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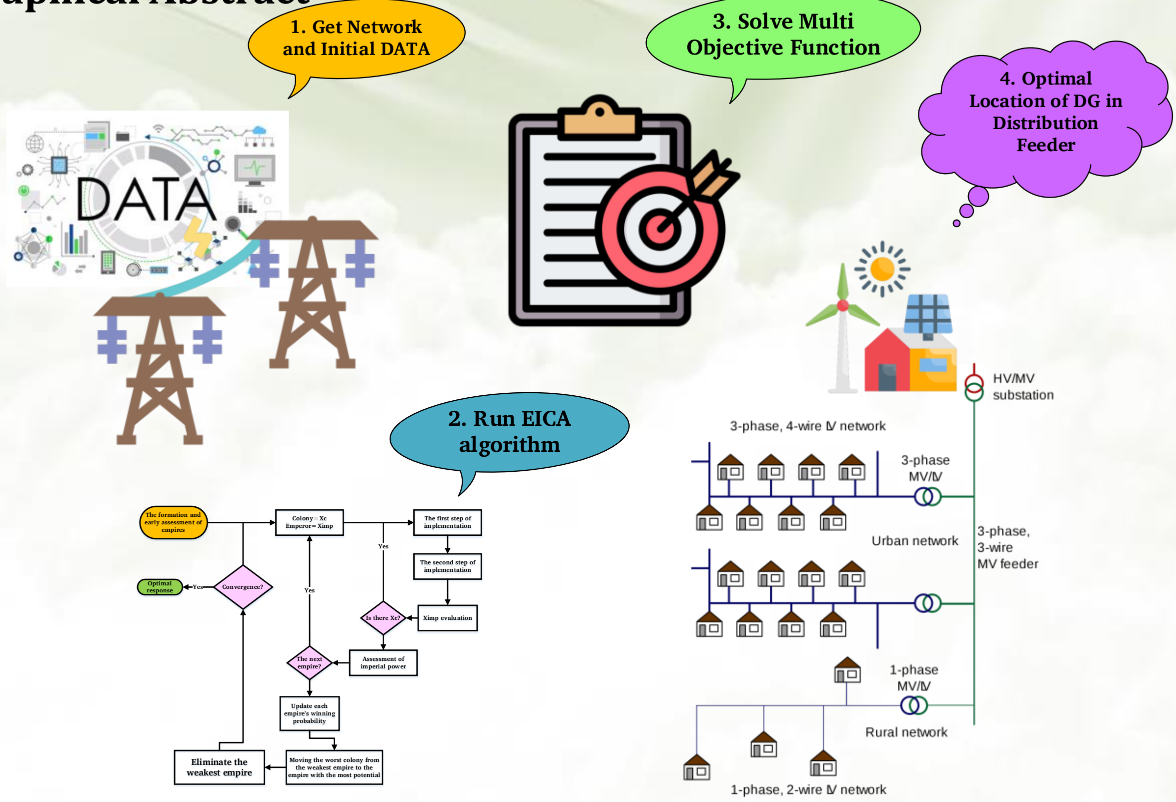
Highlight

- Location and sizing of renewable resources
- Using Enhanced Imperialist Competitive Algorithm
- Carrying out the proposed design on a practical feeder

Graphical Abstract



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Improving the Technical and Economic Indexes of Distribution Network by Three-Stage Enhanced Imperialist Competitive Algorithm

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ABSTRACT

Restructuring the distribution system in the presence of distributed generation (DG) sources is an effective solution to reduce the cost of power generation and improve the technical and economic parameters of networks. This paper models the optimal design of the location and capacity of DGs in a distribution system as a multi-objective optimization problem. The technical parameters of the problem include network losses, voltage stability index, and voltage profile improvement. Moreover, the economic parameters of the problem are the capital and operation costs of the system. The optimization problem presented in this paper is of mixed-integer nonlinear programming (MINLP) type, so the enhanced imperialist competition algorithm (EICA) is adopted to minimize the objective function. In this algorithm, adding a new implementation phase to the ICA increases searchability and thus enhances the algorithm's efficiency over ICA. The proposed method is first implemented on a standard IEEE 33-bus system. Then, a real network is incorporated to optimize the technical and economic parameters. The analysis and comparison of the results demonstrate the efficacy of the suggested algorithm in the optimal design of the system compared to the original ICA .In this article, we are finally able to bring the voltage profile and voltage stability index of the "Rahdarkhaneh" distribution feeder close to 1 pu and significantly reduce the network losses.

1. Introduction

Population growth, economic development, and industrialization of countries have increased the consumption of electrical energy, making it necessary to develop and expand distribution systems and increase investments in this industry. The expansion of distribution systems results in escalated losses, voltage drops, and, thus, a decrease in node voltage stability and load imbalance. Power loss has always been a considerable amount due to the large scale of the distribution network, low X/R ratio, and voltage drop along the path of distribution network feeders, so that it is estimated that more than 13%

of the total power produced in the networks is wasted in distribution networks [1]. In recent years, various measures have been taken to optimize and shift the distribution networks from the traditional structure to the new structure, and DGs have played an essential role in these changes and the new structure [2-5].

1.1. Motivation

DGs provide many advantages for both consumers and distribution companies. If these sources are optimally located, the loss will significantly be reduced, the voltage profile will improve, and by installing DG in weak buses, the operation of the distribution system will perhaps be stabilized. Also, government incentives, low cost of energy transmission, low investment risk, and high efficiency have highlighted the economic importance of DGs in recent years. On the other hand, misplacement of DGs in the network causes problems, such as increasing losses, overvoltage, or voltage drop in the network, and increasing the costs of energy generation and transmission. Hence, researchers have widely discussed optimizing the location and capacity of DGs in the distribution system.

1.2. Literature review

So far, numerous researches have been carried out to optimize the operation of DGs in distribution systems. Most of these studies have used metaheuristic methods to solve the problem of optimizing the location and size of these resources in power systems. For example, authors in [3-5] used mixed particle swarm optimization, multi-objective particle swarm optimization, and the coyote optimization algorithm to minimize power losses and improve the voltage profile in the distribution network, respectively. Also, the optimal location of DGs in an unbalanced distribution network was found by using a genetic algorithm [6]. The differential algorithms, firefly algorithm, and gray wolf algorithm are other methods employed in [7-12] to find the optimal location of DGs, respectively. On the other hand, studies have pursued various objectives in locating DGs. For instance, the effect of installing photovoltaic (PV) DG on reducing losses and improving the voltage profile in a real rural distribution system in Yogyakarta, Indonesia was investigated in [10]. The voltage and reactive power control methods using PVs on a standard 33-bus system were evaluated in [11]. The simultaneous installation of DGs and DSTATCOM in distribution networks to minimize power loss and voltage deviation and maximize the voltage stability index was introduced [12] using the Lightning Search Algorithm (LSA). Also, increasing the system's reliability has been a concern of researchers in the optimal design of the location and capacity of DGs [13]. Four heuristic algorithms for reducing distribution network losses in the presence of DGs were compared in [14]. In some studies, the problem of restructuring and reconfiguring the distribution network has been solved to reduce power losses and improve the reliability index [15-18]. However, many studies on locating DGs in the distribution system have only examined the network's technical parameters in the objective function. For example, the problem of locating DGs to reduce power losses was implemented in [5] and [7]. Authors in [2] discussed the economic aspects of the presence of DGs in the network with the objective function of maximum saving and improvement of the voltage profile. Also, in most articles, studies have been conducted only on standard IEEE networks, while in a few cases, DG location has been done on the real case [10, 13, 19-23]. On the other hand, using a powerful search algorithm to find the optimal solution needs to be considered.

1.3. Research gap

Therefore, to overcome the shortcomings in the research related to the optimal allocation of DGs in the distribution system, this paper presents a new optimal location and sizing of DGs. The method is a nonlinear multi-objective optimization problem in which, in addition to the technical parameters, the economic parameters of the system are also examined. Moreover, the objective function is minimized by the EICA algorithm, which improves the efficiency of the algorithm by adding two separate steps to the conventional ICA.

1.4. Contributions and Novelties

The research contributions are as follows:

1- Locating scattered production resources by a new EICA algorithm

2- Solving the problem of location and capacity of DG in three different modes on a real feeder

3- Dramatically improving the technical and economic parameters of the network

The rest of the paper is organized as follows. Section 2 is dedicated to the formulation and layout of the problem. Section 3 describes the solution method. Section 4 presents the analysis of the results, and finally, Section 5 provides the conclusion.

2. Problem formulation

This section presents the formulation of a comprehensive DG location problem. The objective function considered here includes technical and economic functions, taking into account network constraints, expressed as cost minimization.

2.1. Objective function

The proposed method's objective function is formulated as a multi-objective nonlinear programming (NLP) function. From a technical point of view, reduction of losses, improvement of voltage profile, and enhancement of grid voltage stability are considered. DG investment cost, DG repair and maintenance cost, and DG power generation cost are the economic aspects of the optimization problem [26]. Therefore, the total objective function is formulated as Equation (1):

$$\mathrm{Min}(f)=F_{\mathrm{TOTAL\text{-}COST}}+K_1 f_v+K_2 f_{VSI} \qquad (1)$$

Where coefficients K_2 and K_1 are weighting coefficients for the contribution of each voltage stability index and voltage profile in the objective function, respectively, and $F_{\mathrm{TOTAL\text{-}COST}}$ is the total cost function calculated by Equation (2) [28, 30-32]:

$$F_{\mathrm{TOTAL\text{-}COST}}=F_{\mathrm{installation}}+F_{\mathrm{maintenance}}+F_{\mathrm{operation}}+F_{\mathrm{Reduction\text{-}loss}} \qquad (2)$$

Where $F_{\mathrm{installation}}$, $F_{\mathrm{maintenance}}$, $F_{\mathrm{operation}}$, and $F_{\mathrm{Reduction\text{-}loss}}$ are the costs of investment and installation, repair and maintenance, power generation, and reduction of the cost of purchased power calculated by Equation (3)-(6), respectively.

$$F_{installation}=\sum_{i=1}^{N_{DG}}.\sum_{j=1}^{C_{DG}}COST_{installation,ij} \tag{3}$$

$$F_{maintenance}=\sum_{i=1}^{N_{DG}}.\sum_{j=1}^{C_{DG}}COST_{main,ij}\times\sum_{t=1}^{T}((1+\inf R)/(1+\text{int }T))^{t} \tag{4}$$

$$F_{operation}=\sum_{i=1}^{N_{DG}}.\sum_{j=1}^{C_{DG}}T_J\times G_{DG,ij}\times G_{cost,ij}\times\sum_{t=1}^{T}((1+\inf R)/(1+\text{int }T))^{t} \tag{5}$$

$$F_{Reduction\text{-}loss}=T_j\times C_{energy\text{-}market}\times(Loss+\sum_{n=1}^{num}P_{load}-\sum_{n=1}^{NDG}C_{DG})\times\sum_{t=1}^{T}((1+\inf R)/(1+\text{int }T))^{t} \tag{6}$$

where (inf R), (inf T), (T), and (T_J) denote the inflation rate, interest rate, time horizon, and duration of DG power generation in one year, respectively. Also, f_v is the voltage regulation index determined by Equation (7):

$$f_v=\sum_{i=1}^{N_n}(V_i-V_{rate})^2 \tag{7}$$

Also, parameter f_{VSI} is the voltage stability index in the distribution network, which is defined as Equation (8):

$$f_{VSI}=\frac{1}{\min(SI(n_i))}\qquad i=1...,N_n \tag{8}$$

This index for the evaluation of all network nodes is mentioned in [16] and [24] as given in Equation (9), where SI is the voltage stability index in the *i*th bus. This value must be positive for all buses for the stable operation of the distribution system.

$$SI(n_i)=|V_{i-1}|^4-4[P_iR_{i-1}+Q_iX_{i-1}]|V_{i-1}|-4[P_iR_{i-1}+Q_iX_{i-1}]^2 \tag{9}$$

2.2. Problem constraints

The constraints of the optimization problem are described below:

2.2.1. Power balance constraint

The presence of DG in the network should satisfy the condition of active and reactive power balance in all network buses. Network buses are satisfied as Equation (10) and (11) [34, 35]:

$$P_{gi}-P_{di}-V_i\sum_{j=1}^{N}V_jY_{ij}\cos(\delta_i-\delta_j-\theta_{ij})=0 \tag{10}$$

$$Q_{gi}-Q_{di}-V_i\sum_{j=1}^{N}V_jY_{ij}\sin\left(\delta_i-\delta_j-\theta_{ij}\right)=0 \tag{11}$$

2.2.2. Voltage limits

The presence of the DG in the network should maintain bus voltages within their allowable range, as given in Equation (12) [36]:

$$V_i^{min}<V_i<V_i^{max}\qquad,\qquad i=1...,N_i \tag{12}$$

2.2.3. Lines capacity limits

The limits of line capacity are given in Equation (13):

$$|S_i|\le|S_i^{max}|\qquad,\qquad i=1,...,N_b \tag{13}$$

2.2.4. Generators' power generation limits

The limit on generation units' output power is provided by Equation (14):

$$P_{gi}^{min}<P_{gi}<P_{gi}^{max} \tag{14}$$

The paper adopts the forward-backward sweep method [17, 25, 33] to solve the problem described in Equation (10)-(14).

3. Methodology

The DG optimal location problem presented in this research is a multi-objective optimization problem that simultaneously considers the optimization of economic and technical parameters of the network. The proposed method is formulated as a nonlinear problem solved by metaheuristic methods in MATLAB software. Therefore, EICA [28-30], a new optimization strategy based on human socio-political evolution, is used in this paper to solve the proposed problem. In the following, a brief description of this algorithm is provided, and then the improvement of ICA is discussed using two separate solutions. EICA adds a new implementation step to standard ICA. Through this implementation, a country (neighbor) is randomly selected for each colony in each empire. If the neighbor is better, the colony moves to the neighbor in the same empire, and if the neighbor is weaker, the colony moves away from its neighbor. Also, the newly created colony replaces the current colony if it is better. Therefore, the efficiency of the algorithm is expected to improve. The proposed problem is solved by EICA through the following steps:

Step 1: Initialization of variables

After recalling information on loads and lines, the DGs' size and location are randomly selected. Power flow is performed to minimize Equation (1) to determine the value of the imperialist and colonies of the empires. Countries are created with a random position (Npop) and distributed by the empire (Nimp = Npop/5). The status of all the countries is evaluated, and the worthiest country is determined as the emperor.

Step 2: For each empire, step 3 is repeated.

Step 3: For each colony in the current empire, steps 4 to 6 are repeated.

Step 4: Implementation of Phase I: Every colony except the emperor is moved by Equation (15):

$$X_{c,new}=X_c+(4\times rand-1)+\left(X_{imp}-X_c\right) \tag{15}$$

$X_{c,new}$ is evaluated, and if it is better than X_c, it replaces X_c.

Step 5: Implementation of Phase II: A neighboring colony X_{Nh} is randomly selected. If X_{Nb} is better than X_c, S = +1; otherwise, S = -1. Colony $X_{c,new}$ is created according to Equation (16):

$$X_{c,new}=X_c+ rand\times s +(X_{Nb}-X_c) \tag{16}$$

$X_{c,new}$ is evaluated, and if it is better than Xc, it replaces X_c.

Step 6: If there is a colony with a lower cost than the imperialists, it trades its position within the corresponding empire.

Step 7: Total power (T_{imp}), normalized total power (NT_{imp}), and probability (P_{imp}) for all empires are calculated by Equation (17)-(19):

$$T_{imp}=fitness\left(X_{imp}\right)+k\times\frac{\sum_{i=1}^{N_{imp}} fitness(X_{imp})}{2N_{imp}} \tag{17}$$

$$NT_{imp}=T_{imp}-max\left(T_{imp}\right) \tag{18}$$

$$P_{imp}=\left|\frac{NT_{imp}}{\sum_{i=1}^{N_{imp}} NT_i}\right| \tag{19}$$

Step 8: Transfer the worst colony from the weakest empire to the empire with the highest probability of winning based on (P_{imp}).

Step 9: Destroy the weak empires.

Step 10: Repeat **Step 2** until the termination criterion, i.e., reaching the maximum number of iterations (MaxIter) or a certain number of objective function evaluations, is met. Figure 1 shows the above steps in the EICA algorithm.

4. Results

This section presents the analysis of optimizing the DG's location and capacity in the distribution network using the proposed method in two test systems. This research was designed in four scenarios for each test system, where the number of DGs differed in each scenario. The proposed optimization method was solved for each scenario using both the ICA and EICA algorithms.

4.1. Standard IEEE 33-bus system

To evaluate the presented method, an IEEE standard 33-bus system given in [19] and [27] was studied as the first test system. The simulation results are given in Tables 1-4, while the voltage profile is illustrated in Figure 2. The location and power factor of DGs were different among the scenarios. Installation, maintenance, and operation costs were assumed to be the same in the two algorithms.

According to the values given in Tables 1-4, it can be seen that after optimizing the location and capacity of DGs in the 33-bus network, the technical objectives of the problem were placed in favourable conditions.

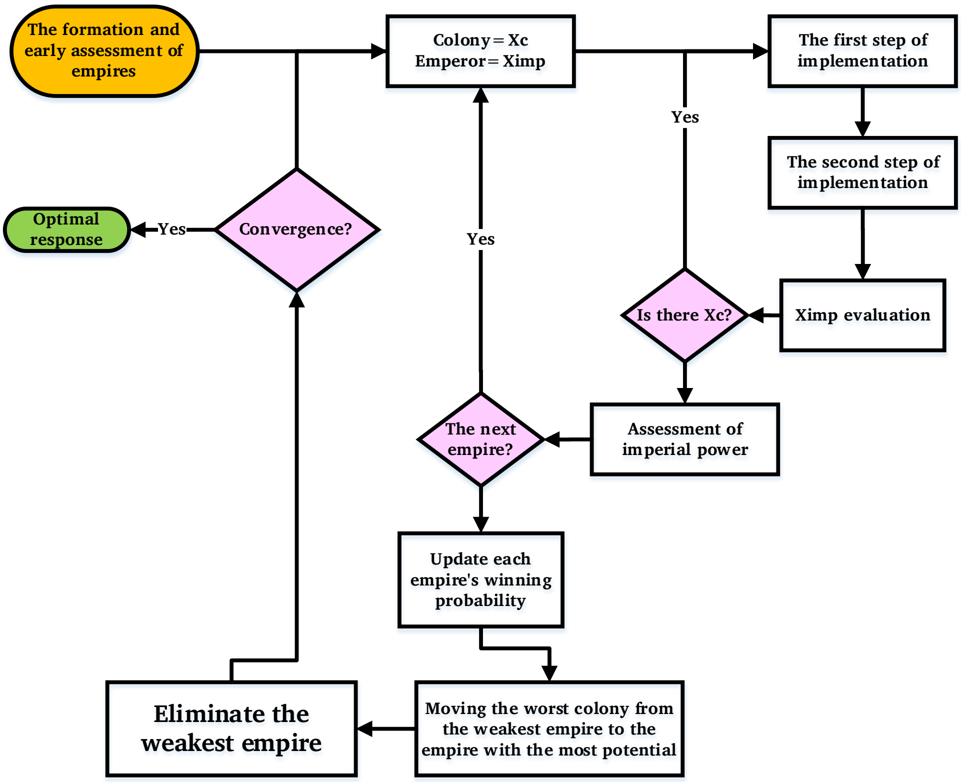
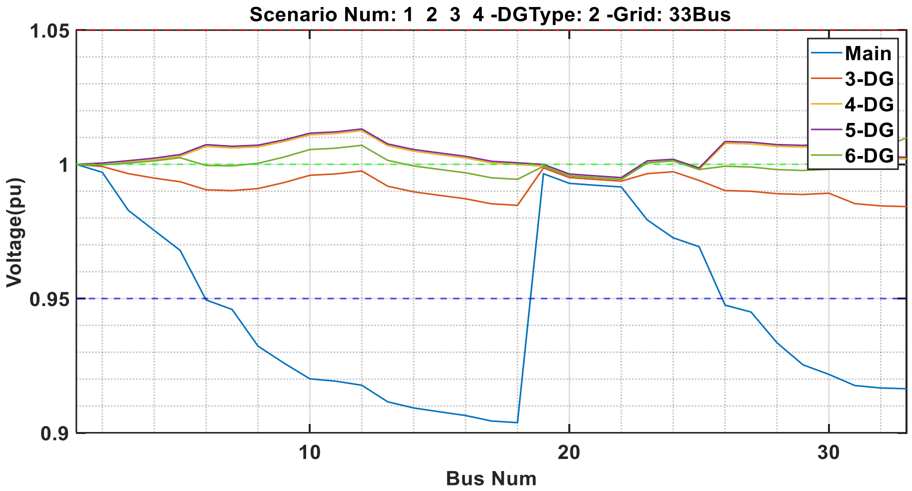
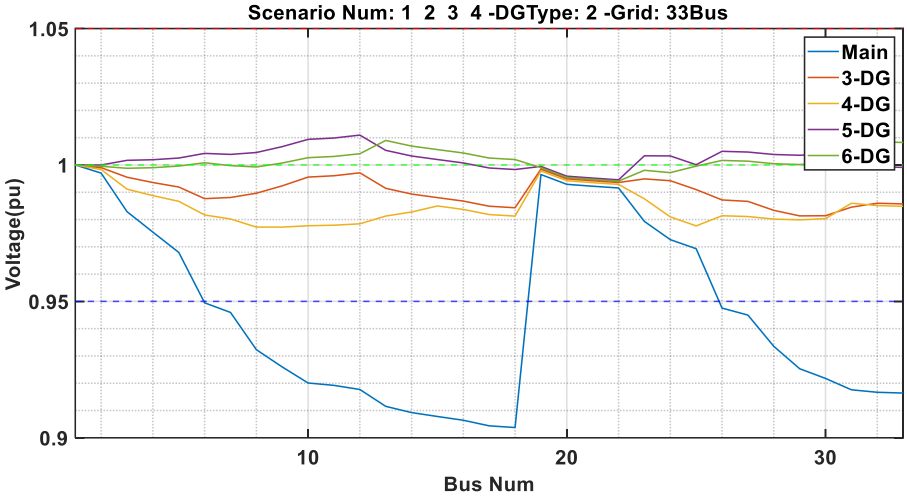


Figure 1. The flowchart of EICA.



(a) Voltage profile in EICA



(b) Voltage profile in ICA

Figure 2. Voltage profile of the 33-bus system.

Table 1. DG capacity (KVA) for the 33-bus system.

DG No.	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	ICA	EICA	ICA	EICA	ICA	EICA	ICA	EICA
DG1	1000	1000	1000	1000	1000	1000	1000	1000
DG2	982	1000	1000	1000	1000	1000	1000	1000
DG3	915	1000	856	1000	947	1000	828	1000
DG4	-	-	762	1000	588	1000	847	1000
DG5	-	-	-	-	736	1000	965	1000
DG6	-	-	-	-	-	-	653	1000

Table 2. DG power factor for the 33-bus system.

DG No.	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	ICA	EICA	ICA	EICA	ICA	EICA	ICA	EICA
DG1	0.82	0.9	0.8	0.8	0.8	0.92	0.96	0.8
DG2	0.98	0.8	0.98	0.93	0.9	0.88	0.8	0.88
DG3	0.98	0.9	0.98	0.88	0.95	0.93	0.98	0.99
DG4	-	-	0.95	0.91	0.91	0.8	0.96	0.89
DG5	-	-	-	-	0.94	0.91	0.96	0.99
DG6	-	-	-	-	-	-	0.98	0.88

Table 3. DG location (bus number) for the 33-bus system.

DG No.	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	ICA	EICA	ICA	EICA	ICA	EICA	ICA	EICA
DG1	12	12	31	30	30	2	33	33
DG2	32	30	33	12	12	26	32	12
DG3	24	24	31	26	24	12	26	5
DG4	-	-	15	24	23	30	25	33
DG5	-	-	-	-	26	24	13	33
DG6	-	-	-	-	-	-	32	24

Table 4. Economic parameters of the system (k$) for the 33-bus system.

Parameter	Base	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
		ICA	EICA	ICA	EICA	ICA	EICA	ICA	EICA
Installation cost	-	954	954	1272	1272	1590	1590	1908	1908
Repair cost	-	848	848	1131	1131	1414	1414	1697	1697
Operation cost	-	3395	3515	4239	4687	5005	5858	6202	7030
Loss cost	418	71	31	82	27	26	27	33	35
purchase cost of	13509	2974	2600	352	-	-	-	-	-
Loss reduction profit	-	346	387	336	391	392	390	384	383
Purchase reduction profit	-	10535	10909	13157	14545	15533	18181	19249	21818
Gross profit	-	10882	11296	13493	14963	15925	18572	19634	22201
Net profit	-	5684	5978	6850	7846	7916	9709	9826	11566

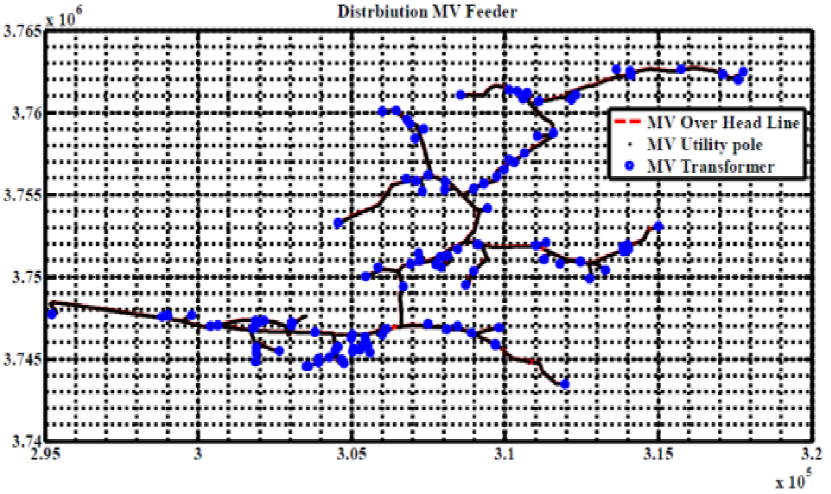


Figure 3. Diagram of the 133-bus system (Rahdarkhaneh feeder).

Thus, the two algorithms stabilized the voltage within the allowed range, and EICA provided a smoother voltage profile.

4.2. The 133-bus system

The actual 133-bus road distribution company located in the city of Borujerd, Iran, was selected as the second test system according to Figure 3. The simulation results are reported in Tables 5-8, while the voltage profile is illustrated in Figure 4. DGs' installation location and power factor differed in different scenarios, and the costs of installation, repairs, and operation in each scenario were assumed to be the same in the two algorithms.

Table 5. DG capacity (kVA) for the 133-bus system**.**

DG No.	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	ICA	EICA	ICA	EICA	ICA	EICA	ICA	EICA
DG1	1000	1000	1000	1000	1000	1000	1000	1000
DG2	914	1000	1000	1000	1000	1000	1000	1000
DG3	909	1000	938	1000	752	994	841	911
DG4	0	0	839	1000	935	1000	783	998
DG5	0	0	0	0	729	853	765	337
DG6	0	0	0	0	0	0	722	1000

Table 6. DG power factor for the 133-bus system**.**

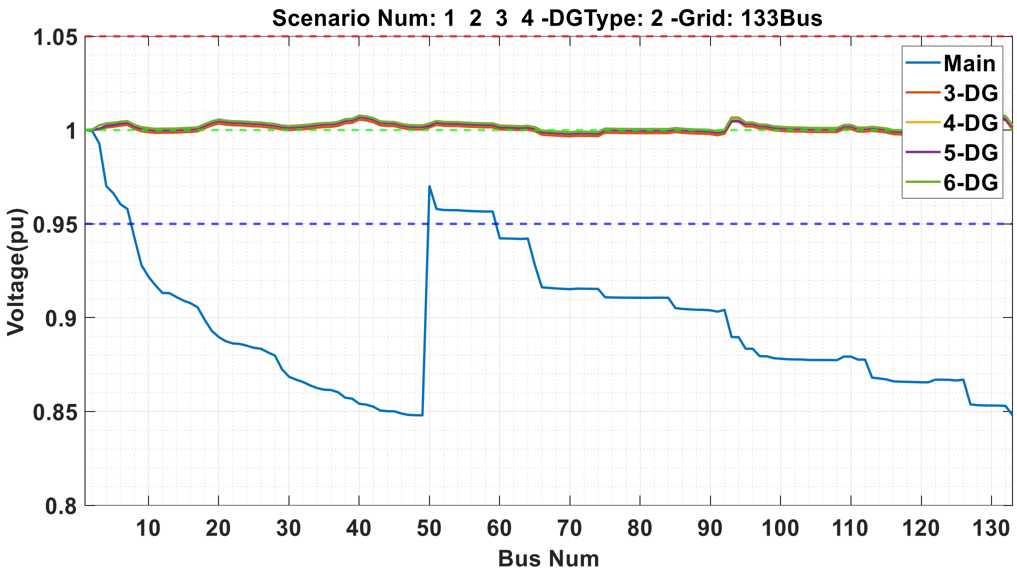
DG No.	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	ICA	EICA	ICA	EICA	ICA	EICA	ICA	EICA
DG1	0.83	0.84	0.8	0.89	0.81	0.88	0.98	0.88
DG2	0.99	0.99	0.98	0.99	0.99	0.89	0.91	0.81
DG3	0.99	0.88	0.99	0.88	0.88	0.97	0.97	0.87
DG4	0	0	0.99	0.88	0.97	0.88	0.98	0.88
DG5	0	0	0	0	0.99	0.92	0.88	0.99
DG6	0	0	0	0	0	0	0.99	0.99

Table 7. DG location (bus number) for the 133-bus system.

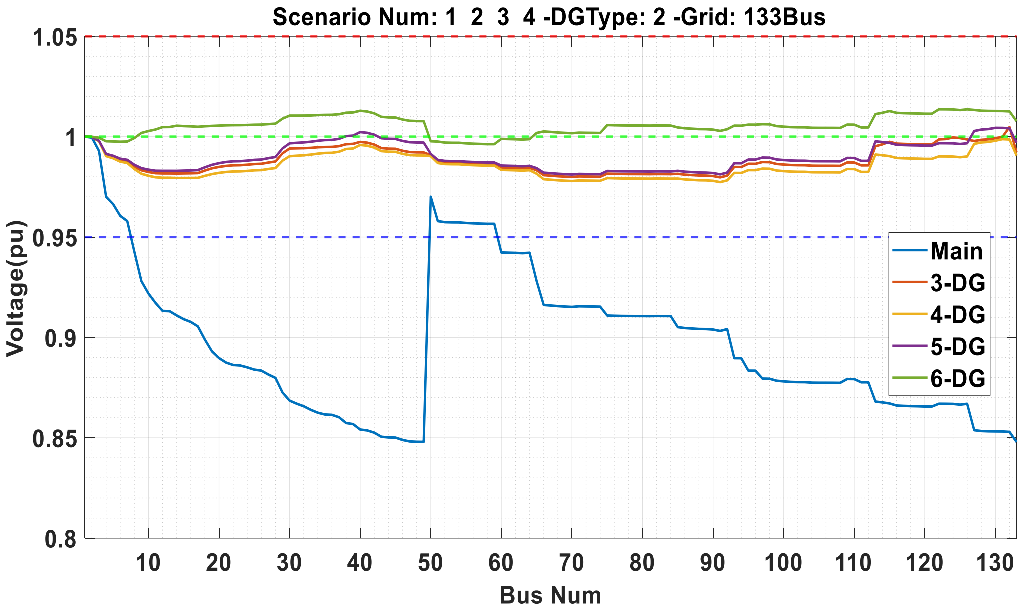
DG No.	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	ICA	EICA	ICA	EICA	ICA	EICA	ICA	EICA
DG1	124	93	131	7	130	40	132	127
DG2	132	7	133	2	133	51	75	2
DG3	132	127	131	127	133	2	127	51
DG4	0	0	113	93	133	20	127	93
DG5	0	0	0	0	130	51	122	127
DG6	0	0	0	0	0	0	129	3

Table 8. Economic parameters (k$) of the 133-us system.

Parameter	Base	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
		ICA	EICA	ICA	EICA	ICA	EICA	ICA	EICA
Installation cost	-	954	954	1272	1272	1590	1590	1908	1908
Repair cost	-	848	848	1131	1131	1414	1414	1697	1697
Operation cost	-	3307	3515	4426	4687	5174	5679	5988	6164
Loss cost	645	77	25	61	23	55	21	32	27
purchase cost of	9025	0	0	0	0	0	0	0	0
Loss reduction profit	-	568	621	582	622	590	624	614	618
Purchase reduction profit	-	10264	10909	13736	14545	16058	17624	18584	19074
Gross profit	-	10832	11530	14320	15168	16648	18249	19199	196921
Net profit	-	5722	6212	7490	8077	8469	9566	9605	9941



(a) Voltage profile in EICA



(b) Voltage profile in ICA

Figure 4. Voltage profile of the 133-bus system.

In the voltage stability index curve, despite the optimal performance of the two algorithms, the EICA solution in Scenario 4 recorded a flat graph close to one. Finally, solving the problem using both ICA and EICA algorithms in the worst scenario reduced the network loss by 41 and 17.5 kW, respectively, reflecting the ability of the EICA solution.With the optimal location of DGs using the ICA and EICA algorithms, the cost of network losses ($417,000) was reduced by 94% in the best case. The purchase of energy deficiency from the upstream network was zero in three scenarios in the EICA algorithm and two scenarios in the ICA algorithm, so the net profit was higher in these scenarios. The profit from loss reduction, the profit from energy purchase reduction, gross profit, and net profit from scenarios 1 to 4 were ascending, showing better results of solving EICA in the optimization problem. Also, despite the faster convergence of the ICA algorithm, the optimal convergence value was lower in the EICA algorithm.

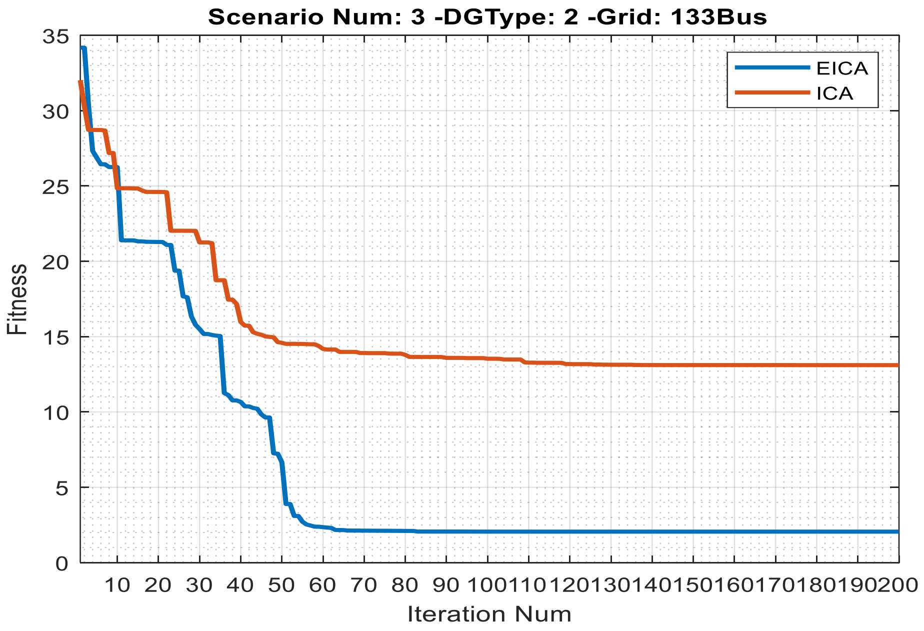


Figure 5. Convergence curve of both algorithms in Scenario 3 on the 133-bus system.

In addition, applying the proposed optimization method to the 133-bus network and comparing the results in Tables 5-8 shows that the EICA solution and the ICA solution stabilized the voltage in the nominal range in four scenarios, and EICA recorded a completely smooth voltage profile in all buses. Also, according to the network stability index curve, the EICA solution was significantly superior to the ICA, and the four scenarios presented a flat graph close to one in terms of stability.

The optimal location of DGs reduced network losses by, on average, 314 kW, and the cost of losses in the EICA solution was reduced by 96%. In solving ICA, the average loss reduction was 91%. Moreover, the installation and repair costs were proportional to the number of DGs in scenarios 1 to 4, and by adding a new DG, $600,000 would be added to the costs.

In solving the optimization problem by the two algorithms, the cost of purchasing energy shortage from the upstream network became zero, so the profit due to the reduction of losses, the profit of reducing energy purchase, and the gross profit increased from scenarios 1 to 4, respectively. Also, the net profit in the EICA solution was, on average, $600,000 more than that in the ICA solution due to more optimal DG placement. Although the EICA solution converged faster than the ICA solution, it had a lower optimal convergence value than the ICA algorithm.

Therefore, by summarizing the mentioned items, it is concluded that:

1) The EICA algorithm recorded a good performance in terms of the optimal location of DG in the distribution network.

2) Multi-objective DG location optimized the technical and economic parameters of the distribution system.

3) The significant reduction in loss costs and not needing to purchase energy from the upstream network in the real network showed the effectiveness of the proposed method in reducing system costs and increasing net profit.

5. Conclusion

This paper focused on determining the location and capacity of DGs as a multi-objective MINLP problem solved in MATLAB. The presented optimization problem was solved using the EICA algorithm for two test systems. First, the optimal location of DG was implemented on a standard 33-bus system to evaluate the proposed method. Then, the presented method was used to optimize a real network's technical and economic parameters. The results were compared with a standard ICA solution to show the better performance of the EICA algorithm. The results demonstrated that the proposed method effectively reduced the costs of the system, including the cost of losses and the cost of purchasing energy, compared to the other methods. Also, multi-objective optimization made the network technical parameters, such as voltage profile, network voltage stability index, and network losses, reach the desired value in addition to the system costs. According to the simulation results and the analysis of the results for different scenarios, the proposed method can be of interest to distribution network operators. The important results obtained in this article in summary are:

1- Reducing network losses
2- Reducing installation costs
3- Improvement of feeder voltage profile and stability

6. Future works

In the continuation of this research, future researchers are suggested to work on the following topics:

1- Positioning considering uncertainty
2- Positioning in the presence of electric vehicles
3- Considering the effect of climate change on the production of renewable resources

References

[1] H. N. Ng, M. M. A. Salama, and A. Y. Chikhani, "Classification of Capacitor Allocation Techniques," *IEEE Trans on Power Delivery*, vol. 15, no. 1, pp. 387-392, 2000.

[2] V. Rafi, and P. K. Dhal, "Maximization Savings in Distribution Networks with Optimal Location of Type-I Distributed Generator Along with Reconfiguration Using PSO-DA Optimization Techniques," *Materials Today: Proceedings*, vol. 33, pp. 4094-4100, 2020.

[3] H. Makvandi, M. Abasi, et al., "Design of New Intelligent Islanding Detection Scheme in Multi-Machine Power Systems to Prevent Wide-Area Blackouts," *12th Smart Grid Conference (SGC)*, pp. 1-7, 2022.

[4] S. Essallah, and A. Khedher, "Optimization of Distribution System Operation by Network Reconfiguration and DG Integration Using MPSO Algorithm," *Renewable Energy Focus,* vol. 34, pp. 37-46, 2020.

[5] M. Z. Malik, M. Kumar, et al., "Strategic Planning of Renewable Distributed Generation in Radial Distribution System using Advanced MOPSO Method," *Energy Reports*, vol. 6, pp. 2872-2886, 2020.

[6] M. Abasi, A. Saffarian, M. Joorabian, and S. G. Seifossadat, "Location of Double-Circuit Grounded Cross-Country Faults in GUPFC-Compensated Transmission Lines Based on Current and Voltage Phasors Analysis," *Electric Power Systems Research,* vol. 195, 107124, 2021.

[7] M. Abasi, A. Rohani, F. Hatami, M. Joorabian, and G. B. Gharehpetian, "Fault Location Determination in Three-Terminal Transmission Lines Connected to Industrial Microgrids Without Requiring Fault Classification Data and Independent of Line Parameters," *International Journal of Electrical Power & Energy Systems,* vol. 131, 107044, 2021.

[8] T. T. Nguyen, T. T. Nguyen, N. A. Nguyen, and T. L. Duong, "A Novel Method Based on Coyote Algorithm for Simultaneous Network Reconfiguration and Distribution Generation Placement," *Ain Shams Engineering Journal*, vol. 12, no. 1, pp. 665-676, 2021.

[9] S. Biswa, S. K. Goswami, and D. Bhattacharya, "Optimal Placement of Distributed Generation in an Unbalanced Radial Distribution System Considering Load Variation," *2019 IEEE Region 10 Symposium (TENSYMP),* pp. 173-178, 2019.

[10] L. M. Belmino, F. S. Soares, et al., "Placement and Sizing of Distributed Generation in Distribution System," *2019 IEEE PES Innovative Smart Grid Technologies Conference - Latin America (ISGT Latin America),* pp. 1-6, 2019.

[11] M. Abasi, A. T. Farsani, A. Rohani, and A. Beigzadeh, "A Novel Fuzzy Theory-Based Differential Protection Scheme for Transmission Lines," *International Journal of Integrated Engineering,* vol. 12, no. 8, pp. 149-160, 2020.

[12] S. M. Sadeghi, M. Daryalal, and M. Abasi, "Two-Stage Planning of Synchronous Distributed Generations in Distribution Network Considering Protection Coordination Index and Optimal Operation Situation," *IET Renewable Power Generation,* vol. 16, no. 11, pp. 2338-2356, 2022.

[13] M. Abasi, M. Joorabian, A. Saffarian, and S. G. Seifossadat, "An Algorithm Scheme for Detecting Single-Circuit, Inter-Circuit, and Grounded Double-Circuit Cross-Country Faults in GUPFC-Compensated Double-Circuit Transmission Lines," *Electrical Engineering*, vol. 104, pp. 2021-2044, 2022.

[14] A. Siadatan, P. Farhadi, B. Taheri, and M. Sedaghat, "Optimal Placement of Various Distributed Generations in Distribution Systems using Firefly Algorithm," *2018 4th International Conference on Electrical Energy Systems (ICEES),* pp. 309-314, 2018.

[15] A. Rohani, M. Abasi, A. Beigzadeh, M. Joorabian, and G. B. Gharehpetian, "Bi-Level Power Management Strategy in Harmonic-Polluted Active Distribution Network Including Virtual Power Plants," *IET Renewable Power Generation*, vol. 15, no. 2, pp. 462-476, 2021.

[16] M. Abasi, N. Heydarzadeh, and A. Rohani, "Broken Conductor Fault Location in Power Transmission Lines using GMDH Function and Single-Terminal Data Independent of Line Parameters," *Journal of Applied Research in Electrical Engineering,* vol. 1, no. 1, pp. 22-32, 2022.

[17] F. S. Gazijahani, and J. Salehi, "Robust Design of Microgrids with Reconfigurable Topology Under Severe Uncertainty," *IEEE Transactions on Sustainable Energy*, vol. 9, no. 2, pp. 559-569, 2018.

[18] A. Sefidgar-Dezfouli, and V. Davatgaran, "Smart Microgrid Optimal Scheduling with Stable and Economic Islanding Capability using Optimal Load Contribution as Spinning Reserve," *International Transactions on Electrical Energy Systems*, vol. 30, no. 11, p.e12566, 2020.

[19] S. A. Shirmardi, M. Abasi, et al., "Designing an Energy Managing System for Distributed Dispersion in Smart Microgrids Based on Environmental Constraints," *12th Smart Grid Conference (SGC), pp.* 1-6, 2022.

[20] J. P. Oliveira, A. B. Rodrigues, and M. G. da Silva, "Probabilistic Evaluation of Voltage Control and Reactive Power Techniques with Photovoltaic Distributed-Generation," *2018 Simposio Brasileiro de Sistemas Eletricos (SBSE)*, pp. 1-6, 2018.

[21] H. Makvandi, M. Abasi, et al., " Design of New Intelligent Islanding Detection Scheme in Multi-Machine Power Systems to Prevent Wide-Area Blackouts" 12th Smart Grid Conference (SGC), 2022. IEEE Index.

[22] M. Abasi, A. T. Farsani, A. Rohani, and M. A. Shiran, "Improving Differential Relay Performance during Cross-Country Fault Using a Fuzzy Logic-Based Control Algorithm," *5th Conference on Knowledge Based Engineering and Innovation (KBEI)*, pp. 193-199, 2019.

[23] Y. Thangaraj, and R. Kuppan, "Multi-Objective Simultaneous Placement of DG and DSTATCOM Using Novel Lightning Search Algorithm," *Journal of Applied Research and Technology*, vol. 15, no. 5, pp. 477-491, 2017.

[24] A. V. Pombo, J. Murta-Pina, and V. F. Pires, "A Multiobjective Placement of Switching Devices in Distribution Networks Incorporating Distributed Energy Resources," *Electric Power Systems Research*, vol. 130, pp. 34-45, 2016.

[25] A. M. Ibrahi, and R. A. Swief, "Comparison of Modern Heuristic Algorithms for Loss Reduction in Power Distribution Network Equipped with Renewable Energy Resources," *Ain Shams Engineering Journal,* vol. 9, no. 4, pp. 3347-3358, 2018.

[26] J. Ebrahimi, and M. Abedini, "A Two-Stage Framework for Demand-Side Management and Energy Savings of Various Buildings in Multi Smart Grid Using Robust Optimization Algorithm," *Journal of Building Engineering*, vol. 53, 104486, 2022.

[27] M. Chakravorty, and D. Das, "Voltage Stability Analysis of Radial Distribution Networks," *International Journal of Electrical Power & Energy Systems*, vol. 23, no. 2, pp. 129-135, 2001.

[28] M. Sadeghi, M. Abasi, "Optimal Placement and Sizing of Hybrid Superconducting Fault Current Limiter to Protection Cordination Restoration of the Distribution Networks in the Presence of Simultaneous Distributed Generation," *Electric Power Systems Research*, vol. 201, 107541, 2021.

[29] M. Abasi, M. Joorabian, A. Saffarian, and S. G. Seifossadat, “A Comprehensive Review of Various Fault Location Methods for Transmission Lines Compensated by FACTS Devices and Series Capacitors,” *Journal of Operation and Automation in Power Engineering*, vol. 9, no. 3, pp. 213-225, 2021.

[30] M. Shahrouzi, and A. Salehi, "Enhanced Imperialist Competitive Algorithm for Optimal Structural Design,” *Scientia Iranica*, vol. 28, no. 4, pp. 1973-1993, 2021.

[31] E. Chegeni, M. Zandieh, and J. Ebrahimi, "Attitude Control of Satellite with Pulse-Width Pulse-Frequency (PWPF) Modulator using Generalized Incremental Predictive Control," *Majlesi Journal of Electrical Engineering*, vol. 8, no. 3, pp. 25-31, 2014.

[32] H. Makvandi, M. Abasi, et al., "Design of an Optimal STATCOM Controller to Enhance Dynamic Stability of the Smart Grid," *2023 27th International Electrical Power Distribution Networks Conference (EPDC)*, pp. 94-101, 2023.

[33] J. Ebrahimi, and M. Abasi, "Design of a Power Management Strategy in Smart Distribution Networks with Wind Turbines and EV Charging Stations to Reduce Loss, Improve Voltage Profile, and Increase Hosting Capacity of the Network," *Journal of Green Energy Research and Innovation*, vol. 1, no. 1, pp. 1-15, 2024.

[34] M. Khalifeh, S. S. Mortazavi, M. Joorabian, and V. Davatgaran, "Studding Two Indices of Voltage Stability in Reliability Constrained Unit Commitment in a Day-Ahead Market," *21st Iranian Conference on Electrical Engineering (ICEE)*, pp. 1-6, 2013.

[35] V. Davatgaran, S. S. Mortazavi, M. Saniei, and M. Khalifeh, "Different Strategies of Interruptible Load Contracts Implemented in Reliability Constrained Unit Commitment," *21st Iranian Conference on Electrical Engineering (ICEE),* Iran, pp. 1-6, 2013.

[36] M. Abedini, R. Eskandari, J. Ebrahimi, M. H. Zeinali, and A. Alahyari, "Optimal Placement of Power Switches on Malayer Practical Feeder to Improve System Reliability Using Hybrid Particle Swarm Optimization with Sinusoidal and Cosine Acceleration Coefficients," *Computational Intelligence in Electrical Engineering*, vol. 11, no. 2, pp. 73-86, 2020.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, have been completely observed by the authors.

Credit Authorship Contribution Statement

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