfying the voltage total harmonic distortion limits when incorporating PV based DG units according to the IEEE Std. 519™- 2014. Besides, the superiority of CSA-G performance is confirmed when compared against some other algorithms, hence, it can be deduced that the proposed CSA-G algorithm is a good choice over the original CSA and other reported algorithms for solving optimization problems.

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