POWER ENGINEERING AND ELECTRICAL ENGINEERING VOLUME: 15 | NUMBER: 5 | 2017 | DECEMBER

A NOVEL MULTI-OBJECTIVE BAT ALGORITHM FOR OPTIMAL PLACEMENT AND SIZING OF DISTRIBUTED GENERATION IN RADIAL DISTRIBUTED SYSTEMS

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DOI: 10.15598/aeee.v15i5.2417

Abstract. *In the few last decades, Distribution Generation (DG) has drawn a great attention by researchers around the world in the field of Radial Distributed Systems (RDSs). Generally, the optimal placement is based on the maximization of the Voltage Stability Index (VSI) and the optimal sizing is based on the minimization of the Total Active Power Losses (TAPLs). Hence, a Multi-Objective Optimization Problem (MOOP) is proposed to achieve the both mentioned objectives. For this purpose, a new simple optimization algorithm known as Bat Algorithm (BA) based on Weight Sum Method (WSM) has been used to resolve the MOOP. Then, the Fuzzy Based (FB) technique is employed to find the Best Compromise Solution. This paper also provides a comparison between the proposed algorithm and other recently published methods. From the obtained results, the advantage of the proposed algorithm is clearly observed from multiple points of view such as enhancement of Voltage Profile (VP), decreasing of the TAPL, and the maximization of the VSI. The investigations have been carried out on a standard IEEE 12-bus, 33-bus, 69-bus, and 85-bus test feeders.*

Keywords

Bat Algorithm, Distributed Generation, Fuzzy Based, Multi-Objective, Power Losses, Radial Distributed System, Voltage Stability Index.

1. Introduction

Nowadays, the Distributed Generations (DGs) are becoming more important in radial distributed systems due to the increase of electrical energy demands [1]. Generally, the DG term refers to the small scale electric power generators (from 1 kW to 50 MW). Generally, the primary sources used in DG units are supplied by renewable energies such as combustion turbine, micro-turbines, fuel cells, micro-hydro turbines, photovoltaic, wind turbines, and other small power sources [2] and [3].

In fact, the radial distribution network has a high R/X ratio mainly in low and medium voltage cable networks. However, known power flow methods such as Gauss-Seidel (GS), Newton Raphson (NR), Fast Decoupled Load Flow (FDLF), etc., are not effective in this case, and may often fail to converge. For this purpose, other algorithms have been proposed to solve this problem. The mostly used algorithm is the Backward Forward Sweep (BFS) technique [4] and [5].

Recently, the employment of DG units in distributed radial networks has drawn a great attention by many researchers around the world due to their effectiveness in power losses reduction, enhancement of voltage stability index, low cost, and the exploitation of renewable energies [6]. For this purpose, different approaches based on classical, and meta-heuristics algorithms have been described in the literature to solve the problem of placement and sizing of DG units. Analytical approach is one of the mostly used algorithms, which was presented in [7] and [8]. The authors in [9] proposed a Grid Search Algorithm (GSA) to reduce the total power losses. Other propositions have also been suggested by many authors [10], [11], [12], [13] and [14] based on meta-heuristics approaches such as Particle Swarm Optimization (PSO), Modified PSO (MPSO), Artificial Bee Colony (ABC), hybrid Ant Colony and Artificial Bee Colony (ACO-ABC) algorithm, and Flower Pollination Algorithm (FPA) in the aim to ensure a high performance of radial distribution networks by minimizing the total power losses and exploitation costs and maximizing VSI. Furthermore, the authors in [15] and [16] have proposed a Strength Pareto Evolutionary Algorithm-II (SPEA-II), and Non-dominated Sorting Genetic Algorithm-II (NSGA-II) for minimizing the power losses and emissions. In [17] and [18] the authors proposed others techniques with several objectives.

In addition, the DG placement and sizing were presented as a MOOP using WSM [10], [11], [12], [13] and [14], which offers practical advantage, such as the computational simplicity. At the same time, the values of weighting factors have a significant impact on the final solution, which is a disadvantage of these methods. Further, the multi-objective evolutionary techniques [15] and [18] were used to solve different optimization problems in power systems due to their ability in finding the global optimum but the complexity of these techniques forces the researchers to find a simple method in order to speed up the convergence.

In this study, an attempt has been made to find the optimal location and sizing of DG unit in radial distribution network using a powerful optimization technique known as the Multi Objective Bat Algorithm (MOBA). To validate the proposed approach, it has been applied to several real networks such as 12-bus, 33-bus, 69-bus, and 85-bus test systems. The obtained results have been analysed and compared with recently published papers.

The rest of this paper is briefly summarized as follows: Sec. 2. and Sec. 3. present the description, the problem formulation, and Multi-Objective Optimal Placement and Sizing of Distributed Generation (MO-OPSDG). In Sec. 4. , the MOBA algorithm is described. The step-by-step procedure for the implementation of the MOBA algorithm is given in Sec. 5. Then, the obtained results are presented. Finally, we conclude the paper.

2. Problem Formulation

2.1. Objective Functions

The main object of optimization is to determine the best location and size of Distributed Generation (DG) units with total active power losses minimized, and voltage stability index in radial distribution networks maximized. In this part, the objective functions and constraints are explained.

1) Minimize the Active Power Losses

Power losses influence distribution system due to the drop of power efficiency represented by the resistance, and the reactance of lines and transformers. The line losses between the receiving and sending end buses denoted as $P_{\text{loss}}(i)$ can be formulated as follows [19]:

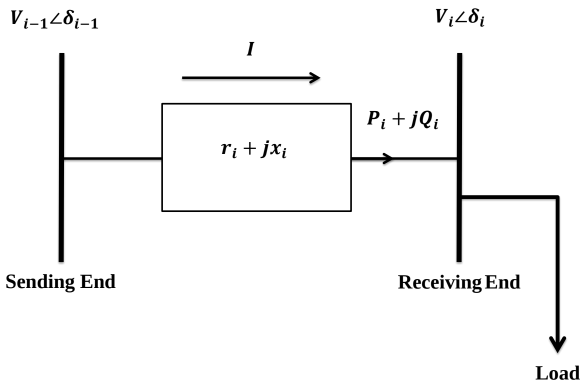


Fig. 1: A two-bus system one line diagrams.

$$P_{\text{loss}}(i) = R_i \frac{(P_i^2 + Q_i^2)}{V_i^2}. \tag{1}$$

The first objective function of the optimal location and size of DG in the radial network problem is to minimize the system power loss. Mathematically, the objective function can be formulated as:

$$H_1 = \sum_{i=2}^{N_{\text{bus}}} P_{\text{loss}}(i) = \sum_{i=2}^{N_{\text{bus}}} R_i \frac{(P_i^2 + Q_i^2)}{V_i^2}, \tag{2}$$

where V_i and δ_i are the voltage magnitude and angle at each bus, respectively; $(R_i + jX_i)$ is the impedance of the line between buses $i-1$ and i; P_i, Q_i are the active (resp. reactive) power injections at the same bus; N_{bus} is the number of buses.

2) Voltage Stability index

The voltage Stability Index (SI) is one of the most important indices that contribute to the security of the network. The installation of the DG units in the distribution system have a great positive influence on the voltage stability index. This has profound implications on distribution system planning practices.

M. Charkravorty et. al in [20] have proposed a new steady state (SI index) for determining the most sensitive node to voltage collapse. The value of voltage Stability Index (SI) is given by Eq. (3).

$$\begin{aligned} SI_i = V_{i-1}^4 - 4(P_i X_i - Q_i R_i)^2 - \\ -4(P_i R_i + Q_i X_i)^2 \cdot V_{i-1}^2 \geq 0. \end{aligned} \tag{3}$$

During the work of the system in the secure and stable range, the value of SI should be greater than zero for all buses $(i = 2, 3, \ldots, N_{bus})$ (The substation bus, and the *SI* is considered as 1 for it), and to avoid the possibility of voltage collapse, the voltage stability index *SI* of all buses should become closer to one. In the proposed algorithm, *SI* value is calculated for each bus in the network, and for the bus having the lowest value of *SI*, it will be considered in the second fitness function.

$$H_2 = \frac{1}{1 + SI_{\min}}, \tag{4}$$

where $SI_{\min}$ is the minimum *SI* value of all the buses.

2.2. Constraints

1) Equality Constraints

Equality constraints are power balance (active and reactive) constraints and include two nonlinear recursive power flow equations. Mathematically, the power flow equations corresponding to both active, and reactive power balance equations are defined as follows [21]:

$$\begin{cases} P_i = V_i \sum\limits_{j=1}^{N_{\text{bus}}} V_j \cdot Y_{ij} \cdot \\ \cdot \cos(\theta_{ij} + \delta_j - \delta_i) \\ Q_i = V_i \sum\limits_{j=1}^{N_{\text{bus}}} V_j \cdot Y_{ij} \cdot \\ \cdot \sin(\theta_{ij} + \delta_j - \delta_i) \end{cases} \quad i = 1, 2, 3, \ldots, N_{\text{bus}}, \tag{5}$$

where P_i and Q_i are the active and reactive power at bus i , Y_{ii} and Θ_{ij} are the admittance magnitude (resp. angle) of branch connecting bus i and j.

Also, the injection active and reactive power produced from the DG unit at the buses of any distribution systems can be expressed as follows:

$$\begin{cases} P_i = P_{Gi} - P_{Di} \\ Q_i = Q_{Gi} - Q_{Di} \end{cases} \quad i = 1, 2, 3, \ldots, N_{\text{bus}}, \tag{6}$$

where P_{Gi} and Q_{Gi} are the active (resp. reactive) power generated at the each bus; P_{Di} and Q_{Di} are the active and reactive load demand at the every bus, respectively.

2) Inequality Constraints

During the optimization process, the objective function is subjected to main constraints in the proposed methodologies, which are:

- **Voltage constraint:** the voltage magnitude of every bus should be conserved within the specified limits as follows:

$$V_{\min} \le V \le V_{\max}, \tag{7}$$

  where $V_{\min}$, $V_{\max}$ are the lower and upper limits of bus voltage, respectively.

- **Active power losses constraint:** the losses after installing DG in power grid should be less than or equal to losses before installing DG.

$$PL \text{ with } DG \le PL \text{ without } DG. \tag{8}$$

- **Distributed generation size constraint:** To obtain a reasonable solution, the power generated by each DG unit must be less than the total active load of the system. Mathematically, this constraint is defined as follows:

$$0 \le \text{size of } DG(P_{DG}) \le \sum_{i=1}^{N_{\text{bus}}} P_{Di}, \tag{9}$$

  where P_{Di} is the active load demand at the same bus.

3. Multi Objective Optimal Placement and Sizing of Distributed Generation (MO-OPSDG)

Many various techniques are available and usable to solve multi-objective optimization problems such as weighted sum approach [22], e-constraint method [23] and evolutionary algorithms [24]. In this paper, the proposed Multi-Mbjective model of the (MO-OPSDG) is solved using the weighted sum technique. In this last technique, different weights are used for the conflicting aim functions to generate different Pareto optimal solutions, and then the different weights selected based on he most satisfying solution from the optimal Pareto set. In the weighted sum technique, the problem is resolved as follows:

$$\text{Min}(H) = w_1 H_1 + w_2 H_2, \tag{10}$$

$$\text{Min}(\sum_{i=1}^{m} w_i H_i) = w_1 H_1 + w_2 H_2, \tag{11}$$

where

$$w_1 + w_2 = 1. \tag{12}$$

- **Fuzzy modeling for normalizing objective functions:** since the aim functions H_1 and H_2 are not in the same dimension and domain, a fuzzy satisfying method is proposed to calculate the normalized form of the objective functions in Eq. (13). The fuzzy membership of each objective H_i is normalized as follows [25]:

  In Eq. (13) k is the index of Pareto optimal solutions, m is the index of objective functions, D is the set of Pareto optimal solutions. In this paper

$$H_{m,pu}^{(k)} = \begin{cases} 1 & H_{\mathrm{m}}^{(k)} \leq H_{\mathrm{m}}^{\min} \\ \dfrac{H_{\mathrm{m}}^{\max} - H_{\mathrm{m}}^{(k)}}{H_{\mathrm{m}}^{\max} - H_{\mathrm{m}}^{\min}} & H_{\mathrm{m}}^{\max} \leq H_{\mathrm{m}}^{(k)} \leq H_{\mathrm{m}}^{\max} \\ 0 & H_{\mathrm{m}}^{(k)} \geq H_{\mathrm{m}}^{\max} \end{cases} \quad \begin{matrix} \forall m = 1, 2, \ldots, n, \\ \forall k = 1, 2, \ldots, D. \end{matrix} \tag{13}$$

for objective functions Eq. (2) and Eq. (4), a fuzzy membership function is expressed as follows:

$$P_{loss_{pu}} = H_{1 \cdot pu} = \frac{P_{\mathrm{loss}}^{\max} - P_{\mathrm{loss}}}{P_{\mathrm{loss}}^{\max} - P_{\mathrm{loss}}^{\min}}, \tag{14}$$

$$SI_{pu} = H_{2 \cdot pu} = \frac{SI^{\max} - SI}{SI^{\max} - SI^{\min}}, \tag{15}$$

After running the MO-OPSDG for different values of weighting factors to select the best compromising solution, fuzzy satisfying method based on logistic membership function is used. After normalization, the best solution of objective functions is obtained by using membership function as follows:

$$BCS = \mathrm{Max}_k(\mu^k) = \\ = \mathrm{Max}_k \left(\frac{P_{\mathrm{loss}\,pu}^{(k)} + SI_{pu}^{(k)}}{\sum\limits_{k=1}^{D} P_{\mathrm{loss}\,pu}^{(k)} + \sum\limits_{k=1}^{D} SI_{pu}^{(k)}} \right). \tag{16}$$

4. Proposed Algorithm

Bat Algorithm (BA) or bat-inspired algorithms is a nature inspired meta-heuristic algorithm. It was recently developed by Yang in [26]. This algorithm is based on the behavior of bats and their special technique that's called echolocation, which is used by bats to identify and locate prey and to avoid barriers when flying. When using echolocation, bats emit a series of high-frequency signals, which are usually in the area of 25 kHz to 150 kHz; all this happens within a few thousandths of a second and does not exceed 10 ms [27]. These bats emit a pulse and listen for the echo that bounces back from surrounding objects. Bat algorithm is developed by idealizing some of the echolocation characteristics of bats. The approximated or idealized rules are:

- All bats employ echolocation technique to sense distance, as well as they also recognize and distinguish the difference between prey/food and background barriers by some magical method.
- Bats randomly fly with velocity v_i at position x_i and generate sound pulses with a constant frequency f_{min}, varying wavelength λ and loudness A_0 to seek for prey. They can habitually regulate the wavelength (or frequency) of their emitted pulses and regulate the rate of pulse emission $r \in [0, 1]$, based on the proximity of their target.
- While the loudness can vary in many ways, we assume that the loudness change from a high (positive) A_0 to a least constant value A_{min}.

4.1. Population

The initial population is a number of virtual bats for $BA(n)$ that is generated randomly. The number of bats should be anywhere between 10 and 40 and after finding the initial fitness of the population for given objective function the values are updated based on movement, loudness, and pulse rate.

4.2. Movement of Virtual Bats

One must identify for every bat i its frequency f_i and the velocity v_i in a d-dimensional search space. Both can be calculated as follows:

$$f_i = f_{\mathrm{min}} + (f_{\mathrm{max}} - f_{\mathrm{min}}) \cdot \beta, \tag{17}$$

$$v_i^k = v_i^{k-1} + (v_i^k - v_{\mathrm{best}}) \cdot f_i, \tag{18}$$

where f_{min} is the minimum frequency, f_{max} is the maximum frequency, and β is normally distributed random number to generate different frequencies in the interval $[0, 1]$. v_i^k is the velocity of the bat i at the iteration k, v_i^{k-1} is the velocity of the bat i at the iteration $k-1$, x_i^k is the position of the bat i at the iteration k and x_{best} is the best solution (position), which is located after comparing all the solutions among all the n bats at each iteration k. A new position of the bat x_i^k is calculated with the new velocity v_i^k and the previous position x_i^{k-1} at time step k:

$$x_i^k = x_i^{k-1} + v_i^k. \tag{19}$$

For the local search part, once solution is selected among the current best solutions, a new solution for every bat is locally generated using random walk.

$$x_{\mathrm{new}} = x_{\mathrm{old}} + \epsilon A^t, \tag{20}$$

where $\epsilon \in [-1, 1]$ is a random number. While A^t is the average loudness of all the bats at this time step.

4.3. Loudness and Pulse Emission

The loudness A_i and the rate of pulse emission r_i are updated accordingly as the iterations proceed. The loudness decreases and the rate of pulse emission increases as the bat closes to its prey, the equations for convergence can be taken as:

$$A_i^{k+1} = \alpha A_i^k, \;\; r_i^k = r_i^0[1 - \exp(-\omega k)], \qquad (21)$$

where α and ω are constants. For any $0 < \alpha < 1$ and $\omega > 0$, we have:

$$A_i^k \to 0, \;\; r_i^k \to 0, \;\; \text{as} \;\; k \to 0. \qquad (22)$$

5. Application of the Proposed MOBA to the Problem

The optimal placement and sizing of DG unit is considered in this study as an optimization problem and is solved by using the MOBA technique. Its corresponding steps are summarized as follows:

- **Step 1:** First, read the system data inputs (load data, line data, and network topology).
- **Step 2:** Select the lower and upper bounds limit for the parameter to be tuned, determine the MOBA settings such as pulse frequency, pulse rates, loudness, and the maximum number of iterations.
- **Step 3:** Generate the initial bat population randomly in the feasible range. Each bat indicates a promising optimal location and size for the DG unit in the distribution network.
- **Step 4:** Evaluate the fitness function. In this step, the expected value of the total active power losses and the voltage stability index of the objective function can be calculated by using BFS approach for each solution or bat.
- **Step 5:** Choose the better bat in the population (minimum TAPL value and the maximum of VSI).
- **Step 6:** Update frequency, velocity and locations of bats using Eq. (17), Eq. (18) and Eq. (19).
- **Step 7:** Run the load flow and determine the total active power loss and the voltage stability index with the updated population.
- **Step 8:** Check the stopping criterion. The stopping criterion can be the maximum number of iterations to update the Bat Algorithm population or a specific value which should be reached by the objective function. If it is satisfied then proceed to step no 9 otherwise return the step no 3.
- **Step 9:** Finally, choose the best compromise solution BCS using fuzzy set theory.

Tab. 1: Pareto optimal solution of MOBA for 33-bus system.

#	$\mathbf{w_1}$	$\mathbf{w_2}$	$\mathbf{H_1}$	**H2**	$\mathbf{H_{1,pu}}$	$\mathbf{H_{2,pu}}$	$\mu^{\mathbf{k}}$
1	0	1	0.1110	0.5591	1	0	0.0384
2	0.05	0.95	0.1110	0.5587	0.9999	0.0157	0.0390
3	0.1	0.9	0.1111	0.5582	0.9995	0.0331	0.0396
4	0.15	0.85	0.1112	0.5577	0.9987	0.0525	0.0404
5	0.2	0.8	0.1113	0.5571	0.9974	0.0743	0.0412
6	0.25	0.75	0.1115	0.5564	0.9954	0.0990	0.0420
7	0.3	0.7	0.1118	0.5557	0.9924	0.1271	0.0430
8	0.35	0.65	0.1122	0.5548	0.988	0.1595	0.0441
9	0.4	0.6	0.1128	0.5538	0.9816	0.1972	0.0453
10	0.45	0.55	0.1148	0.5511	0.9609	0.2965	0.0483
11	0.5	0.5	0.1161	0.5496	0.9468	0.3519	0.0499
12	0.55	0.45	0.1181	0.5478	0.9258	0.4191	0.0516
13	0.6	0.4	0.1212	0.5456	0.894	0.5025	0.0536
14	0.65	0.35	0.1260	0.5428	0.8442	0.6084	0.0558
15	0.7	0.3	0.1338	0.5390	0.7625	0.7477	0.0580
16	0.75	0.25	0.1352	0.5384	0.7477	0.7700	0.0583
17	0.8	0.2	0.1352	0.5384	0.7477	0.7700	0.0583
18	0.85	0.15	0.1352	0.5384	0.7477	0.7700	0.0583
19	0.9	0.1	0.1352	0.5384	0.7477	0.7700	0.0583
20	0.95	0.05	0.2068	0.5323	0	1.0000	0.0384
21	1	0	0.2068	0.5323	0	1.0000	0.0384

6. Results and Discussion

In this section, the proposed MOBA algorithm has been tested on 12-bus, 33-bus, 69-bus, and 85-bus [28], [29] and [30] radial distribution systems.

In these all test feeders, the values of weight are considered in the MO-OPSDG problem. The both TAPL and VSI are considered as conflicting objective functions simultaneously.

In order to solve the MO-OPSDG problem by WSM, we take as an example the 33 test feeder. The maximum and minimum values of the expected total real power loss (i.e. H_1 - maximum and minimum) and voltage stability index (i.e. H_2 - maximum and minimum) are calculated, which are 0.2068 MW, 0.1110 MW, 0.5591 and 0.5323, respectively. Table 1 shows the values of both objective functions for all 21 Pareto optimal solutions.

As explained in Sec. 3. , in order to select the BCS from the obtained Pareto optimal set, a fuzzy satisfying method is utilized here. It is clearly observed from the last column of Tab. 1 that the BCS is Solution#16, with the maximum value of μk (0.0583). The corresponding TAPL and SI are equal to 0.1352 MW and 0.8573, respectively. Correspondingly, the Pareto optimal front of the two objective functions is depicted in Fig. 3. In this figure, the optimal compromise solution (i.e. Solution#16) is also referred.

The DG unit localization, corresponding size, total active power losses, and stability index have been calculated for all different radial distribution test systems considering two cases:

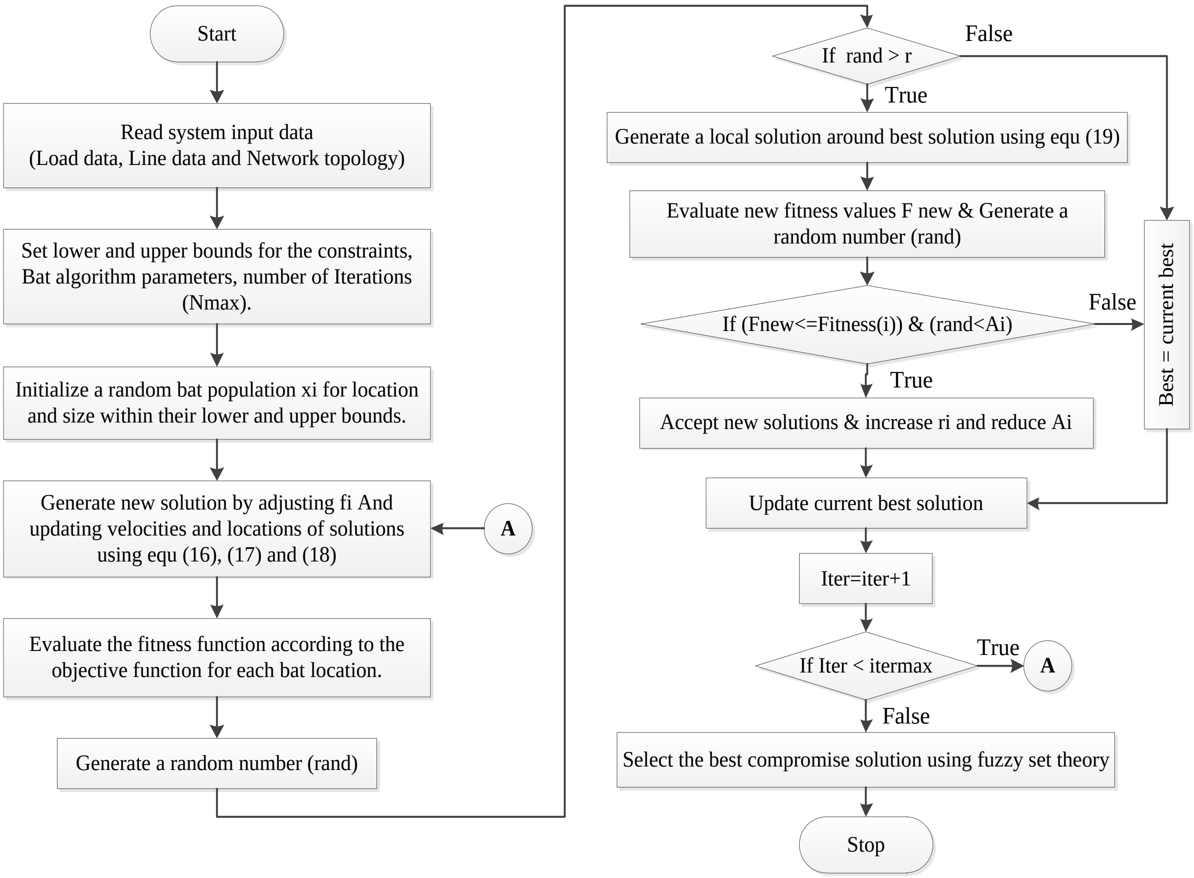


Fig. 2: MOBA flowchart for DG unit placement and sizing.

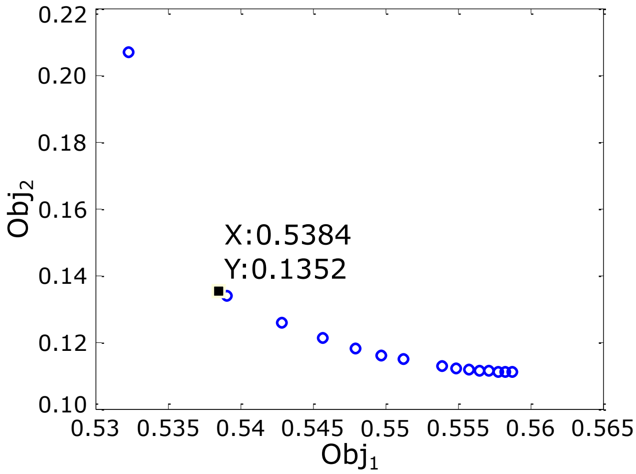


Fig. 3: Pareto optimal front for the IEEE 33-bus test system.

- **Case 1:** without presence of the DG unit.
- **Case 2:** with presence of the DG unit using the proposed MOBA algorithm.

The same parameters (values) given in Tab. 2 using Analytical method [7], Particle Swarm Optimization (PSO) algorithm [11] and Non-dominated Sorting Genetic Algorithm-II (NSGA II) [16] are tabulated in Tab. 3 and Tab. 4. Table 5 describes the comparative results of Total Line Losses Reduction (TLLR), Voltage Profile Improvement (VPI), Bus Voltage Stability Improvement (BVSI), and System Loadability Improvement (SLI) for both existing and proposed methods. The proposed MOBA approach is conducted under MATLAB environment, which is running on Intel Core 2 Duo (2.93 GHz, 2 GB of main memory).

From Tab. 1, it can be observed from the comparison of columns (2) and (7) that the TAPL of all test systems have been significantly reduced after the installation of the DG unit (from 20.69 kW to 13.66 kW in the case of 12 bus, from 211 kW to 135 kW in the case of 33 bus, from 225 kW to 88.48 kW in case of 69 bus and from 316.12 kW to 188.32 kW in the case of 85 bus).

In addition, it can be seen that the VSI is enhanced after the best localization of DG unit. This allows the addition of extra loads without suffering from the problem of voltage collapse.

From Fig. 4(a), Fig. 4(b), Fig. 4(c) and Fig. 4(d), it is clearly observed that the Voltage Profile (VP) in all test feeders has been improved in the presence of DG

Tab. 2: Results obtained by proposed method for different systems.

Test System	**Without DG**				**Proposed method**					
	$V_{\min}$	$SI_{\min}$	**Real Power Loss (kW)**	**System loadability**	**Optimal Bus**	**Optimal Size (MVA)**	$V_{\min}$	$SI_{\min}$	**Real Power Loss (kW)**	**Sys. load.**
12-bus	0.9434	0.7920	20.69	5.30	8	0.4350	0.9956	0.9827	13.66	6.08
33-bus	0.8825	0.6672	211.00	3.40	7	3.7150	0.9622	0.8573	135.20	3.88
69-bus	0.9038	0.6833	225.00	3.20	61	2.6598	0.9728	0.8955	103.75	4.24
85-bus	0.9092	0.5764	316.12	2.54	25	2.4718	0.9402	0.7814	180.77	2.96

Tab. 3: Application of Analytical Method, PSO and NSGA II for DG placement and sizing.

Test System	**Analytical method [7]**		**PSO [11]**		**NSGA II [16]**	
	Optimal Bus	**Optimal Size (MVA)**	**Optimal Bus**	**Optimal Size (MVA)**	**Optimal Bus**	**Optimal Size (MVA)**
12-bus	9	0.22715	9	0.2539	8	0.43500
33-bus	6	2.49078	7	2.8951	7	3.71499
69-bus	61	1.80782	61	2.0264	61	2.66380
85-bus	8	2.20886	-	-	25	2.48451

Tab. 4: Influence of DG placement on system performance using Analytical method, PSO and NSGA II.

Test System	**Analytical method [7]**				**PSO [11]**				**NSGA II [16]**			
	$V_{\min}$	$SI_{\min}$	**Real Power Loss (kW)**	**Sys. load.**	$V_{\min}$	$SI_{\min}$	**Real Power Loss (kW)**	**Sys. load.**	$V_{\min}$	$SI_{\min}$	**Real Power Loss (kW)**	**Sys. load.**
12-bus	0.9823	0.9311	10.77	5.93	0.9850	0.9413	10.82	6.03	0.9956	0.9827	13.66	6.08
33-bus	0.9410	0.7839	111.17	3.38	0.9501	0.8149	114.89	3.78	0.9622	0.8573	135.20	3.88
69-bus	0.9679	0.8778	83.37	3.73	0.9692	0.8824	84.04	4.03	0.9728	0.8956	103.96	4.24
85-bus	0.9245	0.7306	176.13	3.93	-	-	-	-	0.9405	0.7825	180.98	2.96

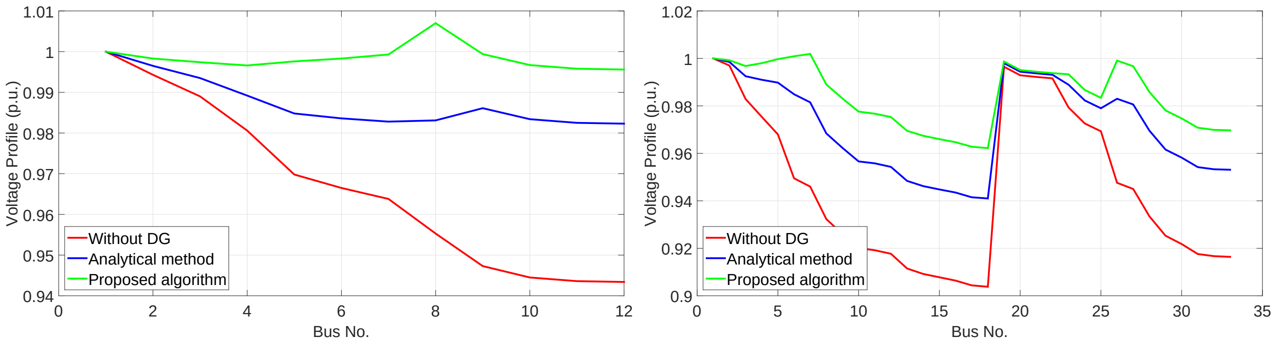
Tab. 5: Performance analysis of existing and proposed algorithms after installation of DG unit on different systems.

Test System		**LLR %**	**VPI %**	**BVSI %**	**SLI %**
12-bus	Analytical method [7]	47.95	2.15	8.66	11.7
	PSO [11]	47.7	2.39	9.68	13.77
	NSGA II [16]	33.97	3.31	13.64	14.72
	Proposed method	33.98	3.31	13.64	14.72
33-bus	Analytical method [7]	47.31	2.72	10.82	8.82
	PSO [11]	45.55	3.27	13.11	11.18
	NSGA II [16]	35.92	4.12	16.83	14.12
	Proposed method	35.92	4.12	16.83	14.12
69-bus	Analytical method [7]	62.95	1.39	5.29	22.5
	PSO [11]	62.65	1.54	5.92	25.94
	NSGA II [16]	53.80	1.98	7.74	32.5
	Proposed method	53.88	1.98	7.73	32.5
85-bus	Analytical method [7]	44.28	6.88	20.23	13.39
	PSO [11]	-	-	-	-
	NSGA II [16]	42.75	5.84	24.56	16.54
	Proposed method	42.82	5.82	24.44	16.54

unit especially in the case of our proposed MOBA approach. Nonetheless, all buses voltages are positioned to be within the acceptable boundaries. The minimum value of voltage is listed in columns (2 and 8) of Tab. 3 and columns (2, 6 and 10) of Tab. 5. From Tab. 5, it is clear that the performance of the proposed algorithm is found either equivalent or better compared to the existing methods in terms of quality of solutions.

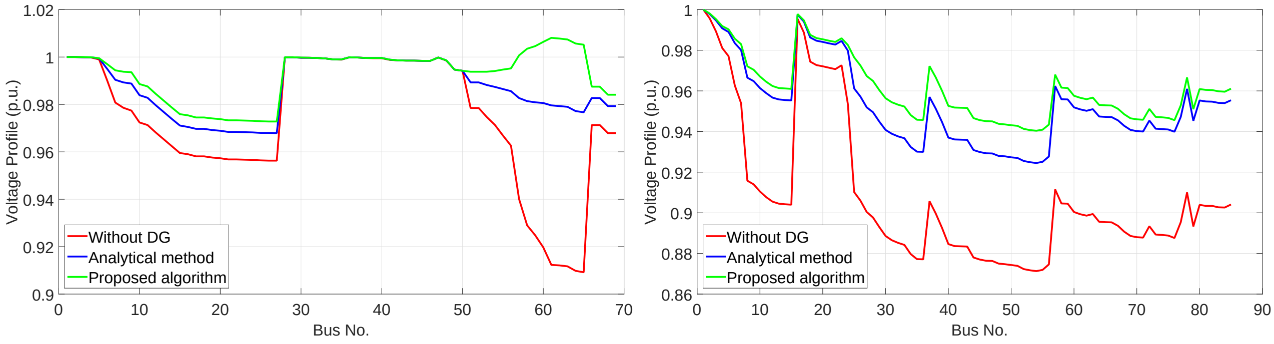
The VSI of all test feeders before and after DG installation is given in Fig. 5. It can be observed from this figure that the weakness of VSI for all buses in the distribution system before installing DG unit is clear.

However, after installing DG unit, the VSI at the buses for distribution systems are considerably improved. The results presented in Tab. 2, Tab. 4 and Tab. 5 indicate that the proposed algorithm is found either equivalent or better in performance than other existing methods in terms of minimum value of VSI and BVSI.



(a) 12-Bus System.

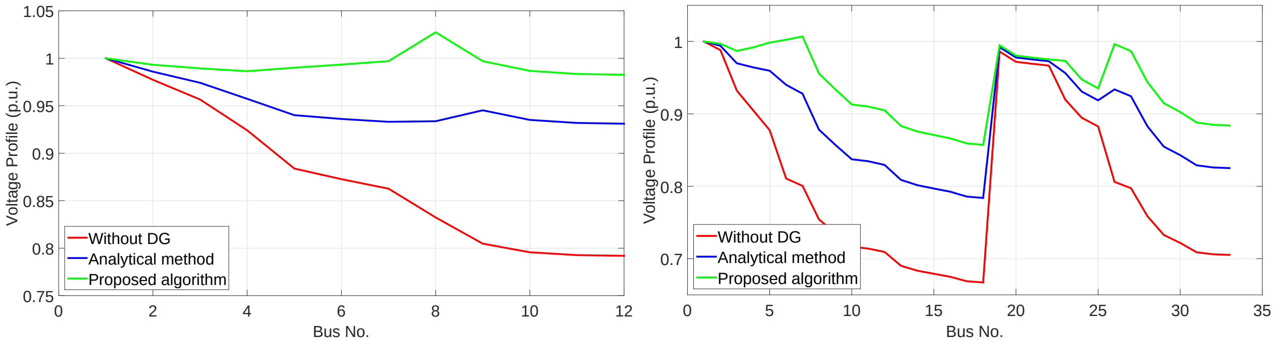
(b) 33-Bus System.



(c) 69-Bus System.

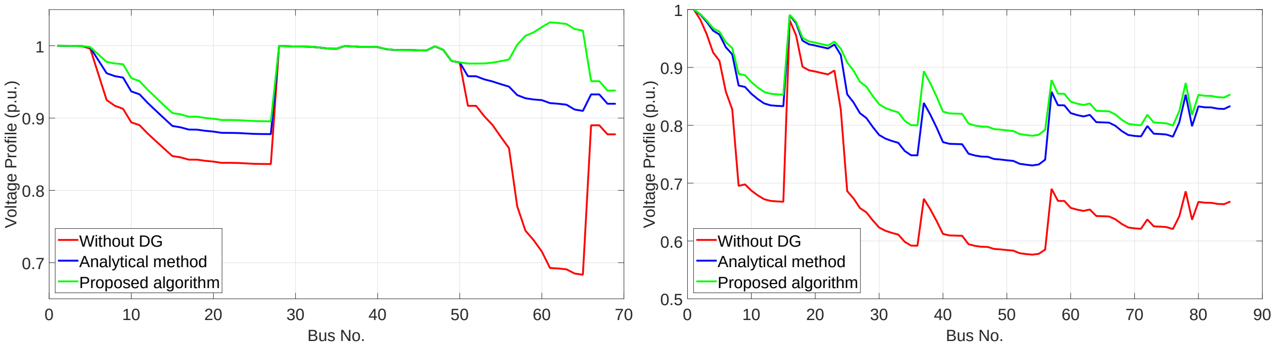
(d) 85-Bus System.

Fig. 4: Voltage profile of radial distribution systems without and with DG using different algorithms.



(a) 12-Bus System.

(b) 33-Bus System.



(c) 69-Bus System.

(d) 85-Bus System.

Fig. 5: Comparison of Bus Voltage Stability Index (SI) using different DG placement algorithms.

It is evident from the last column of Tab. 5 that using the proposed algorithm, system loadability has been significantly improved in all test cases, due to the installation of DG at the best location and of optimum size.

7. Conclusion

This paper has provided a novel MOOP to determine the optimum DG placement and sizing in DRS, considering maximization of VSI and minimization of TAPL together. The Multi-Objective Bat Algorithm has been used to solve this problem. The proposed algorithm is tested on several standard IEEE test systems such as 12-bus, 33-bus, 69-bus, and 85-bus. From the obtained results, it is observed that the best localization and sizing of DG unit give more flexibility to the network and aid to enhance the power system behavior.

A numerical simulation including comparative studies was presented to demonstrate the performance and applicability of the proposed method. The simulation results reveal the superiority of the proposed technique and confirm its potential to enhance the VSI, increase the TAPL and improve the VP and the system loadability for all test feeders.

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