

Multi-Objective Approach for Optimal Size and Location of DGs in Distribution Systems

Seyed Mohammad Sajjadi Kalajahi, Sina Baghali, Tohid Khalili, *Student Member, IEEE*, Behnam Mohammadi-Ivatloo, *Senior Member, IEEE*, Ali Bidram, *Senior Member, IEEE*

Abstract—In the recent years, due to the economic and environmental requirements, the use of distributed generations (DGs) has increased. If DGs have the optimal size and are located at the optimal locations, they are capable of enhancing the voltage profile and reducing the power loss. This paper proposes a new approach to obtain the optimal location and size of DGs. To this end, exchange market algorithm (EMA) is offered to find the optimal size and location of DGs subject to minimizing loss, increasing voltage profile, and improving voltage stability in the distribution systems. The effectiveness of the proposed approach is verified on both 33- and 69-bus IEEE standard systems.

Index Terms— Distributed generation (DG), Exchange market algorithm (EMA), optimization, power loss, and voltage stability.

I. INTRODUCTION

THE growing need for energy and rapid growth of electricity consumption will require new solutions in the electric power distribution systems. Due to environmental and economic constraints, expanding the transmission lines and establishing new fossil fuel-based generation units are not viable. To overcome these constraints, utilizing distributed generation (DG) to compensate for load demands is of great importance. DGs could be installed along with the distribution systems in a variety of capacities from a few kW to 50 MW [1]. To meet the required demand, DGs exploit common energy sources such as fossil fuels and renewable energy sources. Some of these sources are fuel

cells, internal combustion motors, micro-turbines, gas turbines, wind turbines, photovoltaic, and biomass. Distribution systems can gain many benefits from DGs including increasing the overall efficiency, increasing the reliability of the system, improving the system's security index, enhancing power quality, reducing greenhouse gasses, and relieving the capacity of distribution and transmission systems [2].

The distribution system is accountable for the major part of the power system's overall power loss. Unlike the transmission system, the ratio of line resistance to line reactance is high in the distribution system which causes more voltage sags and power loss. Using DGs in distribution systems will enhance the voltage level and decrease power loss. Installing DGs in wrong locations may result in even higher power loss, so finding the optimal location and size of DGs has a significant effect on the system's performance. There have been numerous efforts to propose the optimal placement and sizing of DGs using different methods and various algorithms. In [3], for solving the optimization problem of DG allocations, an analytical approach has been proposed to decrease the power loss. In [4], the placement of one DG has been implemented based on a power sensitivity index with an analytical approach. Dynamic programming has been used in [5] for DG allocation to decrease power loss and increase the system's voltage level. In [6], dynamic planning of DGs has been considered in an active distribution network. The active distribution system has also been investigated in [7] to maximize DG capacity without causing any technical problems to the system. The mixed-integer linear programming (MILP) method is employed in [8, 9] for installing DGs.

In [10], [11], genetic algorithm have been used for optimally installing DGs by minimizing the power loss and enhancing the voltage level as the objective functions of the problem. This algorithm has also been used in [12]

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Seyed Mohammad Sajjadi Kalajahi and Behnam Mohammadi-Ivatloo are with the Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran (e-mails: Mohammad.sajjadi9452@gmail.com, mohammadi@ieec.org). Behnam Mohammadi-Ivatloo is also with Department of energy Technology, Aalborg University, Aalborg, Denmark. Sina Baghali is with the Faculty of Electrical and Computer Engineering, K. N. Toosi University of Technology, Tehran, Iran (e-mail: baghali.sina@email.kntu.ac.ir). Tohid Khalili and Ali Bidram are with the Department of Electrical and Computer Engineering, University of New Mexico, Albuquerque, USA (e-mails: {khalili, bidram}@unm.edu).

with a multi-objective approach considering several load models for DG placements. In [13], network reconfiguration, DG, and fixed/switched capacitor bank placements have been studied simultaneously to achieve a wholesome improvement in the system's behavior in terms of voltage stability, reduction of power loss and the overload's relieving. Optimal allocation of DGs has been studied in [14] by combining genetic algorithm (GA) and simulated annealing-based methods. Fuzzy-based GA for optimal locating and sizing of DGs has been introduced in [15], [16]. In [17], a hybrid method merging intelligent water drops algorithm and GA has been presented to calculate proper sizing and define the optimal place of DGs. Determining the number of DGs and optimal capacity and placement with fuzzy-based multi-objective particle swarm optimization (PSO) algorithm is studied in [18]. The binary PSO-based method is used in [19] for choosing optimal size, place, and time of investment of DGs in the distribution system's planning horizon. In [20], by combining GA and PSO algorithms, the problem of locating and determining the capacity of DGs has been solved with the aim of power loss reduction, voltage stability, and voltage regulation improvement. In [21], Quantum inspired-PSO (Q-PSO) is executed for optimizing the DG placement problem in the power system. Reducing power loss and enhancing voltage stability are the main objectives of the DG placement algorithm in [22]. In [23], chaos embedded symbiotic organism search (CSOS) algorithm has been deployed to minimize the power loss by verifying the optimal location and capacity of DGs. In [24], a multi-objective optimization (MOO) has been introduced to optimize the cost of energy, the power loss, and improve the reliability by optimal sizing and sitting of DGs. Ant-lion optimizer (ALO) is utilized in this paper to optimize the problem. DG placement in [25] is performed utilizing a clonal selection-based artificial immune system method. In [26], optimal placement and sizing of DGs have been studied alongside adjusting the electricity price of DG to maximize DG owners' profit and minimize distribution company cost to meet the demands of the network. A scatter search (SS) method has been used in [26].

In this paper, to solve the problem of optimal placement and sizing and siting of DGs in distribution

systems, the exchange market algorithm (EMA) [27] is utilized. EMA is inspired by human behaviors and reactions in trade sharing at stock markets [28]-[33]. The objective of the proposed optimization approach is to minimize power loss, improve voltage profile, and enhance voltage stability in the distribution systems. The effectiveness of the proposed approach is verified on both 33- and 69-bus IEEE standard systems. The remainder of this paper is organized as: Section II presents the problem formulation. The methodology is discussed in Section III. Section IV provides the obtained simulation results. Finally, the relevant conclusions of the optimal placement and sizing of the DGs in the distribution system are presented in Section V.

II. PROBLEM FORMULATION

The main objectives are minimization of the total power loss and improvement of the voltage profile as well as enhancement of the voltage stability by finding the optimal size and location of DGs. To this end, a multi-objective function is introduced that includes three single objective functions. DGs can provide any amount of power within their minimum and maximum capacity and they can be placed in every bus of the system.

A. Objective Function

The multi-objective function is as follows [23]:

$$OF = F_1 + P_1 \times F_2 + P_2 \times F_3 \quad (1)$$

where F_1 , F_2 , and F_3 are three single objective functions. Also, P_1 and P_2 are penalty factors of the second and third objective functions. In this work, P_1 and P_2 are equal to 0.6 and 0.35, respectively. The total power loss of the distribution system is introduced as F_1 and is presented as follows [20]:

$$F_1 = \sum_{j=1}^{n_b-1} R_j I_j^2 \quad (2)$$

where I_j and R_j show the current and resistance of the j^{th} branch of the system, respectively. The number of buses is n_b . F_2 defines the total voltage deviation as [23]:

$$F_2 = \sum_{i=1}^{n_b} (V_i - V_{\text{rated}})^2 \quad (3)$$

where V_i and V_{rated} are the per-unit voltage of i^{th} bus and rated voltage of system (e.g., 1 pu), respectively.

F_3 is selected using the Voltage Stability Index (VSI). Fig.1 shows a distribution system branch between two

buses. The relationship between load's active and reactive power at bus i , P_i and Q_i , bus i and j voltage, V_i and V_j , and line parameters, X_{ij} and R_{ij} , expressed as [23]:

$$P_i - jQ_i = V_i^* I_{ij} \quad (4)$$

$$I_{ij} = \frac{V_i - V_j}{R_{ij} + jX_{ij}} \quad (5)$$

Using (4) and (5), one can define VSI as:

$$VSI_i = |V_j|^4 - 4[P_i X_{ij} - Q_i R_{ij}]^2 - 4[P_i R_{ij} + Q_i X_{ij}]|V_j|^2 \quad i = 2, 3, 4, \dots, n_b \quad (6)$$

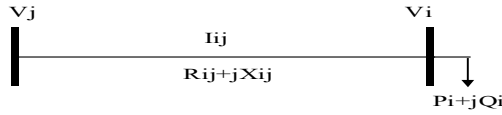


Fig. 1. Diagram of a distribution system's branch.

Normally, the VSI is a positive. By maximizing VSI, voltage stability is improved. So, F_3 is defined as:

$$F_3 = \frac{1}{VSI} \quad (7)$$

B. Constraints

In this paper, the system's inequality and equality constraints are considered. Equality constraints are based on the power flow equations as follows [23]:

$$P_{g,i} - P_i^d - V_i \sum_{j=1}^{Nb} V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (8)$$

$$Q_{g,i} - Q_i^d - V_i \sum_{j=1}^{Nb} V_j Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (9)$$

$P_{g,i}$ and $Q_{g,i}$ are generated active and reactive power of i^{th} bus, respectively. Parameters P_i^d and Q_i^d are demanded active and reactive power of i^{th} bus, respectively; V_i and V_j are the voltage of i^{th} and j^{th} bus, respectively; δ_i and δ_j are i^{th} and j^{th} bus voltage angle, respectively; Y_{ij} and θ_{ij} are admittance magnitude and angle.

The inequality constraints in the optimal placement and sizing of DGs' problem are as follows [23]:

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad (10)$$

$$I_{ij} \leq I_{ij}^{\max} \quad (11)$$

$$P_{i,\min}^{DG} \leq P_i^{DG} \leq P_{i,\max}^{DG} \quad (12)$$

$$Q_{i,\min}^{DG} \leq Q_i^{DG} \leq Q_{i,\max}^{DG} \quad (13)$$

Equations (10)-(13) represent the voltage limitations, maximum loading of distribution lines, active power and reactive power limitations of DGs, respectively.

III. METHODOLOGY

EMA has been inspired by the reaction and decision making of stockholders in the stock market. The two

main states of market, unbalanced and balanced modes, are taken into account in every implementation of this algorithm. The significant difference between the two modes is that in balance mode members take action based on superior member's experiences and peruse gaining profit by searching around optimum point. On the other hand, in unbalanced mode, members are prone to take risks in order to get more interests by exploring unknown optimum solutions. In the final stage of the market modes, the dealers, based on their financial state, are categorized into three groups known as groups one, two, and three. EMA approach has faster convergence compared to other algorithms due to utilizing two operators. In a not oscillation condition, EMA utilizes absorptive operators and in the unbalanced mode, the explorer operators are used to find the optimal point [27]. EMA consists of several stages to find the appropriate solution. These steps are explained in Table I.

TABLE I
EMA ALGORITHM

1	Input Data;
2	Initialize Iteration to 1;
3	Calculate the members' cost by (1) and rank them;
4	Iteration=Iteration+1;
5	Change second group members' shares in balanced mode by;
6	Change third group members' shares in balanced mode;
7	Analyze the members again and rank them by (1);
8	Trade second group members' shares in unbalanced mode;
9	Trade third group members' shares in the unbalanced mode;
10	if Is there termination criterion? then
	Save the optimal values;
	else
	Repeat the steps starting step 3;
	End if

In this study, shareholders (members) are DGs' placement and output power (controlling variables). Accordingly, the shares and costs are the value of the controlling variables and the value of the objective function, respectively. After implementing the first iteration, the market reaches a balanced mode, and shares are determined based on the equations mentioned in [27]. The cost function is reevaluated based on new share values and results are classified then the oscillation mode begins. In this step, share values are altered. Afterward, the cost function is calculated with the new share amounts, and classification is done in the same manner.

This loop continues until the algorithm reaches the termination criteria (maximum iteration number).

IV. SIMULATION RESULTS

The proposed DG placement and sizing approach are implemented on the IEEE 33- and 69-bus radial test systems. The results of EMA are compared with other optimization algorithms to show the effectiveness of the proposed approach. Three DGs are required in the distribution systems and they can provide power in the range of their minimum and maximum values. The maximum and minimum power and power factor of DGs are 1.2 (MVA), 0, and 1, respectively.

A. Case Study of IEEE 33-Bus Test System

The first test system is the IEEE 33-bus test system, the data of this system are derived from [34]. Each objective function is calculated without and with DGs. Table II shows the objective function values without DGs.

System	F_1	F_2	F_3	Obj-Function
33-bus	0.2109	0.1338	1.4988	0.8157

Table III presents the results in the presence of DGs (all the numbers are in per-unit with the base values of 1 (MW) and 12.66 (kV)). In this table, different optimization algorithms are used to find the optimal DGs' location and size. While CSOS results in the maximum power loss reduction, EMA has a better solution in minimizing the voltage deviation and maximizing the VSI. EMA has the best answer for the multi-objective function which shows that it can find the optimal size and site of DGs accurately. Fig. 2 shows the voltage profile without and with DGs by EMA, red curve and blue curve represent voltage profile before and after DGs placement, respectively. So, EMA has improved the voltage profile.

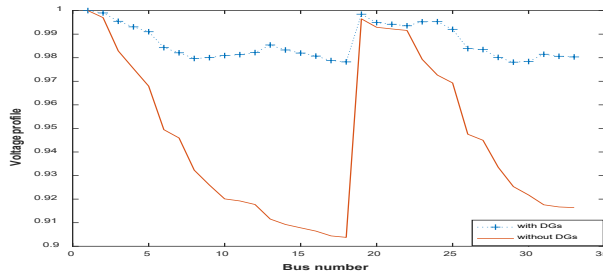


Fig. 2. Voltage profile before and after DG placement in 33-bus system.

B. Case Study of IEEE 69-Bus Test System

The second case study is the IEEE 69-bus test system. This test system data is extracted from [35]. Three DGs are located on the 69-bus test system with a maximum output of 1.2 (MVA) and the power factor of 1. Table IV shows the objective function values in the system without DGs. Table V summarizes the results in the presence of DGs. In this table, different optimization algorithms are used to find the optimal DGs' location and size. As seen, EMA has a better solution in minimizing the voltage deviation and maximizing the VSI. Moreover, EMA has the best answer for the multi-objective function that shows that EMA can find the optimal size and site of DGs accurately. Fig. 3 shows the voltage profile without and with DGs by EMA. As seen, EMA has improved the voltage profile. EMA has fast convergence and finds the optimal solution with less than 50 iterations.

System	F_1	F_2	F_3	Obj-Function
69-bus	0.225	0.0993	1.4635	0.7968

C. Statistical Analysis of Outputs

This section is dedicated to calculating the mean and variance of the objective function for the IEEE 33- and 69-bus standard systems. The best and worst values obtained from these test systems, with the initial population of fifty, are included in Table VI. The comparison of the results mentioned in this table shows that a small deviation can be observed between the best and worst cases. And, the standard deviation (SD) for objective function is small for both cases and the results presented in Table VI verify the effectiveness of EMA in finding the optimal solution.

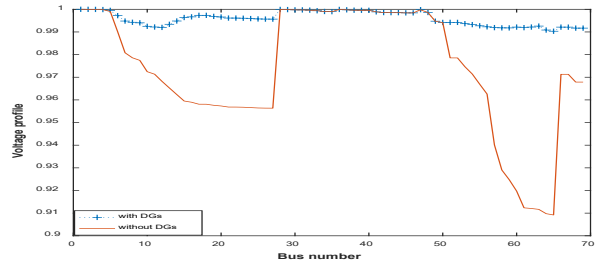


Fig. 3. Voltage profile before and after DG placement in 69-bus system.

System	Mean	Best	Worst	Variance	SD
33-bus	0.4695	0.4641	0.4707	$5.41 \cdot 10^{-6}$	0.0023
69-bus	0.4451	0.4401	0.4477	$1.27 \cdot 10^{-5}$	0.0036

TABLE III
OPTIMAL LOCATING AND SIZING OF DGS FOR THE IEEE 33-BUS TEST SYSTEM

Algorithms	Optimal location	Optimal size (MW)	F ₁ (pu)	F ₂ (pu)	VSI (pu)	F ₃ (pu)	Obj-function (1)	Loss reduction (%)
GA/PSO [20]	11	0.925	0.1034	0.0124	0.9508	1.0517	0.4789	50.97
	16	0.863						
	32	1.2						
GA [20]	11	1.500	0.1063	0.0407	0.9490	1.0537	0.4995	49.62
	29	0.423						
	30	1.071						
PSO [20]	8	1.177	0.1053	0.0335	0.9256	1.0804	0.5035	50.09
	13	0.982						
	32	0.829						
CSOS [23]	14	0.754	0.0714	0.0123	0.8909	1.1224	0.3905*	66.13
	24	1.099						
	30	1.072						
EMA	13	0.963	0.077	0.0078	0.9152	1.0925	0.4641	63.48
	24	1.168						
	31	1.126						

*According to (1), the value of objective function calculated by CSOS is not valid and should be 0.4716 instead of 0.3905.

TABLE V
OPTIMAL PLACEMENT AND SIZING OF DGS FOR THE 69-BUS TEST SYSTEM

Algorithms	Optimal location	Optimal size (MW)	F ₁ (pu)	F ₂ (pu)	VSI (pu)	F ₃ (pu)	Obj-function (1)	Loss reduction (%)
GA/PSO [20]	21	0.910	0.0811	0.0031	0.9768	1.0237	0.4413	63.90
	61	1.193						
	63	0.885						
GA [20]	21	0.929	0.0890	0.0012	0.9705	1.0303	0.4503	60.39
	62	1.075						
	64	0.985						
PSO [20]	17	0.992	0.0832	0.0049	0.9676	1.0334	0.4478	62.97
	61	1.199						
	63	0.795						
CSOS [23]	17	0.537	0.0715	0.0063	0.9223	1.0842	0.3981*	68.16
	61	1.2						
	64	0.536						
EMA	17	0.650	0.0755	0.0017	0.9624	1.039	0.4401	66.44
	61	1.2						
	63	0.857						

*According to (1), the value of objective function calculated by CSOS is not valid and should be 0.4547 instead of 0.3981.

V. CONCLUSION

In this paper, a multi-objective function is proposed to find the optimal size and location of DGs. The main objectives of the optimization problem are minimizing the power loss and voltage deviation and maximizing the VSI. To solve this problem, a metaheuristic algorithm applied which is inspired by the stock market which is called EMA. The EMA has two absorptive and explorer operators which enable it to have fast convergence compared to other algorithms. To prove the effectiveness of EMA, the proposed approach is implemented on two 33- and 69-bus test systems. The results show that EMA obtains a better solution in comparison to CSOS, PSO,

GA, and GA/PSO for the multi-objective optimization problem. EMA method takes less than 50 iterations to find the solution of optimal location and size of DGs.

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