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Optimal Location and Sizing of Distributed Generators Based on Renewable Energy Sources Using Modified Moth Flame Optimization Technique

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ABSTRACT Due to the great impact of the penetration and locations of distributed generators (DG) on the performance of the distribution system, this paper proposes a modified moth flame optimization (MMFO) algorithm. Two modifications are proposed in MMFO to enhance the exploration and exploitation balance and overcome the shortcomings of the original MFO. The proposed MMFO is used to find the optimal location and sizing of DG units based on renewable energy sources in the distribution system. The main objective function is to minimize the total operating cost of the distribution system by considering the minimization of the total active power loss, voltage deviation of load buses, the DG units cost, and emission. This multi-objective function is converted to a coefficient single objective function with achieving different constraints. Also, the bus location index is employed to introduce the sorting list of locations to accomplish the narrow candidate buses list. Based on the candidate buses, the proposed MMFO is used to get the optimal location and sizing of DG units. The proposed MMFO algorithm has been applied to the IEEE 69-bus test distribution system and the results are compared with other published algorithms to prove its effectiveness and superiority.

INDEX TERMS Modified moth flame algorithm, distributed generators, renewable energy sources, bus location index, coefficient single objective function.

NOMENCLATURE

C_{DG}	cost of all DG units
$C_{P_{LOSS}}$	cost of total active power loss of the distribution system
C_E	cost of emission which targeted to minimize it
C_{VD}	reflection of the voltage deviation on the cost
C_c	capital cost ($\$/KW$)
F_c	variable fuel cost ($\$/KWh$)
OM_c	operating and maintenance cost ($\$/KW - year$)
r	interest rate (9%)
n	investment life time ($20 - years$)
P_L	total real power losses in all buses
P_k, Q_k	active and reactive power injected at bus k, respectively
P_{DGi}, Q_{DGi}	generated active and reactive power of DG unit, respectively
$P_{DGi_{max}}$	maximum allowable active power generated from DG unit
P_{Grid}	active power injected from grid
P_d, Q_d	demand of active and reactive power, respectively
Q_{LOSS}	reactive power losses
Q_{Grid}	reactive power injected from grid
V_i, V_j	magnitudes of the voltage at buses i and j respectively
V_D	voltage deviation at load buses
V_M	maximum allowable voltage $V_M = 1.0\, p.u$
V_{Li}	voltage at load bus i
V_{Li}^{max}	maximum magnitude of voltage at load bus i

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V_{Li}^{min}	minimum magnitude of voltage at load bus i
θ_i, θ_j	angles of the voltage at buses i and j respectively
k_i	group of buses that connected to bus i
$G_{ij}, beta_{ij}$	susceptance and conductance of bus admittance matrix, respectively
ω	weight factor that can be determined based on the $\frac{r_i}{x_i}$
$\frac{r_i}{x_i}$	ratio of the feeder resistance to feeder reactance
R_k	resistance of branch k
I_k	current flow of branch k
E_{DG}	total emission released from all DG units
$CO_{2,DGi}$, $NO_{x,DGi}$, $SO_{2,DGi}$	emission products of DG units
W_{LOSS}	factor of power loss ($\$/MW$)
W_E	emission factor in ($\$/KG$)
W_{VD}	voltage deviation economic operator
S_{li}	transmission line loading
N_{DG}	total available number of DG units
N_b	number of total branches
N	number of network buses
N_l	number of load buses
MO_i	the i^{th} moth
F_k	the k^{th} flame
g	logarithmic spiral function
D_i	distance between the i^{th} moth and and k^{th} flame
s	constant indicates the shape of the logarithmic spiral
ε	random number $\in [-1, 1]$
c	the convergence constant
N_f	maximum number of flames
it	current number of iteration
max_{it}	maximum number of iterations

I. INTRODUCTION

Recently, the distributed generators (DG) integrated into the distribution system have major positive impacts on the performance of the system, due to its ability to decrease the loss of transmission lines, improve the voltage stability, increasing the reliability and reducing the pollutant emission based on DG technology types [1]–[3].

The penetration of DG units in the distribution system is becoming more widespread because of the growth of demand load, reduction of pollutant emission and deregulated of the electrical power market. Several DG units technologies are used and categorized according to fuel energy used into dispatchable and non-dispatchable units. The former includes, for example, diesel generators, micro-turbine, and fuel cell. While, the later includes, renewable energy sources based on DG units such as solar photovoltaic systems, wind turbine generators, biomass and micro-hydro generators [4]–[7].

The effectiveness of DG performance is more related to the choice of their adequate location, types, and sizes, where the optimal selection will maximize the benefits of DG units used and avoid their drawbacks for the system such as increasing loss of the system, increasing the operating cost and voltage instability [8], [9]. Incorporating the DG units into the system has different impacts in the case of both steady-state and transient conditions. In the steady-state, there are some problems like reverse power flow, high power losses, voltage fluctuation, reactive power management, miscoordination of the protection scheme, poor power quality, regulation, and reliability of over-load tap changer (OLTC) [10]–[13]. On the other hand, the impacts in the transient state appear due to the islanding of DG units and the phenomena of the uncertainty of the output of DG units such as occurring from the variation of wind speed and shading effects in zones with PV [14]. The severity of these impacts is based on the locations of DG units with the amount of DG penetrations and the DG's technology. Also, due to the nature of renewable DG units, the simultaneous variations of DG's generations for supplying the demand load may cause under or over voltage. The effects of such phenomenon may affect by DG unit locations and weather conditions [15]. In addition, at a specific penetration level of DG units, the performance of the system is improved, but in contrast, beyond this level, the system was subject to degradation by substation and feeder loading, voltage deviation and increased power losses. Moreover, by increasing the penetration of DG units, the operation of the automatic voltage regulator (AVR) inside the OLTC of the transformer becomes more sophisticated and incapable because of occurring the phenomena of reverse power flow and accompanied with high voltage and current which can be controlled by employing different methods summarized in [9], [16].

Consequently, the problem of determining the optimal location and sizes of DG units has subject to great interest recently in order to achieve many objectives such as minimization of real power loss, improvement voltage profile, improvement power system quality and increasing both efficiency and reliability of the distribution system. So, various approaches are proposed in the literature to solve this problem [3], [17]–[21].

The authors in [3] proposed a novel method to determine the optimal size and location of DGs to not only reducing the power loss but ensuring the voltage stability of the system. The improved gravitational search algorithm is proposed in [19] to get the optimal placement and sizing of solar photovoltaic based DGs to minimize the total cost. A combined method of an intelligent water drop (IWD) and hybrid (GA) were proposed in [22] to determine the size and location of DGs in micro-grid for increasing voltage stability, reduce network losses and improve voltage profile. A hybrid fuzzy logic controller technique and ant-lion optimization algorithm's with particle swarm optimization based combination is proposed in [23] to solve the optimal allocation of distributed generations in a radial distribution network to minimize the total cost of operation and deviation of voltage indexes. In [24] at different load levels, the objective function to find optimal location and sizing of DGs is reducing real and reactive power losses which solved by using biogeography-based optimization (BBO) algorithm. An efficient optimization algorithm to optimally allocate the multiple DG units in distribution systems based on sine cosine algorithm (SCA) and chaos map theory is proposed in [25] using three objective functions.

Nowadays, the DGs are planned optimally to achieve economic motive during the liberalized modern power market, so the optimally planning of distributed generators is very important for the operators in the distribution network [26]. In the real distribution network, there are different configurations with many huge buses. In addition to several load levels which may be taken into consideration at different periods, moreover, there are geographical and environmental constraints, this means a very large number of buses to be nominated for distributed generators. All of that may be making the choice of the optimal location and size is not easy and take a huge time. So it is better to use a technique reducing the nominated buses to save the time of searching according to network configuration. Therefore, the bus location index is employed in this paper to create a priority ranking list of candidate buses.

In 2015, the moth flame optimization (MFO) is proposed as a new technique to solve optimization problem in [27]. The MFO which is considered as one of the novel nature-inspired algorithms simulates the navigation method of moths for travelling for long distances. The MFO is appropriate for solving many practical optimization problems because of its brilliant characteristics [28]–[31].

As known, the balance between exploration and exploitation is the greatest significant features for any generalized approach. The exploration points to exploring the global search while the exploitation refers to the local search. According to the theory published in [32], no algorithm is the best appropriate for all the optimization problems. Therefore, there are different modifications are proposed by researchers to improve the characteristics of the MFO regarding the proper balance between exploitation and exploration capabilities.

The opposition based MFO method is proposed in [33] to overcome the disadvantages of the conventional MFO which are trapping in local optima and the slow convergence. In [34] the conventional MFO is combined with lévy flights to gain their merits and to decrease the computational times, especially for the highly complex optimization problems. The chaotic MFO is proposed in [35] to enhance the balance between exploitation and exploration capabilities by employing two chaotic mechanisms.

This paper proposes a modified moth flame optimization (MMFO) algorithm. Two modifications are made in the original MFO to derive the proposed MMFO in order to improve the balance between the exploration-exploitation capabilities of the algorithm and speed up the convergence of the algorithm. Then, the proposed MMFO is employed to find the optimal location and sizing of DGs based on different dispatchable and non-dispatchable DGs units in order to minimize the total operating cost of the distribution system. The total objective function consists of the minimization of fuel cost, total real power loss, voltage deviation and pollution emission for some DGs is treated as weighted economic operators, where a multi-objective problem is converted to coefficient single objective function (CSOF) with considering some constraints of the system. The performance of the developed approach is tested using a standard test system and compared with other published methods to discover its notability for solving the problem described here. The contributions of this paper are to:

- Propose the MMFO algorithm which improves the complementary features of the original MFO by improving the balance between the exploration and exploitation and avoiding the problems of the original MFO.
- Introduce the problem formulation of finding the optimal location and sizing of DG units based on renewable energy sources to minimize the total operating cost considering four different objective functions.
- Use the proposed MMFO algorithm to solve the above problem by converting the multi-objective function consists of four different functions into a coefficient single objective function (CSOF).
- Enhance the solution of the above problem in comparison with the obtained results from published algorithms based on different cases and scenarios using the IEEE 69-bus test distribution system.

This paper is organized as follows: Section II introduces the bus location index (BLI) technique. The mathematical model of the objective problem is described in Section III. In Section IV the MMFO technique is discussed. The simulation results for the test system are presented with a discussion in Section V. Finally, Section VI presents the conclusions of the proposed work.

II. BUS LOCATION INDEX (BLI)

It is known that any change in the injected active and reactive power at any bus of the distribution system will lead to a change in total real power losses. According to this concept, the bus location index (BLI) is formulated as described in [36]. The real power losses can be written as in [37] as following.

$$P_L = \sum_{i=1}^{N} \sum_{j \in k_i} V_i V_j [G_{ij} \cos(\theta_i - \theta_j) + \beta_{ij} \sin(\theta_i - \theta_j)] \quad (1)$$

The power balance equations are written as follow:

$$\Delta P_k = P_k - V_k^2 G_{kk} - V_k \sum_{j=1, j \neq k}^{N} V_j [G_{kj} \cos(\theta_k - \theta_j) + \beta_{kj} \sin(\theta_k - \theta_j)] \quad (2)$$

$$\Delta Q_k = Q_k - V_k^2 \beta_{kk} - V_k \sum_{j=1, j \neq k}^{N} V_j [G_{kj} \sin(\theta_k - \theta_j) - \beta_{kj} \cos(\theta_k - \theta_j)] \quad (3)$$

The variation in real power losses based on the previous concept may be described as follow in [37]

$$\begin{bmatrix} \frac{\partial P_L}{\partial P} \\ \frac{\partial P_L}{\partial Q} \end{bmatrix} = J^{-1} \begin{bmatrix} \frac{\partial P_L}{\partial \theta} \\ \frac{\partial P_L}{\partial V} \end{bmatrix} \tag{4}$$

where $\frac{\partial P_L}{\partial P}$ and $\frac{\partial P_L}{\partial Q}$ are the power loss derivative with respect to injected active and reactive power at bus i respectively. $\frac{\partial P_L}{\partial \theta}$ and $\frac{\partial P_L}{\partial V}$ are the power loss derivative with respect to angle and the voltage of bus i respectively. J is the jacobian matrix,

$$J = \begin{bmatrix} \frac{\partial \Delta P}{\partial \Theta} & \frac{\partial \Delta P}{\partial V} \\ \frac{\partial \Delta Q}{\partial \Theta} & \frac{\partial \Delta Q}{\partial V} \end{bmatrix} \tag{5}$$

where $\frac{\partial \Delta P}{\partial \Theta}$ and $\frac{\partial \Delta P}{\partial V}$ are the partial derivatives of injected active power with respect to angle and voltage magnitude respectively. $\frac{\partial \Delta Q}{\partial \Theta}$ and $\frac{\partial \Delta Q}{\partial V}$ are the partial derivatives of injected reactive power with respect to angle and voltage magnitude respectively.

The BLI can be expressed as follow in [38] for each bus.

$$BLI = \omega \frac{\partial P_L}{\partial P} + (1-\omega)\frac{\partial P_L}{\partial Q} \tag{6}$$

$$\omega_i = \frac{\frac{r_i}{x_i}}{\frac{r_i}{x_i}+1} \tag{7}$$

The weight factor may be a unique value and is calculated as the mean value of all weight factors of buses. This value is accepted particularly and can be used in BLI equation due to the $\frac{r_i}{x_i}$ variation will be very small because all feeders have the same parameters and the same voltage level. According to the values calculated by BLI, the priority ranking list can be constructed in descending order, which means that the greater values of BLI are more favorable to connect DGs.

III. OBJECTIVE PROBLEM FORMULATION

The target of the objective problem proposed here is finding the optimal location and sizing of DGs based on renewable energy sources to minimize the total operating cost with considering equality and inequality constraints. Where some coefficients are utilized to integrate different objective functions for creating only CSOF which used to minimize the total cost of the system.

A. COST FORMULATION OF DG UNITS

The total cost of DG units contains capital installation cost, fuel cost, operating and maintenance cost. It may be formulated as follow [39]

$$C_{DG} = \sum_{i=1}^{N_{DG}} C(P_{DGi}) \tag{8}$$

$$C(P_{DGi}) = C_c P_{DGi_{max}} + \frac{(1+r)^n - 1}{r(1+r)^n}(F_c + OM_c)P_{DGi} \tag{9}$$

B. TOTAL POWER LOSS FORMULATION

The active power losses of the distribution system can be described as follow [40]

$$P_{LOSS} = \sum_{k=1}^{N_b} |I_k|^2 R_k \tag{10}$$

The cost of active power losses can be formulated as following:

$$C_{P_{LOSS}} = P_{LOSS} W_{LOSS} \tag{11}$$

C. POLLUTION EMISSION FORMULATION OF DG UNITS

According to DGs technologies, there are some types of DGs that generate CO_2, SO_2 and NO_x, to deliver the required output power. The reflect of emission on the cost of DG units can be expressed as following in [41]

$$E_{DG} = \sum_{i=1}^{N_{DG}} E(P_{DGi}) \tag{12}$$

$$E(P_{DGi}) = (CO_{2,DGi} + NO_{x,DGi} + SO_{2,DGi})P_{DGi} \tag{13}$$

The cost of emission released by DG units may be formulated as follow:

$$C_E = E_{DG} W_E \tag{14}$$

D. VOLTAGE DEVIATION FORMULATION

The penetration of DG units may be cause variation in the distribution system voltage. Therefore, the voltage violation should be limited. The voltage deviation can be defined as follow [39]

$$V_D = \sum_{i=1}^{N_l} |V_i - V_M| \tag{15}$$

The reflection of the voltage deviation on the cost can be expressed as follow:

$$C_{VD} = V_D W_{VD} \tag{16}$$

E. EQUALITY AND INEQUALITY CONSTRAINTS

According to the objective problem proposed, there are two types of constraints as following:

1) EQUALITY CONSTRAINTS

Power balance equation with considering DG units in the distribution system can be defined as follow [42]

$$P_{Grid} + \sum_{i=1}^{N_{DG}} P_{DGi} = \sum_{j=1}^{N_l} P_d(j) + P_{LOSS} \tag{17}$$

$$Q_{Grid} + \sum_{i=1}^{N_{DG}} Q_{DGi} = \sum_{j=1}^{N_l} Q_d(j) + Q_{LOSS} \tag{18}$$

2) INEQUALITY CONSTRAINTS

a: VOLTAGE LIMIT CONSTRAINTS

The voltage at each bus of the distribution system should be limited as following [42]:

$$V_{Li}^{min} \leq V_{Li} \leq V_{Li}^{max} \tag{19}$$

b: DG LIMIT CONSTRAINTS

The minimum and maximum allowable values of the active and reactive output power of DG units in the distribution system can be defined as follow:

$$P_{DGi}^{min} \leq P_{DGi} \leq P_{DGi}^{max} \tag{20}$$

$$Q_{DGi}^{min} \leq Q_{DGi} \leq Q_{DGi}^{max} \tag{21}$$

c: FEEDER CONSTRAINTS

The loading for each branch of distribution system should be limited using the following equation:

$$S_{li} \leq S_{li}^{max} \tag{22}$$

F. TOTAL OBJECTIVE FUNCTION

In this paper, the above four objective functions which are the minimization of fuel cost, total real power loss, voltage deviation and pollution emission for some DGs are combined and converted into CSOF based on some coeficients. Therefore, the total objective function can be expressed as follows:

$$\begin{aligned} \mathcal{F} &= C_{DG} + C_{P_{LOSS}} + C_E + C_{VD} \\ &= C_{DG} + P_{LOSS}W_{LOSS} + E_{DG}W_E + V_D W_{VD} \end{aligned} \tag{23}$$

IV. PROPOSED OPTIMIZATION ALGORITHM

A. MOTH FLAME OPTIMIZATION OVERVIEW

Moth-Flame Optimization (MFO) recently proposed in [27] is a population-based algorithm which mimics the moth's navigation way in nature. It is based on the navigation way named transverse orientation of the moths. The main idea of the transverse orientation method is employing a fixed angle with respect to the moon by moths during flying. The moths attempt to keep the fixed angle when they see an artificial light that is very close in comparison with the moon, but they fail. So, they fly in a logarithmic spiral mechanism during convergence with the flame [27], [34].

The model of the MFO algorithm consists of two important components. They are moth and flame. The moths represent the members (solutions) which move around the search space, while the flames represent the best position (problem's variables) found for these members. The MFO begins with an initial population of moths and flames which are randomly generated. The moth movement is oriented by the flames. The fitness value of each moth is then calculated based on the problem objective function. In the next iteration, the number of flames is decreased by removing the unfit flames which guide the moths to move to the fittest flame. These processes are repeated until only one flame remains which means that the best solution for the problem is obtained.

After the initial population of moths and flames are generated randomly, the mathematical model of transverse orientation behaviour can be expressed. The position of each moth which is guided by the flames can be updated as follows [27]:

$$MO_i = g(MO_i, F_k) \tag{24}$$

The logarithmic spiral function can be expressed using the following equation [27]:

$$g(MO_i, F_k) = D_i \cdot \exp(s\varepsilon) \cdot \cos(2\pi\varepsilon) + F_k \tag{25}$$

D can be expressed as follows [27]:

$$D_i = |F_k - MO_i| \tag{26}$$

The parameter ε is a very important parameter in (25) where it controls the flying direction of the moth around the flame. Equation (25) permits a moth to navigate around a flame and not essentially within the space between them. To confirm exploitation property, the parameter ε is chosen as a random number $\in [c, 1]$. The parameter c which called the convergence constant is linearly decreased from -1 to -2 over the iterations.

Also, to improve the exploitation property, the number of flames is decreased progressively with the iterations as follows [27]:

$$\text{Flame number} = \text{round}\left(N_f - it * \frac{N_f - it}{max_{it}}\right) \tag{27}$$

More details and the pseudo code of the original MFO algorithm can be found in [27].

B. MODIFIED MOTH FLAM OPTIMIZATION (MMFO)

To derive the proposed MMFO method, two modifications are made in the conventional MFO. In the conventional MFO, the convergence constant (c) is linearly decreased from -1 to -2 over the iterations. Although this decrement emphasizes the exploitation property of the algorithm, it reduces the convergence rate of the conventional MFO. Thus, the convergence constant is decreased exponentially from -1 to -2 in this paper to guarantee the exploration-exploitation balance and increase the convergence rate of the conventional MFO as follows:

$$c = \exp\left(-\left(\frac{it}{max_{it}/2}\right)^2\right) - 2 \tag{28}$$

It is clear from (27) that the number of flames will reduce with iterations. This reduction in the flames' number makes the balance between the exploitation and exploration. Therefore, equation (27) is modified in the proposed MMFO to enhance the balance between exploitation and exploration of the algorithm as follows:

$$\text{Flame number} = \text{round}\left(N_f * \exp\left(-\frac{it}{max_{it}/4}\right)\right) \tag{29}$$

V. SIMULATION RESULTS AND DISCUSSIONS

The developed method presented in the previous section is applied to the IEEE-69 bus radial distribution test system which described in [43] and shown in Fig. 1. The system consists of the main root bus represent the utility grid at bus 69, 70 branches where the system voltage is 12.66 kV. The system load active and reactive power are 3.86 MW and 2.69 MVAR, respectively. While the maximum and minimum voltage limits are 0.95 and 1.05 p.u., respectively [41], [44].

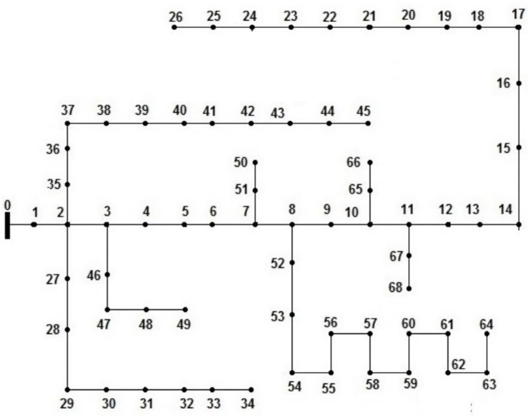

FIGURE 1. Single line diagram of IEEE-69 bus radial distribution test system.

The notability of the developed MMFO method in determining the optimal location and sizing of different DG units is proved in this paper compared with other published algorithms. These algorithms are ant lion optimizer (ALO) [45], grey wolf optimizer (GWO) [46], dragonfly algorithm (DA) [47], conventional MFO [27], modified JAYA (MJAYA) algorithm [48], and Salp swarm algorithm (SSA) [49].

In the implementation of the proposed MMFO and other meta-heuristic methods, many parameters should be chosen. In this paper, the appropriate values of these parameters are obtained based on empirical tests. All the numerical studies have been run on 2.9-GHz i7 PC with 8 GB of RAM using MATLAB 2014a.

Firstly, the sorting list of buses is obtained using the BLI method described in section II to create narrow candidate buses as shown in Fig. 2. Table 1 shows candidate buses

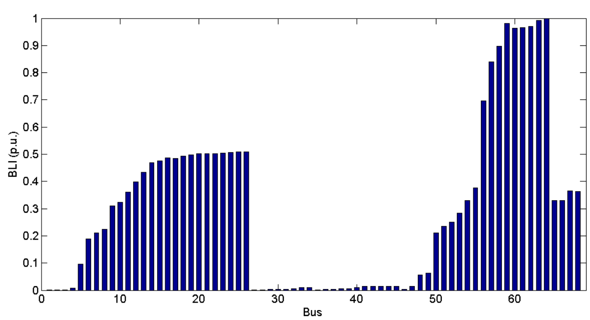

FIGURE 2. BLI values for the IEEE-69 bus radial distribution test system.

TABLE 1. BLI values for the IEEE-69 bus system.

Bus	BLI (p.u.)	Bus	BLI (p.u.)	Bus	BLI (p.u.)
64	1	12	0.397816	42	0.013678
63	0.993268	55	0.375737	43	0.01348
59	0.98034	67	0.365981	41	0.013333
62	0.971294	68	0.3638	40	0.010778
61	0.966651	11	0.361902	34	0.00992
60	0.963226	66	0.330676	33	0.00913
58	0.897912	54	0.330458	4	0.008807
57	0.839368	65	0.32944	32	0.006168
56	0.697021	10	0.323164	39	0.004697
26	0.508581	9	0.309725	38	0.004677
25	0.50826	53	0.284396	37	0.004281
24	0.507385	52	0.251307	31	0.003662
23	0.505223	51	0.235839	30	0.002814
22	0.503262	8	0.223032	36	0.002699
21	0.502959	50	0.21179	29	0.00266
20	0.502305	7	0.211411	46	0.002218
19	0.497075	6	0.18895	3	0.001692
18	0.492458	5	0.095552	28	0.001411
16	0.486484	49	0.062075	35	0.000852
17	0.483816	48	0.056256	27	0.000769
15	0.475544	47	0.015392	2	0.000705
14	0.46897	44	0.014356	1	0.000353
13	0.433426	45	0.014153		

sorting in descending order, accordingly, the first twenty buses from the table were chosen for primary locations of DG units. Then the MMFO method is used to find optimal placement and sizing of DG based on the proposed objective function.

The simulation results are executed with consideration of the system maximum load. Moreover, the maximum capacity of DG power is limited to 30% of the total load demand. In addition, the DG units can deliver active power and reactive power where the DG units are represented as PQ model at power factor 0.9 [41], [44], [50].

To evaluate the MMFO method, different scenarios are carried out as follows:

- Location and sizing for one DG unit
- Location and sizing for two DG units
- Location and sizing for three DG units

In all scenarios, there are six types of DG units (fuel cell, micro-turbine, photovoltaic, wind, hydro and biomass). The specifications of these types can be found in [39], [51]. Table 2 shows the capital costs, variable fuel cots, average operating and maintenance costs, and emission factors for NO_x, SO_2 and CO_2 [39], [41], [52]. Also, the maximum capacity of all DG power is limited to 30% of the total load demand in the range of 0.1 MVA to 1.48 MVA [53], [54].

A. LOCATION AND SIZING FOR ONE DG UNIT

According to different technologies of renewable energy sources as DG units, the simulation results for locating and

TABLE 2. Economic and emission factors of DG units.

	Capital cost ($/KW)	Variable fuel cost ($/MWh)	Operating and maintenance cost ($/KW.year)	Emission factors (Kg/MW)		
				CO_2	SO_2	NO_x
Fuel cell	3500	35	6.5	723.87	0.003628	0.19954
Micro-Turbine	1100	3.67	6.31	502.478	0.003628	0.5215
PV	3010	0	45	—	—	—
Wind	1980	0	60	—	—	—
Hydro	3500	6	15	—	—	—
Biomass	3830	15	95	—	—	—

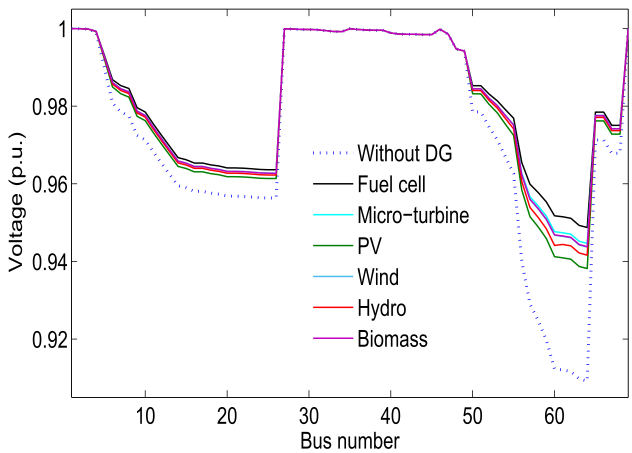

FIGURE 3. The effect of using one DG unit on voltage profile using the developed MMFO.

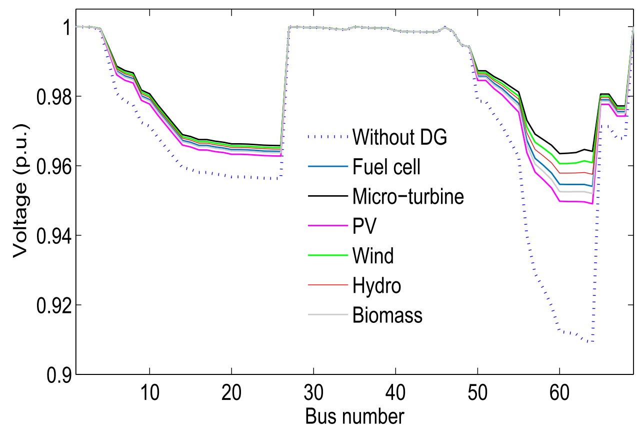

FIGURE 4. The effect of using two DG units on voltage profile using the developed MMFO.

sizing one DG unit using a developed MMFO in comparison with other techniques are shown in Table 3. In addition, the effect of using one DG unit on the voltage profile using the developed MMFO is shown in Fig. 3.

The results show that the minimum total cost of the system was obtained by using the proposed MMFO compared with other meta-heuristic optimization techniques. A great benefit is obvious of the proposed MMFO when using one micro-turbine at optimal bus 60 with optimal sizing of 0.6144 MVA where the total cost of the system is 1.7690 $M\$$ with a reduction of the total power losses to 0.1001 MW which represents percentage reduction 55.15 % from the real power loss without any DG unit. The minimum voltage is increased from 0.9092 p.u to 0.9446 and 0.9488 p.u when using one micro-turbine and one fuel cell, respectively. In addition, Fig. 3 shows that the best voltage profile can be obtained when one fuel cell is used.

B. LOCATION AND SIZING FOR TWO DG UNITS

To confirm the efficiency of the developed MMFO to obtain the best location and size of DG, it is applied for two units of DG. The simulation results for locating and sizing two DG units using a developed MMFO in comparison with other recently published techniques are shown in Table 4. Also, the effect of using two DG units on voltage profile based on the developed MMFO is shown in Fig. 4.

These results prove that the minimum total cost of the system may be obtained using the proposed MMFO compared with other meta-heuristic techniques, based on employing two micro- turbines at optimal buses 60 and 63 with optimal sizing of 0.4423 and 0.6 MVA, respectively where the total cost of the system is equal to 2.0555$M\$$. In addition, the total real power loss is reduced to 0.0628 MW which represents a percentage reduction of 72.08% from the real power loss without any DG unit. The minimum voltage is increased from 0.9092 p.u to 0.9635 upon using two micro-turbines. In addition, Fig. 4 shows that the best voltage profile obtained when two micro-turbines are used.

C. LOCATION AND SIZING FOR THREE DG UNITS

In this case, to prove the superiority of the developed MMFO for finding the optimal location and size of DG, it is applied for three units of DG. The simulation results for locating and sizing three DG units based on developed MMFO in comparison with other published techniques are shown in Tables 5 and 6. Furthermore, the effect of using three DG units on the voltage profile based on proposed MMFO is shown in Fig. 5.

The results clearly indicate that the superiority of the proposed MMFO over other methods, where it gives the minimum total cost. The minimum total cost obtained using the proposed MMFO with inserting three micro-turbines at buses 60, 61 and 63 with optimal sizing of 0.6477, 0.3185 and 0.2293 MVA, respectively and the total cost of the system equal to 2.3064 $M\$$. By inserting three micro-turbines in the system, the total power loss is decreased to 0.0576 MW which represents a percentage reduction of 74.4 % from the real power loss without any DG unit. While the minimum voltage

TABLE 3. Results for using one DG unit.

DG type	Method	DG installation		Power losses	Voltage	Emission	Cost of DG	Total cost
		Size (MVA)	Bus	(MW)	deviation	(Kg)	(M$)	(M$)
Without	—	—	—	0.225	1.836	—	—	—
Fuel cell	ALO	0.7680	60	0.0961	1.3211	386.3186	5.2815	5.5726
	DA	0.7515	63	0.1009	1.3413	378.0147	5.2755	5.5809
	GWA	0.7938	61	0.0865	1.2794	400.3852	5.2916	5.5538
	MFO	0.7619	60	0.0980	1.3289	383.2177	5.2793	5.5759
	MJAYA	0.7777	61	0.1073	1.3356	384.6856	5.2803	5.5568
	SSA	0.781	60	0.0919	1.3030	392.8427	5.2862	5.5645
	MMFO	0.7975	61	0.0849	1.2725	401.1380	5.2921	**5.5494**
Micro-turbine	ALO	0.8157	60	0.0964	1.3110	590.5978	1.6956	1.8285
	DA	0.7766	62	0.1008	1.3352	562.2635	1.6897	1.8236
	GWA	0.7766	61	0.1008	1.3352	562.2635	1.6897	1.8236
	MFO	0.4012	60	0.1683	1.6272	341.8753	1.6232	1.7951
	MJAYA	0.5375	60	0.1551	1.4531	383.8066	1.6527	1.7769
	SSA	0.8425	64	0.0887	1.2776	590.9409	1.6996	1.8220
	MMFO	0.6144	60	0.1001	1.3666	444.8316	1.6654	**1.7690**
PV	ALO	0.8726	60	0.1208	1.3660	—	5.0896	6.4817
	DA	0.9099	60	0.1180	1.3468	—	5.1232	6.5413
	GWA	0.7886	63	0.1279	1.4107	—	5.0121	6.3576
	MFO	0.6296	63	0.1492	1.5097	—	4.8710	6.3658
	MJAYA	0.5500	60	0.1515	1.5363	—	4.7921	6.3082
	SSA	0.6697	63	0.1042	1.2908	—	5.1770	6.3783
	MMFO	0.7412	60	0.1318	1.4343	—	4.9713	**6.2927**
Wind	ALO	0.7883	61	0.0884	1.2884	—	3.7774	4.6644
	DA	0.6876	61	0.1087	1.3797	—	3.6565	4.6923
	GWA	0.7381	60	0.0943	1.3202	—	3.7201	4.6187
	MFO	0.4561	60	0.1467	1.5406	—	3.3788	4.6366
	MJAYA	0.5633	62	0.1593	1.5282	—	3.4981	4.5345
	SSA	0.7993	60	0.0924	1.2614	—	3.7905	4.6165
	MMFO	0.6585	63	0.0964	1.3424	—	3.6216	**4.4439**
Hydro	ALO	0.7084	60	0.1035	1.3596	—	5.2436	5.5205
	DA	0.6207	63	0.1145	1.4039	—	5.2283	5.5346
	GWA	0.7350	60	0.0952	1.3250	—	5.2520	5.5070
	MFO	0.5347	61	0.1246	1.4557	—	5.1851	5.4747
	MJAYA	0.4752	63	0.1747	1.4619	—	5.1441	5.4895
	SSA	0.7233	60	0.0990	1.3409	—	5.2486	5.5136
	MMFO	0.6164	61	0.1045	1.3783	—	5.2126	**5.4557**
Biomass	ALO	0.6478	62	0.1113	1.3968	—	6.7716	8.4441
	DA	0.5691	63	0.1266	1.4546	—	6.6143	8.5163
	GWA	0.6831	60	0.1025	1.3626	—	6.8309	8.3712
	MFO	0.6643	61	0.1067	1.3776	—	6.8045	8.4072
	MJAYA	0.5885	64	0.1544	1.5189	—	6.9388	8.4801
	SSA	0.6643	61	0.1245	1.4461	—	6.8045	8.5017
	MMFO	0.6938	60	0.0980	1.3429	—	6.8634	**8.3361**

can be increased from 0.9092 p.u to 0.9666 while using three units of the fuel cell. In addition, Fig. 5 shows that the best voltage profile can be obtained when three units of the fuel cells are used.

D. DISCUSSION

By employing the reduced sorting list of buses based on the BLI method, the computational time can be minimized. In addition, the efficiency of the investigation is improved whereas preserving the equilibrium through exploitative and exploratory.

From the simulation results, the optimal location and sizing of DG's are different for all cases according to different technologies of DG's based on the suggested objective function. However, the proposed MMFO technique offering great performance compared with other meta-heuristic

TABLE 4. Results for using Two DG units.

DG type	Method	DG installation		Power losses	Voltage	Emission	Cost of DG_1	Cost of DG_2	Total cost
		Size (MVA)	Buses	(MW)	deviation	(Kg)	(M$)	(M$)	(M$)
Without	—	—	—	0.225	1.836	—	—	—	—
Fuel cell	ALO	0.5011 / 0.3193	60 / 63	0.0920	1.2916	252.04093 / 160.54556	3.0241	2.9587	6.2825
	DA	0.6080 / 0.3203	61 / 63	0.0846	1.2407	301.8 / 161.08944	3.0598	2.9590	6.3284
	GWA	0.6368 / 0.2974	60 / 63	0.0697	1.1798	319.51147 / 149.4413	3.0724	2.9507	6.2718
	MFO	0.3078 / 0.5375	63 / 60	0.0835	1.2544	154.4555 / 271.0219	2.9543	3.0377	6.2642
	MJAYA	0.5195 / 0.3153	60 / 63	0.0875	1.2719	261.3119 / 158.6004	3.0308	2.9573	6.2731
	SSA	0.3746 / 0.4231	63 / 61	0.0976	1.3150	188.4214 / 212.8296	2.9786	2.9961	6.2922
	MMFO	0.5654 / 0.2924	60 / 61	0.0770	1.2253	284.59663 / 147.0736	3.0474	2.9490	**6.2477**
Micro-turbine	ALO	0.5380 / 0.5447	61 / 63	0.0668	1.1250	394.36906 / 389.54801	0.9756	0.9746	2.0751
	DA	0.4543 / 0.5225	61 / 63	0.0793	1.2040	285.3957 / 432.40098	0.9620	0.9723	2.0661
	GWA	0.2863 / 0.5995	64 / 60	0.0808	1.2390	205.44573 / 428.8132	0.9364	0.9828	2.0616
	MFO	0.6000 / 0.4401	60 / 63	0.0640	1.1299	434.4000 / 318.64575	0.9839	0.9599	2.0574
	MJAYA	0.4343 / 0.6000	63 / 61	0.0707	1.1565	314.4638 / 434.4000	0.9590	0.9839	2.0678
	SSA	0.5053 / 0.5851	63 / 60	0.0629	1.1074	365.8473 / 365.8473	9.6970	9.8170	2.0691
	MMFO	0.4423 / 0.6000	60 / 63	0.0628	1.1205	320.238 / 434.4000	0.9602	0.9839	**2.0555**
PV	ALO	0.4366 / 0.5921	62 / 61	0.1092	1.2793	—	2.8386	2.9785	7.3702
	DA	0.4619 / 0.6000	61 / 60	0.1072	1.2621	—	2.8614	2.9856	7.4743
	GWA	0.4118 / 0.5670	61 / 63	0.1161	1.3332	—	2.7392	2.8856	7.2969
	MFO	0.3500 / 0.3500	60 / 61	0.1350	1.4503	—	2.7606	2.7606	7.3053
	MJAYA	0.3500 / 0.4500	60 / 64	0.1119	1.3032	—	2.7075	3.0710	7.4802
	SSA	0.6064 / 0.4244	60 / 62	0.1090	1.2784	—	2.9914	2.8276	7.3711
	MMFO	0.3374 / 0.6000	60 / 61	0.1130	1.3100	—	2.7789	2.9856	**7.2599**
Wind	ALO	0.4785 / 0.5610	61 / 63	0.0675	1.1383	—	2.1830	2.2819	5.4007
	DA	0.5500/ 0.4806	60 / 62	0.0680	1.1452	—	2.2688	2.1854	5.3835
	GWA	0.3375 / 0.6000	62 / 63	0.0745	1.1959	—	2.0082	2.5288	5.3108
	MFO	0.4838 / 0.5000	63 / 60	0.0729	1.1770	—	2.1893	2.2088	5.3510
	MJAYA	0.5000 / 0.4671	60 / 62	0.0802	1.2096	—	2.2088	2.1693	5.4259
	SSA	0.4725 / 0.5784	61 / 60	0.0644	1.1248	—	2.1758	2.3028	5.3510
	MMFO	0.5500 / 0.4024	60 / 63	0.0648	1.1394	—	2.2688	2.0917	**5.2670**
Hydro	ALO	0.5598 / 0.4001	60 / 63	0.0749	1.1883	—	3.0323	2.9785	6.2778
	DA	0.3976 / 0.6200	60 / 61	0.0764	1.1752	—	2.9777	3.1627	6.3542
	GWA	0.3765 / 0.6000	62 / 63	0.0624	1.1281	—	2.9825	3.1421	6.2623
	MFO	0.3220 / 0.5485	63 / 60	0.0897	1.2711	—	2.9522	3.0285	6.2727
	MJAYA	0.3160 / 0.5712	63 / 62	0.1100	1.3887	—	2.8495	3.0446	6.3096
	SSA	0.5600 / 0.4185	62 / 60	0.0698	1.1668	—	3.0324	2.9847	6.2660
	MMFO	0.6000 / 0.3122	62 / 63	0.0688	1.1777	—	3.0458	2.9489	**6.2195**
Biomass	ALO	0.3714 / 0.4086	63 / 60	0.0938	1.3060	—	3.8541	3.9286	9.3827
	DA	0.5316 / 0.2183	64 / 60	0.1006	1.3323	—	4.1743	3.5482	9.4400
	GWA	0.3345 / 0.4687	61 / 64	0.0873	1.2808	—	3.7817	4.0331	9.3035
	MFO	0.2137 / 0.6000	63 / 61	0.0872	1.2771	—	3.5389	4.3110	9.3386
	MJAYA	0.4075 / 0.3633	60 / 63	0.0980	1.3234	—	3.9330	3.8268	9.4330
	SSA	0.4879 / 0.3095	60 / 64	0.0890	1.2859	—	4.0870	3.7305	9.3361
	MMFO	0.5154 / 0.2980	63 / 61	0.0821	1.2553	—	4.1419	3.7075	**9.2524**

optimization techniques. The main benefits of the proposed technique are achieved when using multiple DG units.

The outstanding performance of MMFO proposed is assigned through the locations of multiple DG units with different technologies simultaneously. The verification of the proposed method is achieved by considering the elaborate investigation for the location and sizing of two and three DG units with different technologies.

In case of using one DG with different technologies, the most optimal location bus has been 60 based on the proposed MMFO results with sizing varying between 0.6144 MW to 0.7975 MW.

It is seen that the locations of DGs are sequentially take placed by applying the proposed method for the PV, wind, and micro-turbine where the optimal location bus calculated in case of single DG is repeated in case of two DG units, finally the case of three DG units will contain the buses selected in previous cases.

When using three DG units, the proposed method gives better results in comparison with using one or two DG units referring to the reduction of power loss and voltage deviation. For example, Figures 6 and 7 show the relation between the size (number of DG units), power losses and voltage deviation, respectively when one, two or three micro-turbines

TABLE 5. Results for using Three DG units: Part A.

DG type	Method	DG installation		Power losses	Voltage
		Size (MVA)	Buses	(MW)	deviation
Without	—	—	—	0.225	1.836
Fuel cell	ALO	0.4039 / 0.3377 / 0.4893	63 / 62 / 60	0.0590	1.0499
	DA	0.3256/ 0.4963 / 0.5752	62 / 64/ 60	0.0569	0.9885
	GWA	0.5785 / 0.4388 / 0.2967	62 / 60 / 61	0.0519	0.9972
	MFO	0.3170 / 0.3876 / 0.5000	64 / 63 /60	0.0660	1.0882
	MJAYA	0.1558 / 0.4963 / 0.5213	60 / 63 / 62	0.0572	1.0576
	SSA	0.561 / 0.332 / 0.462	60 / 68 / 63	0.0521	0.9450
	MMFO	0.4295 / 0.3395 / 0.4532	61 / 63/ 60	0.0526	1.0273
Micro-turbine	ALO	0.3548/ 0.7127 / 0.1892	63 / 60 / 61	0.0607	1.0527
	DA	0.5000 / 0.3185 / 0.4509	60 / 64 / 63	0.0643	1.0593
	GWA	0.2980 / 0.7427 / 0.1892	58/ 60 / 62	0.0625	1.0692
	MFO	0.5000 / 0.3082 / 0.4522	60 / 61 / 63	0.0527	1.0122
	MJAYA	0.6000 / 0.3083 / 0.3509	60 / 64 / 62	0.0568	1.0360
	SSA	0.5340 / 0.4356 / 0.2371	60 / 63 / 58	0.0569	1.0534
	MMFO	0.2293 / 0.3185 / 0.6477	63/ 61 / 60	0.0576	1.0607
PV	ALO	0.3435/ 0.6100 / 0.2742	60 / 63 / 65	0.0973	1.1722
	DA	0.143 / 0.609 / 0.575	20 / 61 / 63	0.0941	1.0883
	GWA	0.2055 / 0.2563 / 0.7500	62 / 59 / 61	0.0987	1.1896
	MFO	0.4700 / 0.4453 / 0.2866	60 / 61 / 63	0.0992	1.1928
	MJAYA	0.5500 / 0.5500 / 0.2488	60 / 63 / 68	0.0644	0.9951
	SSA	0.4685 / 0.3203 / 0.5000	63 / 20 / 60	0.0788	1.0765
	MMFO	0.4900 / 0.4255 / 0.2868	60 / 61 / 63	0.1001	1.1984
Wind	ALO	0.2013 / 0.6158 / 0.4546	63 / 60 / 61	0.0492	0.9994
	DA	0.4214 / 0.5678/ 0.2958	61 / 63 / 62	0.0539	0.9861
	GWA	0.7037 / 0.3300 / 0.2218	61/ 64 / 59	0.0502	1.0077
	MFO	0.526 / 0.431 / 0.2173	61 / 60 / 63	0.0516	1.0266
	MJAYA	0.4378 / 0.4215 / 0.4589	61 / 63 / 62	0.0465	0.9671
	SSA	0.3545 / 0.3134 / 0.5689	60 / 68 / 63	0.0510	1.0089
	MMFO	0.1711/ 0.3256 / 0.6491	20 / 63 / 60	0.0555	0.9799
Hydro	ALO	0.2720 / 0.6254/ 0.3469	64 / 61/ 63	0.0616	1.0599
	DA	0.3832 / 0.2423 / 0.6292	63 / 62 / 60	0.0651	1.0708
	GWA	0.6477 / 0.2709 / 0.3692	60 / 58 / 61	0.0513	1.0040
	MFO	0.4972 / 0.3474 / 0.5000	60 / 63 / 62	0.0519	0.9831
	MJAYA	0.4885 / 0.5125 / 0.2037	63 / 60 / 68	0.0647	1.0597
	SSA	0.3420 / 0.6350 / 0.2627	62 / 60 / 63	0.0545	1.0332
	MMFO	0.5095/ 0.2295 / 0.4232	60 / 63/ 61	0.0569	1.0664
Biomass	ALO	0.5491 / 0.2348 / 0.3397	60 / 63 / 62	0.0669	1.1188
	DA	0.6000 / 0.5106 / 0.1263	63 / 61/ 64	0.0562	1.0608
	GWA	0.5752/ 0.3685 / 0.2012	60 / 63 / 61	0.0614	1.0893
	MFO	0.4059 / 0.3406 / 0.4213	63 / 61 / 60	0.0670	1.1033
	MJAYA	0.1278 / 0.5426 / 0.5258	64 / 60 / 63	0.0630	1.0210
	SSA	0.6500 / 0.1824 / 0.2836	61 / 62 / 60	0.0726	1.1406
	MMFO	0.3457 / 0.3377 / 0.4893	61 / 63 / 62	0.0562	1.0576

are used. These figures indicate that the reduction of power loss is increased from 55.15 % and 72.08 % using one or two micro-turbine units, respectively to 74.4 % using three micro-turbine units. Moreover, the voltage deviation is reduced from 1.3666 and 1.1205 using one or two micro-turbine units, respectively to 1.0607 % using three micro-turbine units.

The multiple locations of DG units might be useful but should be inspected firstly economically as seen from results for different types of DG technology where the increasing number of DG units will increase the total system cost.

To show the convergence property of the developed MMFO in comparison with other methods, Figs. 8 and 9 illustrate the convergence curves of the developed MMFO and other methods in case of using three DG units. From these figures, one can observe that the objective function of the developed MMFO converges smoothly to the optimum

TABLE 6. Results for using Three DG units: Part B.

DG type	Method	Emission (Kg)	Cost of DG_1 (M$)	Cost of DG_2 (M$)	Cost of DG_3 (M$)	Total cost (M$)
Without	—	—	—	—	—	—
Fuel cell	ALO	203.1667 / 169.8631 / 246.0927	2.1929	2.1691	2.2236	6.9781
	DA	163.7768 / 249.6389 / 289.3256	2.1647	2.2262	2.2546	7.0357
	GWA	290.9980/ 220.7405/ 149.2250	2.2558	2.2055	2.1543	6.9453
	MFO	159.4626 / 194.9842 / 251.5000	2.1616	2.1871	2.2275	7.0236
	MJAYA	78.3702 / 249.6389 / 262.2139	2.1036	2.2262	2.2352	6.9575
	SSA	281.6800 / 165.9900 / 231.3800	2.2491	2.1663	2.2131	6.9859
	MMFO	216.0385 / 170.7685 / 227.9596	2.2107	2.2021	2.1697	**6.9326**
Micro-turbine	ALO	256.8752 / 516.0237/ 137.0097	0.6967	0.7505	0.6718	2.3895
	DA	362 / 230.5795 / 326.4661	0.7185	0.6912	0.7111	2.4167
	GWA	215.7520 / 537.7437 /137.0097	0.6881	0.7550	0.6718	2.3707
	MFO	362.0000 / 230.5795 / 326.4661	0.7185	0.6912	0.7111	2.3643
	MJAYA	434.4000 / 223.2335 / 254.0661	0.7335	0.6897	0.6961	2.3810
	SSA	386.6363 / 315.3816 / 171.6714	0.7236	0.7088	0.6790	2.3737
	MMFO	165.9770 / 230.5800 / 468.9630	0.6778	0.6912	0.7407	**2.3064**
PV	ALO	———	2.0900	2.3099	2.0004	8.3108
	DA	———	1.8901	2.3009	2.2788	8.4524
	GWA	———	1.9457	1.9915	2.4358	8.1928
	MFO	———	2.1839	2.1617	2.0189	8.2063
	MJAYA	———	2.2559	2.2559	2.0747	8.2649
	SSA	———	2.1825	2.0491	2.2109	8.2457
	MMFO	———	2.2109	2.1604	1.9800	**8.1636**
Wind	ALO	———	1.3998	1.8971	1.7036	6.0995
	DA	———	1.6639	1.8396	1.4809	6.2038
	GWA	———	1.4243	1.5541	2.0026	6.0858
	MFO	———	1.8396	1.6706	1.4189	6.0951
	MJAYA	———	1.6835	1.6640	1.7088	6.1073
	SSA	———	1.5835	1.5343	1.8408	6.1111
	MMFO	———	1.3634	1.5489	1.9371	**6.0182**
Hydro	ALO	———	2.1391	2.2581	2.1643	7.0945
	DA	———	2.1766	2.1291	2.2594	7.1183
	GWA	———	2.2656	2.1387	2.1719	7.0290
	MFO	———	2.2150	2.1645	2.2159	7.0452
	MJAYA	———	2.2120	2.2201	2.1161	7.1080
	SSA	———	2.1627	2.3614	2.1360	7.0323
	MMFO	———	2.2191	2.1248	2.1900	**6.9502**
Biomass	ALO	———	3.3380	2.7098	2.9138	10.6737
	DA	———	3.3899	3.2112	2.4432	10.6687
	GWA	———	3.3901	2.9770	2.6426	10.6010
	MFO	———	3.0020	2.8715	3.0328	10.6388
	MJAYA	———	2.4463	3.2751	3.2416	10.5947
	SSA	———	3.4898	2.5552	2.7576	10.6831
	MMFO	———	2.9315	2.9155	3.2183	**10.5898**

solution without any unexpected oscillations which approves the convergence dependability of the developed MMFO. In addition, the developed MMFO needs fewer iterations in comparison with other methods to obtain the solution. This is due to the improved exploration and exploitation mechanism in the developed MMFO.

To further prove the effectiveness of the developed MMFO method over other methods, Figs. 10- 12 show the computational time for the developed MMFO method and other algorithms for one, two, and three DG units, respectively. These results prove that the developed MMFO method is more effective than others when computational time is considered.

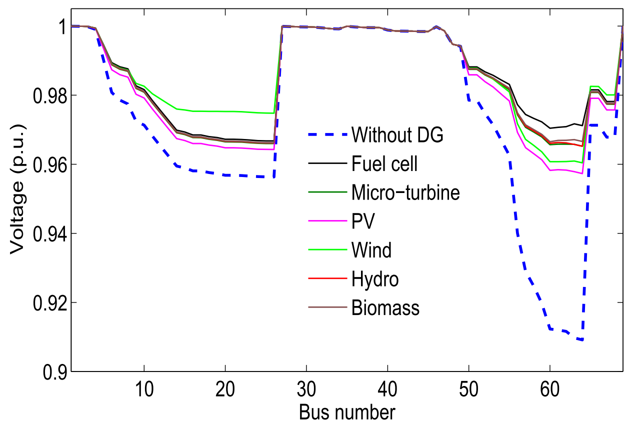

FIGURE 5. The effect of using three DG units on voltage profile using the developed MMFO.

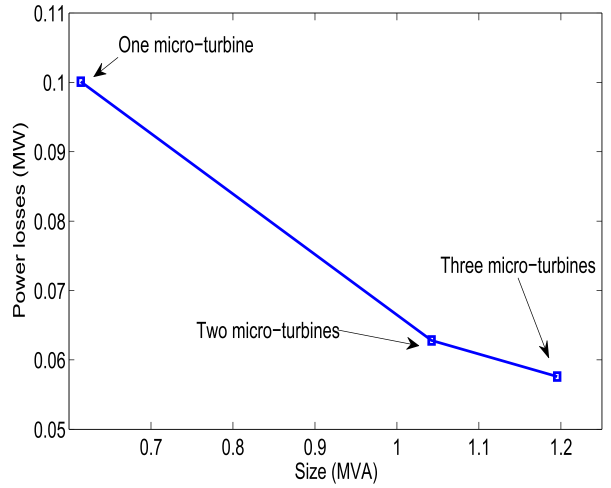

FIGURE 6. The relation between the size and power losses when one, two or three micro-turbines are used based on MMFO.

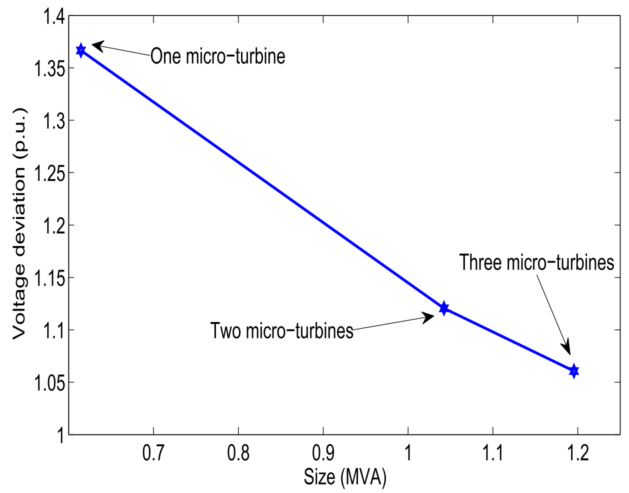

FIGURE 7. The relation between the size and voltage deviation when one, two or three micro-turbines are used based on MMFO.

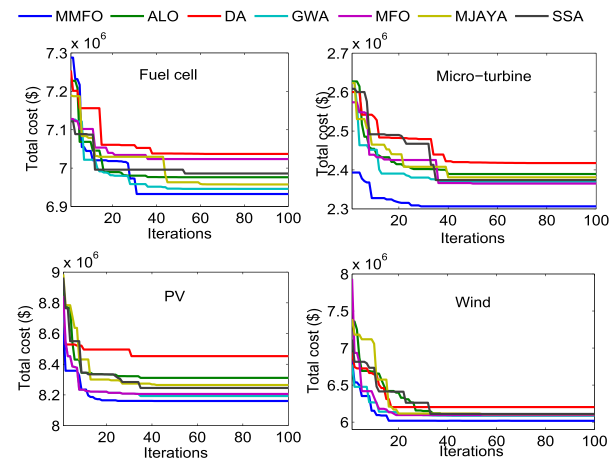

FIGURE 8. Comparison between the convergence characteristics of the developed MMFO and other methods in case of use three DG units: Part A.

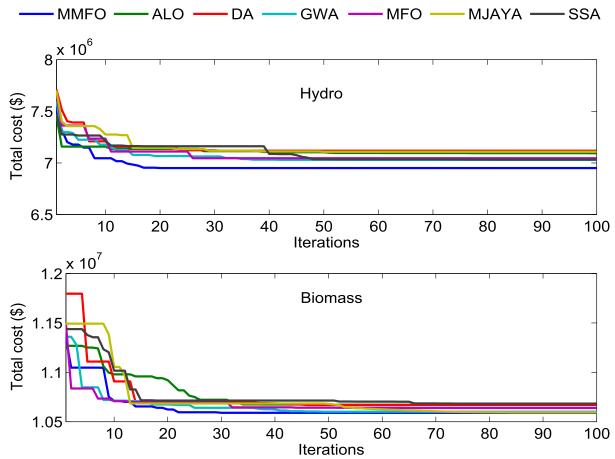

FIGURE 9. Comparison between the convergence characteristics of the developed MMFO and other methods in case of use three DG units: Part B.

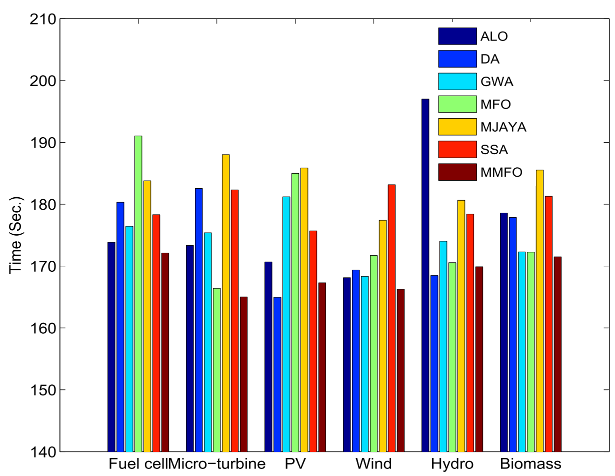

FIGURE 10. The computational time of all methods for using one DG unit.

The computational time of the developed MMFO is quite less and better than other optimization methods in most cases while it is comparable with other optimization methods in a few cases. As a whole, the developed MMFO is computationally efficient than the conventional MFO and other methods as a result of using the improved exploration and exploitation

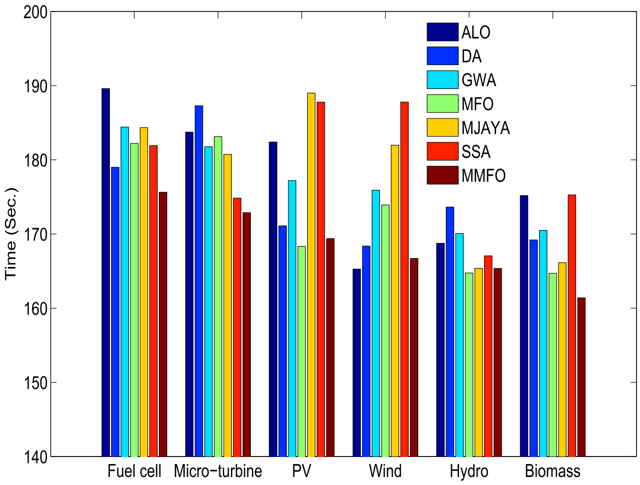

FIGURE 11. The computational time of all methods for using two DG units.

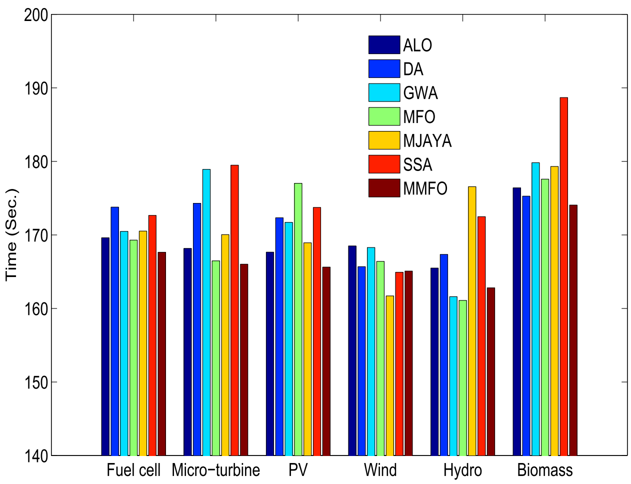

FIGURE 12. The computational time of all methods for using three DG units.

mechanism which accelerates the convergence of the MMFO method.

VI. CONCLUSION

The MMFO algorithm is proposed in this paper to find the optimal location and sizing of DG units based on renewable energy sources to minimize the total operating cost considering four different objective functions. The MMFO is developed to overcome the disadvantages of the conventional MFO, by improving the balance between the exploration and exploitation and speed up the convergence of the algorithm. Also, the total objective function which consists of four different functions is converted to coefficient single objective function. The performance of the developed MMFO algorithm is verified using a standard test system and compared with some meta-heuristic methods to discover its notability based on different scenarios. It can be noticed from the results that the MMFO algorithm provided a better reduction of the objective function for all scenarios over other meta-heuristic methods used in the comparison. The comparisons' results with other meta-heuristic methods evidently demonstrate that the MMFO algorithm outperformed these meta-heuristic methods whatever the number of DG units.

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