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A new optimal allocation of DGs in distribution networks by using coot bird optimization method

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Abstract

Energy is one of the most important topics in the world today and is considered as one of the most effective factors for the development of countries. Due to the limitation of non-renewable energy sources and undesirable effects of consuming these resources on the environment, the strategy of countries has changed towards the use of renewable energy. Renewable energy sources do not decrease over time and operate independently of price fluctuations and are more available, thus being able to play a greater role in modern power systems. Therefore, the optimal location and use of these resources will have an impact on modifying the parameters of the power grid. In this paper an analytical approach for optimal placement and sizing of distributed generation (DG) in power distribution networks to minimize the power loss, bus voltage limits, DG capacity limits, current limits, and DG penetration limit. In the first step, determines the DG capacity causing maximum benefit at different buses, and then selects the best location for DG placement which corresponds to highest benefit in the buses. This method is applicable for sizing and siting of single as well as multiple DG units. The coot bird optimization method (CBOM) is proposed for solving optimal placement, size, and power factor (PF) of DG in distribution network. The suggested method is tested on the IEEE 33-bus, 69-bus, Distribution Networks. The proposed CBOM method has good performance to find optimal placement, size, and PF of DG and it can be applied for various distribution system.

Keywords: Distributed generation, Optimal placement, Coot bird optimization method, Power loss, Distribution system

Introduction

Power electric is one of the types of energy that is considered more due to its easy of conversion, and use, low risk and also environmental considerations. Electricity as a source of energy required by various economic sectors on the one hand as an indicator of social welfare on the other hand is considered as the levers of development and the issue of price and cost is of special importance for different economic sectors.

The use of cheap and affordable energy is one of the most important issues in the world today. With the growing population of the world and limited energy resources, all countries are facing energy problems. In recent years, reason to a phenomenon called energy crisis energy has become very important. This means that economic agents are always looking for cheaper factors with higher efficiency, lower costs and efforts to improve technology to reduce consumption, and to focus on energy issues and reach a long-term horizon to reform the structure of energy consumption. Therefore, renewable energy sources are considered as one of the priority options to reduce costs and reduce emissions from fossil fuels. These sources are in small powers with a few kilowatts and large resources with megawatts and can be connected directly to the distribution network or customer.

The benefits of DG sources are numerous, some of which include reducing power losses, improving power quality, modifying voltage profile specifications, reducing operating costs, reducing environmental pollution, etc., which are divided into three categories according to Fig. 1 (Balu and Mukherjee 2021).

The main problem in finding the optimal location and size of DG units in the distribution system depends on the performance of the power grid and the limitations of DG performance and investment constraints. In addition to the optimal choice of installation location, the desired amount of DG units will also have a great impact on the parameters of voltage, line current and even network power losses.

In general, there are two techniques for optimal locating and size of DG units (Memarzadeh and Keynia 2020), which are: The 53 first methods based on optimization (El-Fergany 2015; Ali et al. 2017; Wang et al. 2014; Singh et al. 2020; ChithraDevi et al. 2017; Abdelaziz et al. 2015; Galgali et al. 2021; Ismael et al. 2018; Diaaeldin et al. 2019; Manna and Goswami 2020; Kumar et al. 2020; Huy et al. 2020; García and Mena 2013). For example, Ali et al. (2017) proposed Ant Lion Optimization Method (ALOA) for optimal location and sizing of DG based renewable sources for various Distribution Networks. The backtracking Search Optimization Method (BSOA) is proposed for assigning distribution of generators (DGs) along with radial distribution networks (El-Fergany 2015). The objective functions are reducing the actual network losses and increase the voltage profile. Wang et al. (2014) proposed a mixed-integer program (MIP) approach for microgrid planning to decide optimal locations, sizes and mix of dispatchable and intermittent DG. Singh et al. (2020) proposed hybrid elephant herding and particle swarm optimizations for optimal DG integration in distribution networks. ChithraDevi et al. (2017) proposed Stud Krill herd Method (SKHA) for optimal placement and sizing of DG in radial distribution system. Abdelaziz et al. (2015) proposed big bang-big crunch method for

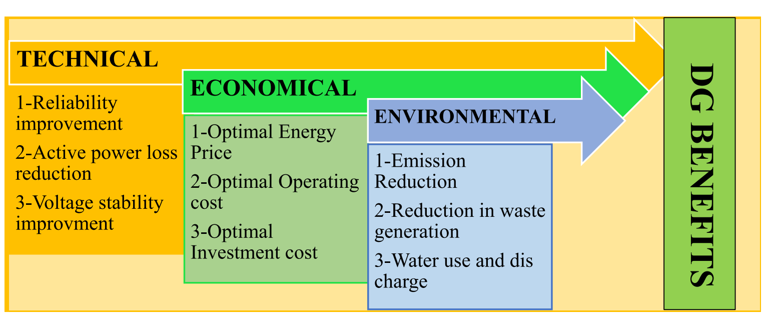

Fig. 1 Benefits with DG integration

optimal planning of dispatchable DG. Galgali et al. (2021) proposed an optimal placement of DG as a multi-criteria decision-making (MCDM) case and candidate buses are systematically evaluated by applying Fuzzy TOPSIS. Ismael et al. (2018) proposed the Crow Search Method (CSA) for the sizing and placement of DG in distribution networks. Diaaeldin et al. (2019) proposed discrete–continuous hyper-spherical search Methodfor allocated soft open points and DG units simultaneously with and without network reconfiguration. Manna and Goswami proposed the Lightning Search Method (LSA) to find the optimal location of DG units (Manna and Goswami 2020). Kumar et al. (2020) propose a new opposition-based tuned-chaotic differential evolution (OTCDE) method for optimal placement of multiple DG units. Huy et al. (2020) proposed Differential Evolution Methodto optimally integrate multiple distributed generation sources simultaneously into the distribution grid. García and Mena proposed Modified Teaching–Learning Based Optimization (MTLBO) algorithm to determine the optimal placement and size of DG units in Distribution Networks (García and Mena 2013).

The second category is analytical methods. For example, Acharya et al. (2006) proposed an analytical method to calculate the optimal size and location for DG in Distribution Networks. Hung and Mithulananthan presented three analytical expressions, to determine the optimum sizes and operating strategy of DG units considering power loss minimization and a methodology to identify the best location (Hung and Mithulananthan 2011). Murthy and Kumar proposed voltage stability index (VSI) methods for optimal location and sizing of DG (Murty and Kumar 2015). Ettehadi et al. (2012) proposed voltage stability analysis as a security measure for DG placement in distribution network.

Optimization algorithms possess their respective strengths and weaknesses. For instance, the PSO algorithm excels at solving problems with small and simple dimensions, yet it falters when applied to high-dimensional, complex, and hybrid scenarios, often succumbing to premature convergence. The Success-History based Adaptive Differential Evolution (SHADE) algorithm, an enhanced version of the Differential Evolution (DE) algorithm, effectively tackles hybrid and complex problems, demonstrating resilience against premature convergence. However, its performance diminishes when confronted with high-dimensional problems. GA and gravitational search algorithms (GSA) share similar limitations. In this study, we endeavored to address these limitations. CBOM method outperforms other algorithms on both unimodal and multimodal functions. It exhibits superior performance on hybrid functions compared to the other algorithms. Notably, the CBOM approach diverges from the PSO algorithm in several aspects. It dispenses with the previous speed parameter, and each search agent's position is updated based on its current position and the positions of designated group leaders. Moreover, CBOM method introduces a novel approach by incorporating chain movement and random movement in various directions during position updates. A pivotal distinction lies in how search factors adapt their positions. In CBOM, each search factor adjusts its position based on its current state and the positions of leaders, without direct involvement of the global best (gBest). Only the leaders are directly linked to the gBest. Unlike PSO, where all search agents maintain a uniform constant movement and velocity, CBOM allows for diverse movements. A search agent in CBOM may exhibit chain movement or random movement, providing greater flexibility. An essential differentiation surfaces in the mechanism of leader selection. In our proposed algorithm, leaders adopt distinct movements, including chain movement, random movement, and positioning based on their roles. In multi-leader PSO, leaders remain stationary, representing several global bests. In contrast, CBOM method empowers leaders to update their positions dynamically, leveraging a unique search mechanism to enhance exploration and exploitation. As previously discussed, the CBOM method addresses various critical aspects, including rapid problem-solving, mitigation of local optima entrapment, proficiency in handling intricate problem domains, and consistently yielding optimal and efficient outcomes. Given these advantageous attributes, the authors opted to employ the CBOM method to tackle the aforementioned problem.

The efficacy of the aforementioned approach in addressing diverse challenges has also been examined in various contexts. For instance, Houssein et al. (2022) introduced a battery parameter identification strategy utilizing the CBOM method. Koc (2022) proposed a rapid community detection algorithm in social networks based on the coot bird metaheuristic optimizer. Hussien et al. (2022) extended the CBOM method for optimizing the control of islanded microgrids. Sheng et al. (2023) proposed a hybrid dynamic economics emissions dispatch model for distributed power systems, encompassing thermal generating units, wind farms, and photovoltaic plants, utilizing the CBOM method. Wang et al. (2022) presented an optimized deep belief network model for precise wind energy prediction, leveraging the CBOM method for model optimization.

In this paper CBOM method is presented for solving optimal placement, size, and PF of DG in distribution network. It is one of the most recently algorithms that simulate regular and irregular movements of coot on the surface of the water. The objective function of proposed method in this paper for optimal placement of DG is total active power system losses. To show the efficiency of proposed optimization algorithm for solving the problem of optimal size, location, and PF of DG, IEEE 33 and 69 bus Distribution Networks have been used as case studies. The results of CBOM are compared with various published paper to detect its capability in solving the problem of optimal size, location, and PF of DG.

This paper is organized as follows. In Sect. "Problem formulation", the problem formulation of the problem is presented. In Sect. "Coot bird optimization methods", The description of CBOM is explained. The numerical result of the proposed model is presented in Sect. "Simulation and results", and the conclusion is given in Sect. "Conclusion".

Problem formulation

In this section the objective function of DG placement and sizing is presented and then governing constraints of this problem are introduced. This problem has been modelled as a single objective optimization problem. The objective is the system real power losses minimization.

Objective function

The objective function of DG placement and sizing is electrical energy losses which are expressed as follows:

$$Of = min(P_{Loss}) \tag{1}$$

where P_{Loss} is the total active power system losses and expressed as follow:

$$P_{Loss} = Real\left[\sum_{l=1}^{N_{line}} \left(\frac{\left|V_l^i - V_l^j\right|}{Z_l}\right)^2 * R_l\right] \quad (2)$$

where in Eq. (2), V_l^i is the voltage of line l and bus i, V_l^j is the voltage of line l and bus j, Z_l is the impedance of line l, and R_l is the resistance of line l.

Constraints of DG placement and sizing problem

Proper operating conditions of the network are achieved when initially the governing constraints of network are satisfied and then the objective functions will be optimized. Constraints of the DG placement and sizing such as bus magnitude of bus voltage, line current for each line of the system, DG capacity, DG power factor are as follows:

$$V_i^{min} \leq V_i \leq V_i^{max} \quad (3)$$

where V_i^{min} and V_i^{max} are the minimum and maximum voltages at each bus, respectively.

$$I_l \leq I_l^{max} \quad (4)$$

where I_l is the line current of the *lth* line and I_l^{max} is the maximum capacity of the *lth* line of the distribution network.

$$P_{DG}^{min} \leq P_{DG} \leq P_{DG}^{max} \quad (5)$$

where P_{DG}^{min} and P_{DG}^{max} are the minimum and maximum power output limits of the DG.

$$PF_{DG,i}^{min} \leq PF_{DG,i} \leq PF_{DG,i}^{max} \quad (6)$$

where $PF_{DG,i}$ is the power factor of *ith* DG, $PF_{DG,i}^{min}$ and $PF_{DG,i}^{max}$ are the minimum and maximum power factor of *ith* DG.

Coot bird optimization methods

The coots are small water birds that have many movements on the water (Naruei and Keynia 2021). In order to proposed a new optimization method, the behavior of coot's swarm on water is considered. CBOM is simulate regular and irregular movements of coots on the water. The four different movement on the water surface in this Method is considered. These movements include: random movement to this side and that side, chain movement, adjusting the position based on the group leaders, leading the group by the leaders towards the optimal area. The process of the Method is detailed as follows:

1. Generate the initial population using Eq. (7):

$$Cootpos(i) = rand(1,d) * (ub - lb) + lb \quad (7)$$

where $Cootpos(i)$ is the position of *ith* coot, d is the number of decision variables, *ub*, *lb* are the upper and lower band of search space.

2. In the next step, for each coot position the objective function of the optimization problem is calculated. Also, the choice of *Ncoot* (number of coots), *NL* (number of leaders), is randomly. Then, the best coot or leader is found as the global optimum.

3. Position update. At iteration *iter*, the coots position on the water is updated based on four movements which is described below.

Random movement to this side and that side:

To simulate this movement, first using Eq. (7) a random position is generated that called Q. Then, to prevent the Method to stuck in the local optimal, using Eq. (8) the coot position is updated.

$$Cootpos(i) = Cootpos(i) + A * R_2 * (Q - Cootpos(i)) \tag{8}$$

where R_2 is a random number between 0 and 1, A is calculated based on Eq. (9).

$$A = 1 - iter * \left(\frac{1}{maxiter}\right) \tag{9}$$

where *maxiter* is the maximum iteration.

Chain movement

The average position of two coots is used to simulate the chain movement. For this purpose, using Eq. (10) the average position of two coots is calculated.

$$Cootpos(i) = 0.5 * (Cootpos(i-1) + Cootpos(i)) \tag{10}$$

where $Cootpos(i-1)$ is the position of second coot.

Adjusting the position based on the group leaders

The coots usually adjust their position based on the group's leaders and follow them. For choosing a leader by coot Eq. (11) is used.

$$K = 1 + (iMODNL) \tag{11}$$

where NL is the number of leaders, K is the leader's index number, i the index number of current coot.

In this movement the coots update their position based on Eq. (12).

$$Cootpos(i) = Leaderpos(k) + 2 * R_1 * \cos(2\pi R) * (Leaderpos(k) - Cootpos(i)) \tag{12}$$

where $Leaderpos(k)$ is selected leader position, R is a random number between -1 and 1, and R_1 is a random number between 0 and 1.

Leader movement

To attain the optimal answer, the leader must update its position according to Eq. (13).

$$\begin{Bmatrix} B * R_3 * \cos(2\pi R) * \left(gbest - Leaderpos(i)\right) + gbestR_4 < 0.5 \\ B * R_3 * \cos(2\pi R) * \left(gbest - Leaderpos(i)\right) - gbestR_4 \geq 0.5 \end{Bmatrix} \quad (13)$$

where *gbest* is the position ever found, R is a random number between -1 and 1, R_3 and R_4 are random number between 0 and 1, and B is calculated based on Eq. (14).

$$B = 2 - iter * \left(\frac{1}{maxiter}\right) \quad (14)$$

4. Convergence. As the number of iterations increases, the best solution of the optimization problem is identified.

Simulation and results

This study delves into the optimization of the optimal placement and sizing of DGs within distribution networks using the CBOM Method. The investigation encompasses two distinct operational modes: unit power factor and optimal power factor. Additionally, the optimization process spans both the considered distribution networks and operational modes, encompassing scenarios with one to three DG units. The effectiveness of the CBOM in achieving optimal DG location, sizing, and power factor adjustment is showcased through the application to two IEEE distribution networks: the 33-bus and 69-bus networks. These networks serve as illustrative case studies to demonstrate the capabilities of the proposed methodology. The computational implementation of the CBOM-based optimization strategy is carried out using MATLAB R2020b software. This research addresses a significant issue in the realm of distribution networks by harnessing the potential of the CBOM algorithm to determine the most suitable location, size, and power factor adjustment for DG units. The choice of case studies and the application of the proposed methodology underscore its utility and effectiveness in optimizing the integration of DGs into distribution networks.

IEEE 33 bus distribution system

This system consists of 33 bus, 32 branches. The nominal active and reactive load on the network is 3.715 MW, and 2.3 MVAr, and also the active and reactive power losses are 210.99 kW and 143.13 kVAr (Memarzadeh and Keynia 2020).

Based on simulation results, Table 1 presents the optimal size, and location for both power factor modes. In this table is compared the results of the four different cases included, without DG, one DG, two DG, and three DG. As can be seen, with the installation of DG, power loss has been significantly reduced. Also, the voltage buses are within the allowable range. For the case that one DG at unit PF is installed in the network power loss decreased by 50.723%. Also, the lowest bus voltage is related to bus 18 with the value of 0.9511. This improvement is also greater for the optimum PF, so that power loss is reduced by 70.394% and the minimum bus voltage has reached 0.9643. For the case that two DG is installed in the distribution system the network is in a better condition. So that the power loss for the unit PF has been reduced by 58.687% and the minimum bus voltage has reached 0.9685. Another noteworthy point is that with reduction of 566 kW in the size of the DG compared to the case where one DG is installed in the network, the power loss has been reduced by approximately 16 kW. Similarly, for

Table 1 IEEE 33 bus distribution system results

Number of DG	Location	Size (kW)	PF	Total DG Size (kW)	Total real power loss (MW)	Loss reduction (%)	Minimum bus voltage @bus
Without DG	–	–	–	–	0.21099	0	0.9131 @18
One DG	6	2575.315	1	2575.315	0.10397	50.723	0.9511 @18
	26	2410.084	0.819644	2410.084	0.062466	70.394	0.9643 @18
Two DG	13	851.5087	1	2009.1407	0.087167	58.687	0.9685 @33
	30	1157.632	1				
	13	819.6654	0.884545	2062.7914	0.029312	86.107	0.9804 @25
	30	1243.126	0.8				
Three DG	13	801.7063	1	2946.6753	0.072787	65.502	0.9687 @33
	24	1091.329	1				
	30	1053.64	1				
	14	739.0424	0.882467	2944.4054	0.012744	93.96	0.9916 @8
	24	1048.879	0.883921				
	30	1156.484	0.8				

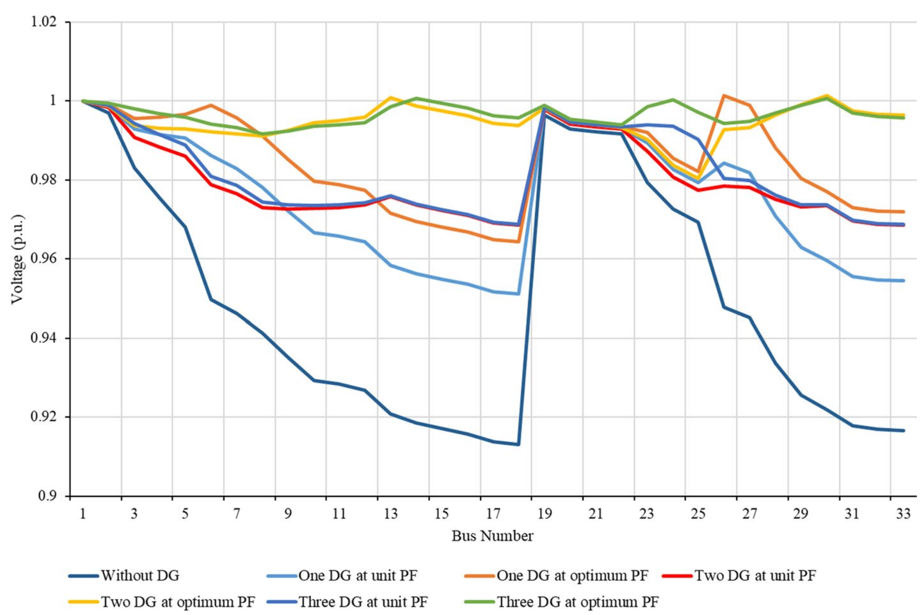

Fig. 2 Voltage profile for IEEE 33 bus distribution system

optimal power factor, the improvement of network conditions is significant. For example, network losses have decreased by 86.107%, which is considerable. The best results are for when three DG are installed in the distribution network. In this case when DGs at unit PF is installed in the network power loss decreased by 65.502%. Also, the lowest bus voltage is related to bus 33 with the value of 0.9687. This improvement is also greater for the optimum PF, so that power loss is reduced by 93.96% and the minimum bus voltage has reached 0.9916. So the minimum bus voltage is close to 1.

In Fig. 2 the voltage profile of all cases is shown. As can be seen, by installation of DG in the IEEE 33 bus distribution system, the voltage profile is in a better condition. In the cases that DG in optimum power factor, all voltage bus is in their allowed limits. In other words, these cases have the best network voltage profile. This shows that considering the PF as one of the decision variables of the optimization Methodhas a significant effect on the voltage profile. Among the different cases, the installation of three DG at the optimal PF has a significant effect on the voltage profile. So that the voltage profile is almost flat.

Comparing the results of CBOM with previous results

In order to illustrate the effectiveness of the proposed optimization Method for DG placement and sizing, the results obtained from the proposed method are compared with other published methods that are reported in Tables 2, 3, and 4. The results presented in these tables for unit PF. Comparison of results for IEEE 33-bus system with one DG unit is presented in Table 2. It is clear that the present method in this paper has the best performance in terms of loss reduction. It can be observed that the power loss is 103.97 kW for the case with one DG unit. The lower power loss value indicated that the CBOM successfully outperforms other previous methods in searching the best optimum solution.

Comparison of results for IEEE 33-bus system with two DG unit are presented in Table 3. As can be seen in this case study, the amount of power loss is lower than most other mentioned method in this table. This value is 87.17 kW. Another noteworthy point is that the amount of optimal capacity determined by the CBOM is less than other methods.

Comparison of results for IEEE 33-bus system with three DG units are presented in Table 4. In this case, the total power loss is reduced to 72.79 kW, which is the lowest one compared to other mentioned method in this table. Also, the percentage of reduction of power loss is 65.50%, which is the highest reduction percentage among the methods presented in this table.

Table 2 Comparison of results for IEEE 33-bus system with one DG unit

Method	Size (MW)	Location	Total real power loss (kW)	Loss reduction (%)
Analytical (Acharya et al. 2006)	2.49	6	111.24	45.12
Hybrid approach (Sultana and Roy 2016)	2.49	6	111.17	45.16
GA (Hassan et al. 2017)	2.38	6	132.64	34.56
Method 1 (Mahmoud et al. 2015)	2.49	6	111.24	47.28
Method 2 (Mahmoud et al. 2015)	2.6	6	111.02	47.38
Method 3 (Mahmoud et al. 2015)	1.5	30	125.21	40.66
EA (Mahmoud et al. 2015)	2.53	6	111.07	47.36
EA-OPF (Mahmoud et al. 2015)	2.59	6	111.02	47.38
ELF (Hung and Mithulananthan 2011)	2.601	6	111.10	47.34
IA (Hung and Mithulananthan 2011)	2.601	6	111.10	47.34
LSF (Hung and Mithulananthan 2011)	0.743	18	146.82	30.41
BSOA (El-Fergany 2015)	1.8575	8	118.12	44.02
SFS (Koc 2022)	2.590	6	111.02	47.38
CSFS3 (Nguyen and Vo 2019)	2.590	6	111.02	47.38
CBOM	**2.575**	**6**	**103.97**	**50.723**

Table 3 Comparison of results for IEEE 33-bus system with two DG units

Method	Size (MW)	Location	Total DG Size (MW)	Total real power loss (kW)	Loss reduction (%)
Method 2 (Mahmoud et al. 2015)	0.72	6	2.52	91.63	56.57
	1.8	14			
EA (Mahmoud et al. 2015)	0.844	13	1.993	87.172	58.68
	1.149	30			
EA-OPF (Mahmoud et al. 2015)	0.852	13	2.01	87.17	58.69
	1.158	30			
AM-PSO (Kansal et al. 2016)	0.83	13	1.94	87.28	58.64
	1.11	30			
IA (Hung and Mithulananthan 2011)	1.800	6	2.520	91.63	56.61
	0.720	14			
LSF (Hung and Mithulananthan 2011)	0.720	18	1.620	100.69	52.28
	0.900	33			
BSOA (El-Fergany 2015)	0.880	13	1.804	89.34	57.66
	0.924	31			
SFS (Nguyen and Vo 2019)	0.852	13	2.010	87.17	58.69
	1.158	30			
CBOM	**0.852**	**13**	**2.009**	**87.17**	**58.69**
	1.158	**30**			

IEEE 69 bus distribution system

The second network discussed in this paper is the IEEE 69 bus distribution system. The active and reactive load of this distribution network is 3.8 MW and 2.69 MVAr (Memarzadeh and Keynia 2020). The active and reactive power losses of this test system are 225.001 kW and 102.165 kVAr, respectively.

Like the IEEE 33 bus distribution network, four different cases included, without DG, one DG, two DG, and three DG is considered in this network. The result of optimal size, and location for both power factor modes in four cases is presented in Table 5. As it is known, with the installation of DG, the power loss has been significantly reduced and the bus voltages has returned to the allowable limits. For the case that one DG at unit PF is installed in the network power loss decreased by 63.012%. Also, the lowest bus voltage is related to bus 27 with the value of 0.9683. In this case by installing DG the bus voltages have returned to their permissible values. This improvement is also greater for the optimum PF, so that power loss is reduced by 89.702% that is a significant amount of improvement. The minimum bus voltage has reached 0.9725. For the case that two DG is installed in the distribution system the network is in a better condition. So that the power loss for the unit PF has been reduced by 68.144% and the minimum bus voltage has reached 0. 9789. Similarly, for optimal power factor, the improvement of network conditions is significant. For example, network losses have decreased by 96.798%, which is considerable. It is noteworthy that by determining the optimal power factor relative to the unit power factor, the amount of DG capacity has decreased by approximately 516 kW, which is a considerable number. The best results are for when three DG are installed in the distribution network. In this case when DGs at unit PF is installed in the network power loss decreased by 69.143%. Also, the lowest bus voltage is related to bus

Table 4 Comparison of results for IEEE 33-bus system with three DG units

Method	Size (MW)	Location	Total DG Size (MW)	Total real power loss (kW)	Loss reduction (%)
Method 2 (Mahmoud et al. 2015)	0.9	6	2.52	81.05	61.59
	0.9	14			
	0.72	31			
EA (Mahmoud et al. 2015)	0.798	13	2.947	72.787	65.50
	1.099	24			
	1.050	30			
EA-OPF (Mahmoud et al. 2015)	0.802	13	2.947	72.787	65.50
	1.091	24			
	1.054	30			
AM-PSO (Kansal et al. 2016)	0.79	13	2.87	72.89	65.45
	1.07	24			
	1.01	30			
GA-PSO (Moradi and Abedini 2012)	1.2000	32	2.9880	103.40	50.99
	0.8630	16			
	0.9250	11			
GA-IWD (Moradi et al. 2014)	1.2214	11	3.1180	110.51	47.62
	0.6833	16			
	1.2135	32			
SA (Injeti and Kumar 2013)	1.1124	6	2.4677	82.03	61.12
	0.4874	18			
	0.8679	30			
KHA (Hussien et al. 2022)	0.8107	13	2.4885	75.412	64.26
	0.8368	25			
	0.8410	30			
BFOA (Kowsalya 2014)	0.6521	14	1.9176	89.90	57.38
	0.1984	18			
	1.0672	32			
IWO (Prabha and Jayabarathi 2016)	0.6247	14	1.7856	85.86	57.47
	0.1049	18			
	1.0560	32			
IA (Hung and Mithulananthan 2011)	0.9	6	2.52	81.05	61.62
	0.9	12			
	0.72	31			
LSF (Hung and Mithulananthan 2011)	0.720	18	2.430	85.07	59.68
	0.810	33			
	0.900	25			
BSOA (El-Fergany 2015)	0.632	13	1.669	89.05	57.79
	0.487	28			
	0.550	31			
QOTLBO (Sultana and Roy 2014)	0.8808	12	3.0114	74.101	64.88
	1.0592	24			
	1.0714	29			
SFS (Nguyen and Vo 2019)	0.802	13	2.947	72.79	65.50
	1.091	24			
	1.054	30			
CBOM	**0.802**	**13**	**2.947**	**72.79**	**65.50**
	1.091	**24**			
	1.054	**30**			

Table 5 IEEE 69 bus distribution system results

Number of DG	Location	Size (kW)	PF	Total DG Size (kW)	Total real power loss (MW)	Loss reduction (%)	Minimum bus voltage @bus
Without DG	–	–	–	–	0.225	0	0.9092 @65
One DG	61	1872.689	1	1872.689	0.083224	63.012	0.9683 @27
	61	1828.451	0.814874	1828.451	0.02317	89.702	0.9725 @27
Two DG	17	531.4872	1	2773.4872	0.071677	68.144	0.9789 @65
	61	1781.461	1				
	17	522.3443	0.828229	2257.0243	0.007204	96.798	0.9943 @50
	61	1734.68	0.813865				
Three DG	11	526.8575	1	2626.1658	0.069428	69.143	0.9790 @65
	18	380.3413	1				
	61	1718.967	1				
	11	537.029	0.831323	2556.6919	0.004277	98.099	0.9943 @50
	21	346.5029	0.83261				
	61	1673.16	0.81302				

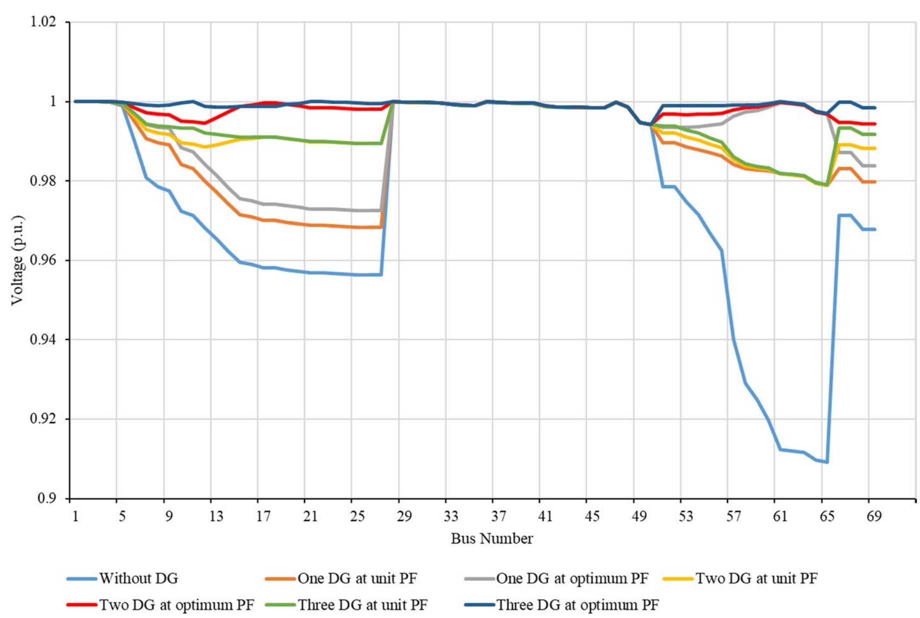

Fig. 3 Voltage profile for IEEE 69 bus distribution system

65 with the value of 0.9790. This improvement is also greater for the optimum PF, so that power loss is reduced by 98.099% and the minimum bus voltage has reached 0. 9943. Therefore, it can be concluded that by installing three DG units and determining their optimal location, size and power factor, the network is in a very good condition. Power loss have been significantly reduced and the voltage of all network buses are close to 1.

The voltage profile for the six mentioned cases is shown in Fig. 3. As can be seen, the installation of DG has caused the voltage profile to be in a better condition. Meanwhile, the use of DG at optimum PF has a greater effect on improving the voltage profile. As it is known, after installing DG, the voltage of all system buses has been significantly improved. This shows that considering the PF as one of the decision variables of the optimization Methodhas a significant effect on the voltage profile. Among the different cases, the installation of three DG at the optimal PF has a significant effect on the voltage profile and the voltage of all network buses are close to 1. So that the voltage profile is almost flat.

Comparing the results of CBOM with previous results

In order to illustrate the effectiveness of the proposed optimization Method for DG placement and sizing, the results obtained from the proposed method (Bold Numbers) are compared with other methods that are reported in Tables 6, 7, and 8.

For single DG installation, result comparison with other method in this problem is proposed in Table 6. The lower power loss value indicated that the CBOM successfully outperforms other previous methods in searching the best optimum solution.

Comparison of results for IEEE 69-bus system with two DG units are presented in Table 7. As can be seen in this case study, the amount of power loss is lower than most other mentioned method in this table. This value is 71.677 kW. Another noteworthy point is that the amount of optimal capacity determined by the CBOM is less than other methods. In other word, the proposed optimization method successfully outperforms other previous methods in searching the best optimum location, size, and PF.

Comparison of results for IEEE 69-bus system with three DG units are presented in Table 8. In this case, the total power loss is reduced to 69.428 kW, which is the lowest one compared to other mentioned method in this table. Also, the percentage of reduction of power loss is 69.143%, which is the highest percentage among the methods compared in this paper.

Table 6 Comparison of results for IEEE 69-bus system with one DG unit

Method	Size (MW)	PF	Location	Total real power loss (kW)	Loss reduction (%)
ABC (Abu-Mouti and El-Hawary 2011)	1.9	1	61	83.31	62.96
GA (Hassan et al. 2017)	1.872	1	61	83.18	63.02
Analytical (Gözel and Hocaoglu 2009)	1.808	1	61	92	59.1
GA (Pisica et al. 2009)	1.794	1	61	83.43	62.91
CSA (Tan et al. 2012)	2	1	61	83.8	62.74
SGA (Tan et al. 2012)	2.3	1	61	89.4	60.3
PSO (Tan et al. 2012)	2	1	61	83.8	62.75
MTLBO (García and Mena 2013)	1.82	1	61	83.323	62.95
BB-BC (Abdelaziz et al. 2015)	1.873	1	61	83.225	63
SFS (Nguyen and Vo 2019)	1.873	1	61	83.22	63.01
CSFS3 (Nguyen and Vo 2019)	1.873	1	61	83.22	63.01
CBOM	**1.873**	**1**	**61**	**83.22**	**63.01**
BB-BC (Abdelaziz et al. 2015)	1.801	0.81	61	23.1737	89.697
ALOA (Ali et al. 2017)	1.827	0.82	61	23.1925	89.69202
CBOM	**1.828**	**0.8149**	**61**	**23.17**	**89.702**

Table 7 Comparison of results for IEEE 69-bus system with two DG units

Method	Size (MW)	Location	PF	Total real power loss (kW)	Loss reduction (%)
GA (Shukla et al. 2010)	0.555	11	1	71.7912	68.08
	1.777	61	1		
GA (Pisica et al. 2009)	0.006	1	1	84.233	62.55
	1.794	62	1		
CSA (Shukla et al. 2010)	0.6	22	1	76.4	66
	2.1	61	1		
PSO (Shukla et al. 2010)	0.7	14	1	78.8	64.97
	2.1	62	1		
MTLBO (García and Mena 2013)	0.52	17	1	71.776	68.09
	1.732	61	1		
LSM (Kollu et al. 2014)	0.4461	27	1	100.39	55.38
	1.3791	65	1		
AGA (Ganguly and Samajpati 2017)	0.389	18	1	72.763	67.66
	1.848	61	1		
SFS (Nguyen and Vo 2019)	0.531	17	1	71.68	68.14
	1.781	61	1		
CSFS3 (Nguyen and Vo 2019)	0.531	17	1	71.68	68.14
	1.781	61	1		
CBOM	**0.531**	**17**	**1**	**71.677**	**68.144**
	1.781	**61**	**1**		
ALOA (Ali et al. 2017)	0.603	17	0.83	20.9342	90.69
	1.2	61	0.8		
CBOM	**0.522**	**17**	**0.828**	**7.204**	**96.798**
	1.735	**61**	**0.814**		

Conclusion

In this paper, the CBOM method has been successfully implemented for solving the optimal placement, sizing, and PF of DG problem in Distribution Networks. The objective function of proposed method in this paper for optimal placement of DG is total active power system losses. The effectiveness of the proposed method is evaluated using different Distribution Networks and the results are compared with the proposed methods of other papers. The results indicated that the CBOM has excellent performance in finding the optimal size, location, and PF of DG. For example, in the IEEE 33 bus network with three DG unit, the optimal size of DG for optimum PF is selected 2944.4054 kW. Using the method presented in this paper to find the optimal location, size, and PF of DG in this case study, power loss has decreased by 93.96%, the voltage of all buses is within the allowable limit. It is obvious from the comparison that the proposed approach provides a notable performance in terms of power loss reduction. As can be seen from the results, by solving the above problem, the network losses have been reduced significantly, and the voltage of the busses has been within acceptable limits. In other words, by solving this problem, two very big challenges of distribution networks have been significantly improved. In other words, by using DGs, not only environmental pollution can be reduced, but important challenges

Table 8 Comparison of results for IEEE 69-bus system with three DG units

Method	Size (MW)	Location	PF	Total real power loss (kW)	Loss reduction (%)
Method 2 (Mahmoud et al. 2015)	0.34	11	1	69.97	68.90
	0.51	17	1		
	1.7	61	1		
EA (Mahmoud et al. 2015)	0.467	11	1	69.62	69.06
	0.38	18	1		
	1.795	61	1		
AM-PSO (Kansal et al. 2016)	0.51	11	1	69.54	69.09
	0.38	17	1		
	1.67	61	1		
LSM (Kollu et al. 2014)	0.4168	27	1	73.60	67.28
	1.6026	61	1		
	0.1966	65	1		
GA-PSO (Kansal et al. 2016)	0.9105	21	1	81.1	63.95
	1.1926	61	1		
	0.8849	63	1		
GA-IWD (Moradi and Abedini 2012)	0.9115	20	1	80.91	64.04
	1.3926	61	1		
	0.8059	64	1		
SA (Injeti and Kumar 2013)	0.4204	18	1	77.1	65.73
	1.3311	60	1		
	0.4298	65	1		
KHA (Sultana and Roy 2016)	0.4962	12	1	69.563	69.08
	0.3113	22	1		
	1.7354	61	1		
BFOA (Kowsalya 2014)	0.2954	27	1	75.23	66.56
	1.3451	61	1		
	0.4476	65	1		
IWO (Prabha and Jayabarathi 2016)	0.2381	27	1	74.59	66.78
	1.3266	61	1		
	0.4334	65	1		
QOTLBO (Sultana and Roy 2014)	0.8114	15	1	80.585	64.18
	1.1470	61	1		
	1.002	63	1		
SFS (Nguyen and Vo 2019)	0.527	11	1	69.43	69.14
	0.380	18	1		
	1.719	61	1		
CBOM	**0.527**	**11**	**1**	**69.428**	**69.143**
	0.380	**18**	**1**		
	1.719	**61**	**1**		

of the distribution network such as losses and voltage profile can be significantly improved. Moreover, the proposed CBOM is robust and it can be applied for various distribution system. Also, the CBOM which described in this paper to solve the optimal DG placement, size, and PF problem can be used to solve other optimization problems related to power systems, including energy management of renewable resources, voltage and reactive power control, capacitor location, distribution system reliability improvement, etc. For future works, in order to improve the performance of the CBOM method, it can be combined with other optimization methods such as the GA, or to avoid falling into the local optimum, it can be combined with different learning methods such as cube chaos mapping.

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Author contributions
GM: Investigation_Methodology, Software Development, Writing—Original draft, Formal analysis. MA: Data Acquisition and Curation, Software Implementation, Validation, Conclusion, Statistical Analysis. FK: Conceptualization, Writing—Reviewing and Editing. Supervision, Visualization, Project administration, Resources. All authors read and approved the final manuscript.

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