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A Chameleon algorithm for solving economic dispatch problem in microgrid system

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ABSTRACT

The economic power dispatch (ED) is considered a critical optimization issue in the power system and microgrid. There are several objectives through the economic load dispatch issues such as reducing the operating cost, total emission, or start-up operations. This paper presents a Chameleon swarm algorithm (CSA) for determining the optimal ED of distributed energy resources (DER) in the microgrid. The proposed technique numerically mimics and executes chameleons' behavioral processes to their quest for food, such as their action for rotating their eyes to identify and grab prey using the speed of their sticky tongues. In this study, the CSA has been applied to obtain the optimal power dispatch from DER using the photovoltaic (PV) plants, combined heat power (CHP) systems, and traditional diesel generators. The obtained results from the simulation are compared with the conventional metaheuristic algorithms which have been used in previous studies, such as particle swarm optimization (PSO), genetic algorithm (GA), and artificial bee colony (ABC). Experimentally, the proposed algorithm for solving the ED problem determined the best value of the power dispatch and high performance compared to other metaheuristics methods.

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1. INTRODUCTION

Electrical power systems are a complex engineering topic due to the nonlinear loads and computationally challenging characteristics [1]. The economic power dispatch (ED) problem in electrical power systems generally and in the microgrid is considered critical due to its non-linearity constraints and subjects. The traditional ED methods are frequently used to determine the best aggregate for power products to decrease fuel costs under various limitations. However, because of the growing public awareness of the dangers of fossil fuels, the ED cannot treat these constraints [2]. The most modern ED aims to allocate load demand among generators cost-effectively while meeting various equality and inequality objectives in the system [3].

The ED problem has been solved using different traditional optimization approaches. In the microgrid, such as the classical optimization techniques which are developed based on the numerous traditional programming methods like El-Keib and Ding [4] proposed two dispatch strategies to obtain the optimal solution for the ED problem subject to environmental constraints using the linear programming. Gibson and Stocks [5] presented lambda iteration method that deals with the interaction of economic loading and the power generation and the optimal fuel procurement on an electric power system. According to Takriti and Krasenbrink [6], a non-convex mathematical approach has been presented for the economic power-dispatch problem with fuel consumption. Research by Rau [7], a mixed-integer linear program method has been described for bid and offer-based ED problems. With minimal take requirements, the proposed method can handle unbundled items and the different objectives. According to Costa and Kariniotakis [8], dynamic programming has been offered for scheduling problems and a deterministic solution for ED problems in the microgrid. This method obtains optimal results when the uncertainties associated with the scheduling problem are considered. According to Nguyen and Crow [9], Lagrangian method is applied to determine the optimal day-scheduling for different distributed energy resources (DER) such as batteries, diesel generators, PV stations, and wind turbines. The results demonstrate that the suggested method can operate the microgrid at its best with a high degree of certainty without investigating many cases. However, these traditional methods have shortcomings, such as low performance when addressing optimization problems when huge arithmetic operations.

During the years, metaheuristics approaches have been proposed and utilized to solve the ED problem and avoid the issues that result from the traditional optimization methods such as Zhao *et al.* [10] proposed the cuckoo search algorithm (CSA) for determining the economic dispatch problem for different research spaces considering the constraints and the objective function such as valve-point effects, prohibited operating zones, transmission losses, and ramp rate limits. Research by Ma *et al.* [11], artificial bee colony algorithm (ABC) has been used to solve ED problems, which can be economically or environmentally. The problem has been described as a complex constrained optimization problem. The straightforward constraint checking method is proposed to deal with many constraints of this problem. The final results have been compared with the other frequently applied methods to solve the environmental and ED problem. Elsied *et al.* [12] proposed a real-time simulation based on genetic algorithm (GA) to reduce operating and emissions cost, parallelly maximizing the power dispatch from the microgrid resources. Research by Elsied *et al.* [12], the environmental emission and other constraints have been solved using a particle swarm optimizer (PSO). The authors described a technique that transfers the proposed objectives function to a single objective function is to minimize the computation time and increase the accuracy of the optimal solution of the variables.

Other metaheuristic optimization approaches have also been introduced to solve ED problem, including teaching-learning based optimization (TLBO) [13], artificial immune system (AIS) [14], harmony search algorithm [15], and crow search algorithm (CSA) [16], firefly algorithm [17], gravitational search algorithm [18], differential evolution [19], biogeography-based optimization [20], gray wolf optimizer algorithm [21]. The hybrid metaheuristic techniques were applied further to find the ED problem's global optimum solution for more accuracy. The suggested hybrid approaches are more resilient and perform better when solving non-convex and non-linear systems such as a modified GA and a highly improved version of particle swarm optimization (MGAIPSO) [22], new PSO with local random search (NPSO-LRS) [23], differential evolution and sequential quadratic programming (DE-SQP) [24], continuous quick group search optimizer (CQGSO) [25], hybrid big bang–big crunch optimization algorithm [26], ant colony optimization, ABC and harmonic search algorithms (ACO-ABC-HS) [27], Jaya and TLBO algorithm (JAYA-TLBO) [27], multi-population Jaya algorithm (MO-SAMP JAYA) [28], the GA and whale optimization algorithm [29], and optimal stopping rule (OSR) and GA (OSR-GA), OSR-TLBO, and OSR-FA [30].

Braik [31] created the Chameleon swarm algorithm (CSA) algorithm in 2021, a nature-inspired swarm intelligence approach based on the behaviors of the chameleon. CSA has been effectively employed to solve unimodal and multimodal numerical optimization and power system engineering issues due to its basic idea and easy implementation using the open-source library function [32]. In this study, the CSA has been applied to obtain the optimal power dispatch from DER using the photovoltaic (PV) plants, traditional diesel generators, and combined heat power (CHP) systems. The obtained results were compared with the most popular metaheuristic algorithms.

The structure of this study is described as follows; section 2 describes the problem formulation of the proposed microgrid to solve the ED problem. Section 3 describes the CSA. Section 4 details the results and comparison of the proposed algorithm and other popular algorithms. Section 5 shows the conclusion.

2. PROBLEM FORMULATION

ED aims to obtain the optimal generation from the DER resources to minimize the total operation cost [33]. The energy management system unit is considered the central control unit in the microgrid to find and obtain the values of the power dispatch from all DER units to respond to the load demand during the operation and ensure economic operations. The ED involved in the energy management system consists of an optimization module as shown in Figure 1.

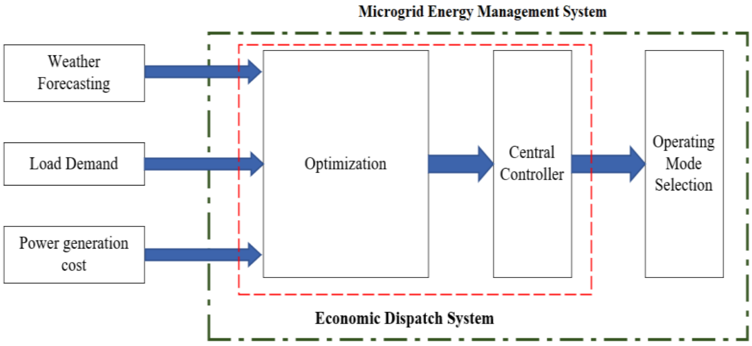

Figure 1. ED scheme for the energy management system

a. Objective function

The problem presented in this study is similar to those addressed in the literature [18]. The ED problem aims to reduce total operation cost in the microgrid for a given load demand while maintaining different constraints in consideration. The following is the problem's objective function:

$$C_i(P_i) = \alpha_i \, P_i^2 + \beta_i \, P_i + \gamma_i \tag{1}$$

where α, β, γ are the operation coefficients in each i DER, P is the power delivered in each element i, C is the total operation cost in each i DER, In the microgrid, the aim function of an ED problem is to lower the overall operating cost of DERs, which is given by:

$$min\, OF = \sum_{i=1}^{n} (\alpha_i \, P_i^2 + \beta_i \, P_i + \gamma_i) \tag{2}$$

where OF is the primary objective function, and n describes the number of the operating DER in the microgrid. While the total power generated is minimized, the energy management system functions with the optimal power dispatch from the DERs to meet the power demands, as represented in Figure 2.

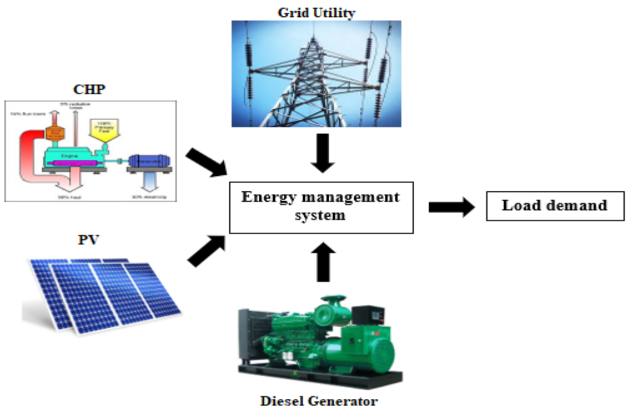

Figure 2. EMS unit in the proposed microgrid

b. Equality constraint

The objective function described in (2) is subjected to constraint (3). To achieve power balance, the total generated power must satisfy the power demand:

$$\sum_{i=1}^{n} P_i = P_L \tag{3}$$

Where P_L represents the total power demand by the loads in kW. The objective function of each i DER is defined by:

$$min\,OF = \sum_{i=1}^{n}(\alpha_i\ P_i^2 + \beta_i\,P_i + \gamma_i) - P_i \times \sum_{i=1}^{n} P_i - P_L \tag{4}$$

c. Inequality constraint

Each DER unit's power dispatch is limited to the lower and maximum limitations. The inequality constraint is defined as (5):

$$P_{i\,min} < P_i < P_{i\,max} \tag{5}$$

3. CAMELEOM SWARM ALGORITHM

Over the years, several optimization techniques using the classical techniques such as the linear and non-linear programming approaches have been proposed to resolve a wide variety of optimization issues in science and engineering. In 2021, Barik proposed a metaheuristic technique named CSA based on chameleons' hunting and food exploration for surviving effectively in deserts and trees. Since searching and exploration are the main advantages in the metaheuristic's algorithms. To find the optimal result, which is the prey, Barik's proposed method uses the chameleon's roam approach all over the search space. In this technique, chameleons utilize their globular eyes to scan a vast search radius, utilizing every possible area in the search domain. When hunting, the chameleons apply their incredibly long and sticky tongues to grab the prey quickly and efficiently. An adaptive parameter was proposed to help the chameleons effectively sear in the search space throughout iterations of CSA to obtain a better balance between exploration and exploitation for more consistent results. Tracking the prey, following the prey with their eyes, and attacking the prey are all steps in their food hunting process [34]. The mathematical models are explained in the sub-sections.

3.1. Initialization

As the other metaheuristic algorithms, initializing the population is used by CSA to begin the optimization process. The number of chameleons population n can be represented in search space dimension d, where each individual represents a two-dimensional matrix $n{\times}d$ size solution of the problem proposed. The position X of i is created randomly in a N dimension and given by the matrix:

$$X_i = \left(x_i^1, x_i^2, x_i^3, \dots\dots\dots.\, x_i^j\right) \quad \text{for } i\text{=1,2,3…., j.} \tag{6}$$

where j presents the number of variables. The initial population is generated using (7) which utilizes a random generation in the search space dependent on the number of chameleons and the number of the variables:

$$X_i = l_j + r.\,(u_j - l_j) \tag{7}$$

where r describes random values between [0,1]; l_j and u_j are the limits of each individual X_i.

For each new chameleon position, the value of the solution is evaluated using a fitness function. If the new position's solution quality is better than the previous position's solution quality, the individual's position is updated. The chameleons in the CSA technique, stay in their current position if their solution quality is better than the new one.

3.2. Search for prey function

The equation number (8) is applied to describe each chameleon's movement while foraging:

$$X_{new}^{i,j} = \begin{cases} X_{current}^{i,j} + P_1\left(P_{best}^{i,j} - P_{global}^{j}\right) r_2 + P_2\left(P_{global}^{j} - X_{current}^{i,j}\right) r_1 \\ \qquad r_1 \geq P_p \\ X_{current}^{i,j} + \mu\left(u_j - l_j\right) r_3 + l_b^j\, sgn\,(rand - 0.5)\, r_1 \\ \qquad r_1 < P_p \end{cases} \tag{8}$$

where P_1 and P_2 are two positive numbers that determine the exploring capabilities of the chameleon; r_1, r_2, and r_3 describe random values between [0,1]; P_p describes the probability of each individual perceiving target; $sgn\,(rand - 0.5)$ indicates the efficiency of the direction exploration which can be -1 or 1; μ describes the function of iterations parameter that decrease with the number of iterations; $X_{current}^{i,j}$ and $X_{new}^{i,j}$ the current and the new position of each individual i in the number of the decisions j; and $P_{best}^{i,j}$ and P_{global}^{j} imply the best and global best positions of the chameleon, respectively.

3.3. Chameleon eyes' rotation

As mentioned above, the chameleons determine the location of their prey by rotating their eyes. This eye rotation feature helps them in finding the prey in 360 degrees. The following steps consider this manner: i) move the chameleon to its initial location at the center of gravity; ii) get the rotation matrix that indicates where the prey should be grabbed; iii) change the location of the chameleons by applying the rotation matrix at the center of gravity; and iv) transfer the chameleons to the initial location.

3.4. Grabbing prey

The chameleons attack their prey when it is very close. The nearest chameleon to the prey is considered the best chameleon and the optimal individual. Thus, this chameleon attacks the target using its tongue. The position of the optimal chameleon is updated where its tongue can be double its length to get the prey. The method can assist the chameleons in following the best individual and expanding the search space to grab the prey effectively. The velocity of the chameleon when its droop can be represented:

$$v_{t+1}^{i,j} = \omega v_t^{i,j} + c_1\left(G_t^j - y_t^{i,j}\right)r_1 + c_2\left(P_t^j - y_t^{i,j}\right)r_2 \quad (9)$$

where $v_{t+1}^{i,j}$ describes the velocity of each individual i in j dimension and the number of the iteration $t+1$; $v_t^{i,j}$ represents the velocity at iteration t; ω is the inertia weight that is linearly decreased with every iteration t; c_1 and c_2 are values to control the influence; r_1 and r_2 are random values in range the of [0,1]; P_t^j is the optimal value of the chameleon; and G_t^j is the best global value of the chameleons.

4. NUMERICAL ANALYSIS AND RESULTS

An example of a modified IEEE 37 bus test feeder to which CSA is applied to solve the ED problem is illustrated in Figure 3. Three two PV plants, traditional diesel generators, and a CHP system are the DER investigated in this work. The load structure and test feeder were created using ref [35], [36].

The power demand from the loads over 24 hours is represented in Figure 4. The capacity of the diesel generators DG1, DG2, DG3, and the CHP station is design by 400 kW, 500 kW, 600 kW, and 1,000 kW, respectively. Each of the PV systems has a global capacity of 600 kW. The real PV generation data was obtained from the University of Malaya's Power Electronics and Renewable Energy Research Laboratory (PEARL). Figures 5 and 6 illustrate the forecasted solar radiation and temperature, respectively. Figure 7 illustrates the PV generating profiles. The cost coefficients of each DER in the microgrid are shown in Table 1 [18]. The proposed algorithm has been simulated using MATLAB 2022a. Under Windows 10, the simulation work was performed on an Intel (R) Core i5-8400 CPU running at 2.8 GHz with 8 GB RAM. Table 2 represent the global parameters of the proposed metaheuristics techniques.

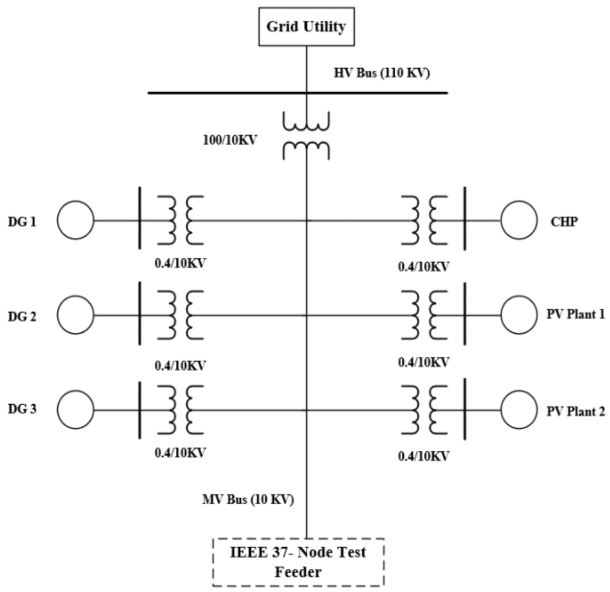

Figure 3. The modified IEEE 37 bus test feeder

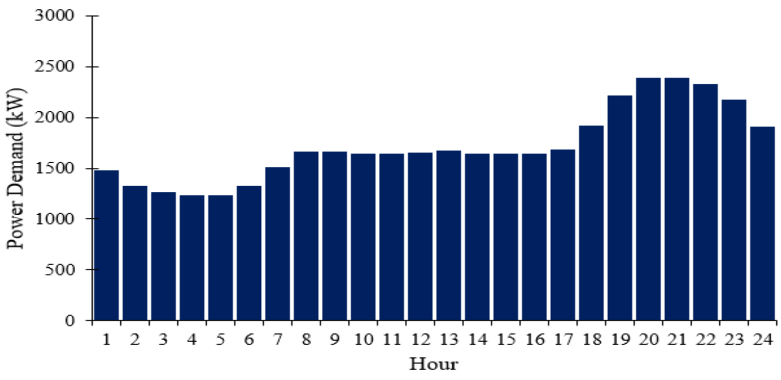

Figure 4. The hourly power demand

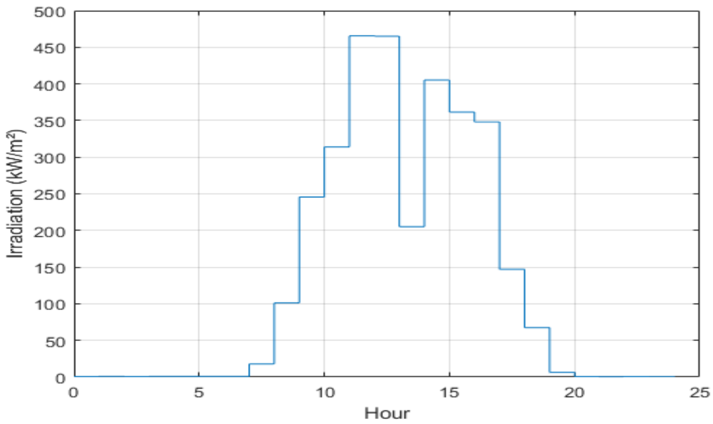

Figure 5. Forecasted solar irradiation profile over the next 24 hours

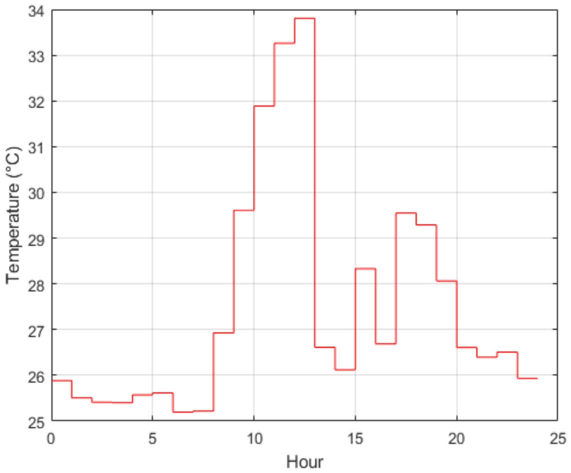

Figure 6. The forecasted temperature profile over the next 24 hours

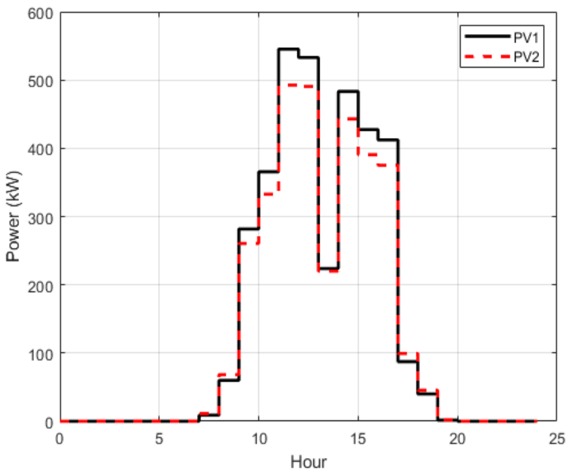

Figure 7. The forecasted generation of PV over the next 24 hours

Table 1. The cost coefficients of each DERs

Plant	γ	β	α
DG1	62	105	0.009
DG2	75	175	0.01
DG3	37.4	160	0.008
PV1	4.45	29.3	0.0055
PV2	4.46	29.58	0.0055
CHP	5.21	75.73	0.0083

Table 2. The global parameters of the proposed metaheuristics techniques

Parameters	Details	CSA	GA	PSO	ABC
PoP	Size of population	200	200	200	200
V	Number of variables	6	6	6	6
T	Number of iteration	1000	1000	1000	1000
P 1		0.25	-	-	-
P 2		1.5	-	-	-
μ		1.0	-	-	-
C 1	Cognitive coefficient	1.75	-	2	-
C 2	Social coefficient	1.75	-	1.5	-
r 1	Random cognitive coefficient	*Ran* [0,1]	-	*Ran* [0,1]	-
r 2	Random social coefficient	*Ran* [0,1]	-	*Ran* [0,1]	-
r 3		*Ran* [0,1]	-	-	-
G_0	Gravitational constant	-	-	-	-
β	Gradient constant	-	-	-	-
ε	Zero offset constant	-	-	-	-
Mut %	Mutation rate	-	65	-	-
Cro%	Crossover rate	-	10	-	-
A	The predetermined number of trials for abandonment	-	-	-	400
mr	Modification rate	-	-	-	0.8

Figure 8 shows the optimal power generation using the CSA method and the load demand. It can be noted that the power generated from the DERs respects the load demand. The other optimization approaches used for comparisons, such as the GA, PSO, and ABC, have satisfied the power demand from the load. Figures 9 to 12 illustrate the optimal values of the power that were delivered by DERs using CSA, GA, PSO, and ABC while considering the generation limits. Table 3 represents the performance evaluation of all the techniques that have been compared. Based on CSA, the cost obtained is the lowest operating cost compared to the other metaheuristic techniques in every hour. The proposed algorithm has the best optimization performance compared to other techniques for achieving the optimal power dispatch by having the lowest overall cost in each hour or for the entire 24 hours.

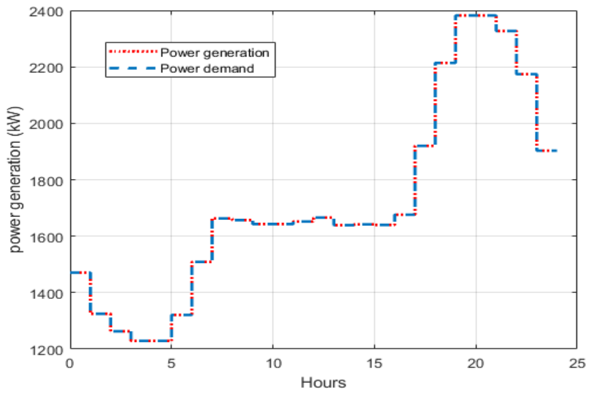

Figure 8. Comparison between the power demand and the power generation from DERs

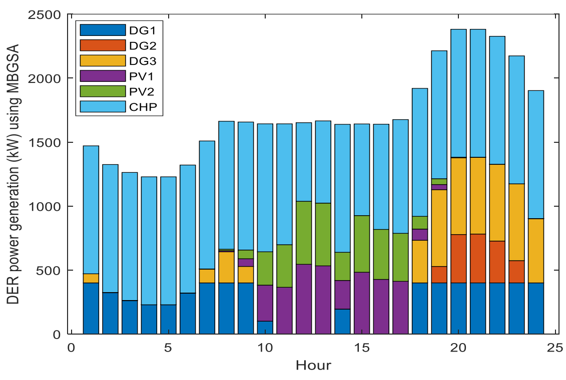

Figure 9. The optimal values of each DER using CSA

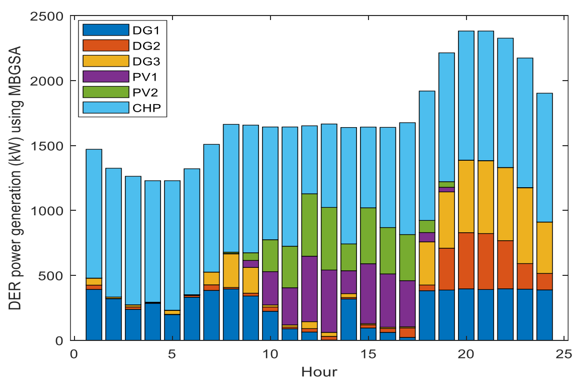

Figure 10. The optimal values of each DER using GA

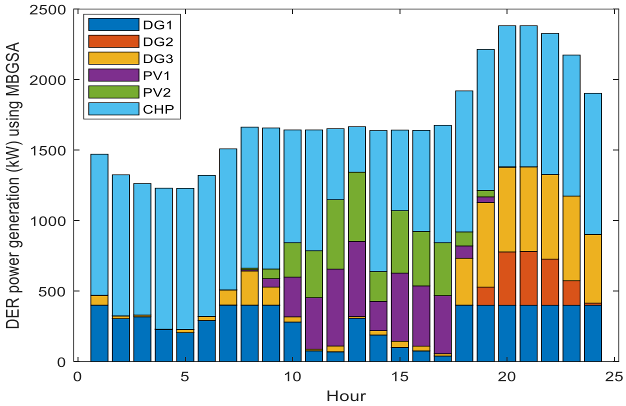

Figure 11. The optimal values of each DER using PSO

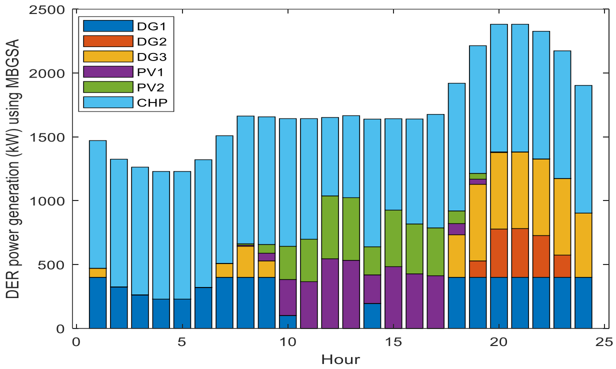

Figure 12. The optimal values of each DER using ABC

Figure 13 shows the convergence capability of CSA and other metaheuristic approaches applied in hour 24. The convergence demonstrates the expression of cost function value versus iterations. It can be noted that the proposed approach converges faster and requires fewer iterations. Furthermore, the results illustrate that the proposed approach can achieve optimal results even when PV generations do not exist.

Table 3. The optimal cost using CSA and the other techniques

Hour	CSA	GA	PSO	ABC
1	139023.2979	140455.0809	139048.3	139023.2979
2	119268.10	120075.2571	120279.9	119268.1034
3	112432.76	114653.1408	114305.7	112432.7637
4	108706.8134	110376.2642	108854.7	108706.8134
5	108702.8312	110554.1167	109899.9	108702.8312
6	118819.1788	120514.2667	120286.9	118819.1788
7	145141.9809	147684.2749	145199.6	145141.9809
8	167547.4304	170017.6142	167559.5	167601.103
9	152192.2919	158733.887	152204.7	152192.2919
10	111663.049	119862.5194	118400.4	111663.049
11	101035.339	109900.8064	102972.9	101035.3387
12	83352.99036	93676.75558	87906.57	83352.99036
13	85282.9628	93175.65744	93591.17	85282.96275
14	118664.063	127476.2338	122152.3	118664.0628
15	88273.9438	94657.01731	93525.8	88273.94383
16	93978.428	101042.3914	97919.61	93978.42804
17	98931.9533	110481.7598	100680.1	98931.95327
18	187446.6703	192070.0477	187455.8	187446.6703
19	251721.82	256172.6631	251721.8	251721.8206
20	294244.4149	296069.9403	294244.4	294244.4149
21	294817.12	296383.2933	294817.1	294817.1233
22	284816.081	285880	284816.1	284816.0806
23	257564.46	257990	257264.5	257275.1967
24	215125.173	212537.4748	210253.9	210125.1728
Total cost ($)	**3784753.159**	3840440.463	3775361.948	3733517.572

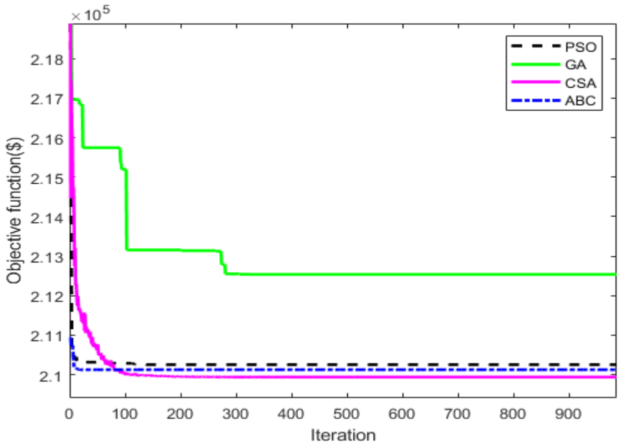

Figure 13. Convergence of the best operation cost of the techniques proposed at hour 24

5. CONCLUSION

ED problem is a complex issue in the optimization power system. In this paper, we proposed a CSA to solve the quadratic equation of the ED problem by considering the load demand, the power delivered from the DERs, and different constraints. The comparisons and results demonstrated that the proposed algorithm is effective and fast at performing the convergence for the non-linear optimization problems. The obtaining results from the CSA have been compared with the most popular algorithms used in the previous literature. The proposed approach can be considered an efficient alternative technique based on the results obtained.

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