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Optimal economic environmental power dispatch by using artificial bee colony algorithm

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ABSTRACT

Today, most power plants worldwide use fossil fuels such as natural gas, coal, and oil as the primary resource for energy reproduction primarily. The new term for economic environmental power dispatch (EEPD) problems is on the minimum total cost of the generator and fossil fuel emissions to address atmosphere pollution. Thus, the significant objective functions are identified to minimize the cost of generation, most minor emission pollutants, and lowest system losses individually. As an alternative, an artificial bee colony (ABC) swarming algorithm is applied to solve the EEPD problem separately in the power systems on both standard IEEE 26 bus system and IEEE 57 bus system using a MATLAB programming environment. The performance of the introduced algorithm is measured based on simple mathematical analysis such as a simple deviation and its percentage from the obtained results. From the mathematical measurement, the ABC algorithm showed an improvement on each identified single objective function as compared with the gradient approach of using the Newton Raphson method in a short computational time.

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1. INTRODUCTION

Over the past two decades, there has been a significant increase in the general interest in using global optimization approaches in power system operations. The continually increasing demand for energy resources is a result of a rise in standard of living [1]. This is due to the fact that as the population and economy of the world expand, so does the demand for a power supply.

While for energy demand increment, the economic allocation of the produced energy must be minimized to decrease energy supplies. Because of the high emissions due to fossil fuels thus the traditional economic power plants should reconsider fuel prices for generators [2], [3]. People, animals, and plants are all impacted by the emissions that fossil fuels release into the atmosphere, such as sulphur dioxide, nitrogen oxides, and carbon dioxide. In fact, acid rain, reduced visibility, and global pollution cause harm. The utility sector was obliged to limit its pollution from energy plants as a result of rising responsibility for the sustainability of the atmosphere and the approval of the 1990 Clean Air Law [4]. Therefore, instead of producing power demand with the traditional cost purpose of economic power dispatch, emissions can be reduced [5]–[7]. Additionally, due of the interconnection and complexity of the power networks, researchers have recently become interested in power systems, especially those who have studied the global optimization technique [8].

In the past 20 years, the solution has generally been classified into three categories: conventional methods, intelligent search, and fuzzy set application. An example of the traditional methods commonly is known as linear programming (LP), non-linear programming (NLP), and mix integer non-linear programming (MINLP). However, each of the proposed mathematical techniques has drawbacks, such as complicated variable setup, sluggish convergence in multimodal optimization, and inadequate exploration capabilities [9]. Besides that, the gradients-based methods such as lambda iteration method (LIM), gradient method (GM), base point (BP), participation factor (BF), and Newton method have been reported to tend in producing poor results due to a non-convex, non-continuous, and highly non-linear problems [4]. Therefore, advanced meta-heuristics intelligent search methods such as genetic algorithm (GA), evolutionary programming (EP) and artificial immune system (AIS) were presented as an alternative to overcome the weaknesses. Besides that, modern swarm-based algorithms identified as simulated annealing (SA), ant colony optimization (ACO), and particle swarm optimization (PSO), bacterial foraging optimization (BFOA), and gravitational search algorithms were also introduced by most previous researchers in solving the highly non-linear and complicated problems [6]–[10]. These methods focused on optimizing the selected objective function by providing globally optimal solutions [4]–[7], [10].

Further, a modern swarming of global optimization method called the ABC algorithm, developed specifically for ED problems, is one of the most significant swarm-based algorithms [11]–[15]. The environmental economic power dispatch of thermal units will also be analysed using an improved ABC algorithm [16]. As well, the enhanced binary ABC algorithm is applied for optimization problem [17]. In 2005, Dervis Karoboga created the swarming intelligence algorithm, which was inspired after the intelligent drilling behaviour of honeybee swarms [18], [19]. Honeybee swarms, which have three essential components: nutritive supplies (food source), forage bees, and employee bees, and two significant modes of operation: recruitment from nectar suppliers and the rejection of the source, develop common intelligence through the utilization of clear and concise model to choose a forage [20], [21]. —

– Food source: Several factors, including their proximity to the hive, the quality of their nectar, and the distance between the sources, determine the value of the food supply.
– Employed bees: Have an identical food supply, they carry the information about this source to communicate with other bees living in the hive about the location, accessibility, and profitability of the food source.
– Unemployed bees: The hive of bees continues exploitation of the food supply. Also, unemployed bees are known as scouts who explore potential food sources near the hive and search for nectar using their collective bee experience. There are between 5% and 10% of scouts overall. The onlooker group is waiting in the hive at the same time to verify the information provided by the employed bees.

Many experiments have shown that the ABC algorithm solved numerous optimization problems [18]–[22]. The ABC algorithm is based on how natural bees forage for nectar and communicate with one another about food sources in the proximity of the hive. Among other benefits, the artificial bee colony optimization method's simplicity, high adaptability, resilience, lack of controlling parameters, and ease of implementation association. Additionally, the ABC is also capable of handling the objective with stochastic nature with fast convergence. For that reason, the ABC algorithm is a popular swarming intelligence algorithm due to simplicity development and versatile, especially for more complexity optimization solutions [23], [24].

As an action, this research developed an ABC algorithm with adoption of initialization, reproduction process next to replacement of bee and selection progression. The approach is to determine the best answer for each objective function of economic environmental power dispatch (EEPD) problems, which are considered total generation cost, emission polluted, and system losses minimization. Thoroughly, the simulation was conducted in order to obtain the best possible solution. Hence, the solution with the minimum total generation cost, lowest emission produced by power plant, and the less entire system losses will be the best possible result. The ABC algorithm simulation was executed on both the standard IEEE 26 bus system and IEEE 57 bus system by MATLAB software programming.

2. METHODOLOGY

2.1. Environmental economic power dispatch

Several important objectives function was identified in solving the EEPD problems. Primarily, the EEPD solution was tested on the standard IEEE-26 bus system and IEEE-57 bus system respectively in determining the total cost, total emission, and losses minimization during network operation. The following section will describe the formula involved for those objective functions.

2.1.1. Objective functions

The aims of the EEPD are called as objective function and can be applied individually [4]. While the limitation for all operational constraints must also be satisfied as well. Thus, the following sections will be a mathematical formulation for each objective function.

a) Total generation cost

The primary objective function of EEPD has been identified as total generation cost minimization and named as EEPD1. The essential formulation in calculating the EEPD1 is presented mathematically in (1) [25]. Where Ci (Pgi) is the function total cost for generation unit of i, Pgi is the generation power of i unit, ai, bi, ci is the respective of cost coefficient for unit i, and C_{Total} is the total cost of the generation units.

$$C_{Total} = \sum_{i=1}^{Ng} C_i\ (Pg_i) \text{ dollar per hour } \left(\frac{\$}{\text{h}}\right) C_i(Pg_i) = \alpha_i + b_i Pg_i + C_i Pg_i^2 \quad (1)$$

b) Total emission

Another significant single objective function is known as EEPD2 which aimed for total emission minimization. The corresponding mathematical formula can be found using (2) [25]. Where, E_{Total} is the total emission function for all generation units while γi, βi, αi, εi, λi is the corresponding emission coefficient for unit i, and Pgi is the real power generation unit i.

$$E_{Total} = \sum_{i=1}^{Ng} (\gamma_i Pg_i^2 + \beta_i P_i + \alpha_i) * (10^{-2})$$
$$\varepsilon_i exp(\lambda_i Pg_1) \quad ton/h \quad (2)$$

c) Total system loss

The final objective function is to achieve the lowest possible total losses during the power system operation, which is labeled as EEPD3. Consequently, in (3) is the related mathematical formula for losses calculation [5]. Where, T_{Los}s is the total losses in power generation, Pg_i real power generation unit i, and P_{demand} is the total demand of the bus system.

$$T_{Loss} = \sum_{i=1}^{Ng} Pg_i - P_{demand} \ Watt\ (W) \quad (3)$$

2.1.2. Constraints

As well, the operational system constraints were also fulfilled to ensure the secured network during the operation. The constraint was categorized into equality and inequality system constraints capabilities in order to achieve all the identified objective functions. Therefore, the following section will discuss the related formulation for them.

a) Equality constraint

The equality constraint is about the total demand required for the power system network to operate. The total generation units produced must meet the entire power demand by considering the system losses as well. Therefore, the formulation for the equality constraint is given mathematically as in (4) [5]. Where, P_{demand} is the total system demand and T_{Loss} is total system losses.

$$\sum_{i=1}^{Ng} Pg_i = P_{demand} + T_{Loss} \quad (4)$$

b) Inequality constraint

While the inequality constraint is defined as the limitation for each generation units for the power system network during operation. Thus, the specific range of the generation units to operate effectively is described by a mathematical presentation as shown in (5) [5]. Where, P_{min} and P_{max} is the minimum and maximum real power generation of unit i.

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

During the system operation, the allowable maximum and minimum voltage must be satisfied too. According to previous research, the minimum voltage must be within 0.9 p.u to 1.05 p.u for IEEE 26 bus system and within 0.95 p.u to 1.1 p.u for IEEE 57 bus system during system operation to ensure secure of the system [4]. Where, V_{min} is the minimum voltage and V_{max} is the maximum voltage.

$$V_{min} \leq V \leq V_{max} \quad (6)$$

2.2. Overview artificial bee colony

ABC method is a stochastic swarming search algorithm that takes its ideas from the manner bees search for nectar. The artificial bee colony is related with the ABC search method using three sorts of bees: employees, onlookers, and scouts. Artificial bees employed in the colony form a portion, and other bees are known to as observers. Only an employed bee is involved in the searching process for each location of a food supply. It can be claimed that the amount of bees working is equal to the quantity of food sources nearby the hive. The new food supply, which they will abandon, is the responsibility of the employed bee. The job of collecting the chosen nectar will then be completed by a group of scout bees. The algorithm considers the location of the food source to be a potential solution, and the quantity of nectar comes in for the fitness of each potential solution [14]. The flowchart in Figure 1 represents a whole necessary process involved in ABC algorithm simulation to find the best suitable solution for the EEPD problem.

As mentioned, this approach is a vital simulation tool for determining the EEPD1, EEPD2, and EEPD3 individually for both standard IEEE 26 and IEEE 57 bus systems. An identified six generator busses for IEEE 26 bus system while the seven generators' units for IEEE 57 bus system are considered as an initial population solution, Pgi to be modified within their distinct range as shown in the mathematical (5) in order to achieve particular mentioned single objective functions. The common Newton Raphson load flow method is then executed to ensure all constraints are meet as presented in (4) to (6) earlier. At the same time, the particular objective function is also calculated to determine the best possible solution.

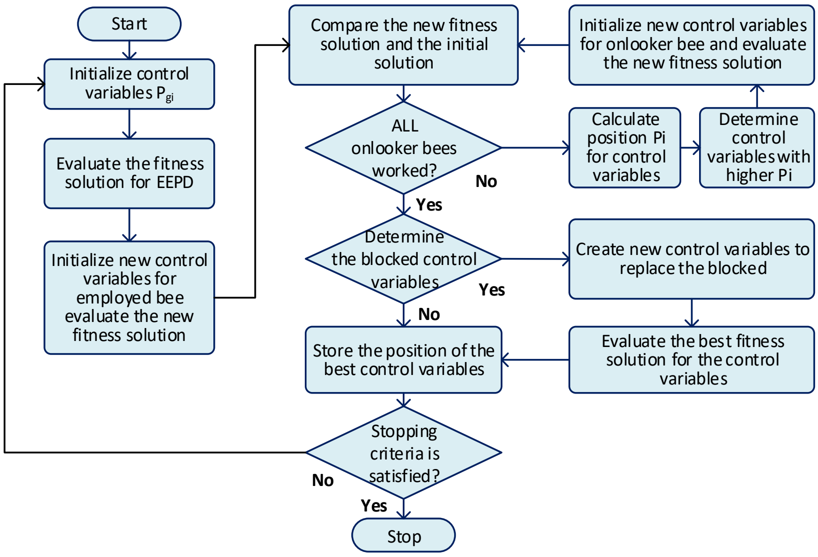


Figure 1. Flowchart of the ABC algorithm for single EEPD solutions

As shown in Figure 1, the initial process involves the searching phase by several scout bees for the suitable generator's capacity within their limitation as formulated previously in (5) and known as the control variables. In the process, the particular objective function according to (1) to (3) was calculated individually and verified its convergence toward the optimal solution. The onlooker's scout updates the searching parameters for better suitable solutions. All these processes were keep repeated until reaching the best reasonable result or the stopping criterion was met. Basically, three main process occurred in ABC algorithm were initialization, reproduction, replacement, and selection process. Accordingly, the explanation about the process involved will be described in the following section.

2.2.1. Initialization

The initial control variable (*Pg*=1,2…D) were spread randomly. To meet the initial population solution over number of generation units that need to be optimized or also known as dimensional problem space, D. The searching solution in this phase are evaluated by employed bees and completed by scout bees.

2.2.2. Reproduction

In order to recruit new employees, this algorithm made the employed bees explore their food sources and inform the observer bees of their discoveries. The onlooker bees will pick a food source based on this information. Bees that are observing will more likely select a higher-quality food source. Artificial bee onlookers play a part in selecting the control variable values during this process based on the probability value, P_i, associated with those generation units, which may be determined using the following expression in (7).

$$P_i = \frac{fit_i}{\sum_{i=1}^{Ne} fit_i} \tag{7}$$

Where fit_i is the single EEPD solution of generation unit which is proportional to the total number of generation units, D and N_e (No of population/2) is the number of food sources which is the number of employed bees, n_e involved. In this process, the onlookers do the modification on the particular number of generation units using (8) and evaluate the new fitness or EEPD result.

$$V_{ij} = P_{gij} + \emptyset_{ij}(P_{gij} - P_{gkj}) \tag{8}$$

Where k ∈ {1, 2,…., n_e} and j ∈ {1, 2, …..,D} are randomly placing indexes and have to be dissimilar from i. $\emptyset_{ij}$ is random number in between [-1, 1] which to control the solution of the neighborhood. If the fitness value is higher than the earlier solution thus the replacement process will then take place.

2.2.3. Replacement of bee and selection

The employed bees, who are subsequently identified as scouts, quit the solution in the event that a predetermined number of trials have not shown fitness solution. Thus, "limit," a crucial control parameter in the ABC algorithm, must be applied to the number of trials necessary to identify a solution. Usually, the limitation is from 0.001 n_eD to n_eD. If the abandoned solution $P_{gij,}\ j \in (1,2.\dots.D)$ hence the scouts seeking for a new solution $P_{gij,}$ using (9).

$$P_{gij} = P_{gj\,min} + rand(0,1) \times (P_{gj\,max} - P_{gj\,min}) \tag{9}$$

Where $P_{gj\,min}$ and $P_{gj\,max}$ are the minimum and maximum capacity of the generation unit to be optimized. Besides that, the ABC has four control parameters to be specified which are the number of employed bees, number of unemployed or onlooker bees, the limitation value, and the colony size. The ABC solution was carried out by the combination in local search from the responsibility of employed, onlookers, and scout bees by attempting a balance exploration process [17].

2.3. Pseudo-code for ABC algorithm

The pseudocode is a simplified of programming code to achieve the required results for the ABC algorithms that applied for the EEPD solution [13].

- Initialize the control variable values P_{gi}, i = 1…D
- Evaluate the individual objective function EEPD (fitness)
- Iteration = 1 (repeat)
- Generate new solution V_i by an employed bee using (7)
- Use the greedy selection process for the employed bees searching solution
- Calculate the probability values P_i for the solution of the generation unit X_i using (8)
- Generate a new solution V_i for the onlookers from the generation unit, P_{gi} choosing based on P_i and evaluate the fitness
- Use the greedy selection process for the onlookers.
- Verify the abandoned solution for scout. When exist, and modify it with the new randomly produced solution P_{gi} by (9)
- Keep all the best possible answers until existing
- Iteration = iteration + 1
- Continue until the stopping condition achieved

2.5. Percentage of deviation

The percentage of deviation is introduced as a measurement tool to evaluate the improvement solution using the introduced ABC algorithm. Therefore, the simple mathematical formulation is presented as in (10).

$$\%\,Deviation = \frac{(EEPD_{i_{base}} - EEPD_{i_{ABC}})}{EEPD_{i_{base}}}\,x100 \tag{10}$$

Where $EEPD_{i_{base}}$ and $EEPD_{i_{ABC}}$ are the base individual objective function solution and individual objective function solution solved by ABC algorithm, respectively. Based on the aim of the single objective functions of EEPD thus the results obtained from the ABC should be lower than the base values as given by the above equation.

3. RESULT AND DISCUSSION

The simulation task is implemented by the development of artificial bee colony (ABC) algorithm using MATLAB simulation environment. The committed generating units identified as Pg2, Pg3, Pg4, Pg5, and Pg26 were selected as control variables for the standard IEEE 26 bus system EEPD solution. The Pg2, Pg3, Pg6, Pg8, Pg9, and Pg12 were taken as control variables in the standard IEEE 57 bus system to solve the individual EEPD problem. The results for each objective were categorized into EEPD1 (minimum total cost), EEPD2 (minimum total emission), and EEPD3 (minimum system losses).

The solution highlighted the results gained from the particular objective function as the fitness while another two functions were observed. Each solution shown the result for a single objective function through 100 iterations using an identical optimization model performance. The results will discuss on the best possible answers among the individual objective functions obtained in terms of their standard deviation, and the percentage of the deviation. The outcome solution from ABC will then be compared with the solution provided from the conventional method known as Newton Raphson load flow using a gradient searching approach developed by author Saadat [26] named base case solution.

3.1 Result for standard IEEE 26 bus system

The results obtained from each singular objective function for IEEE 26 bus system is recorded in the following Figures 2(a)-(c). In getting the optimal solution thus these individual objective functions were tested on the identical parameter of the ABC algorithm. Initially, the distinct number of populations used is tested which is 10, 20 and 30 population accordingly to identify the best model for the EEPD solution as displayed in the figure.

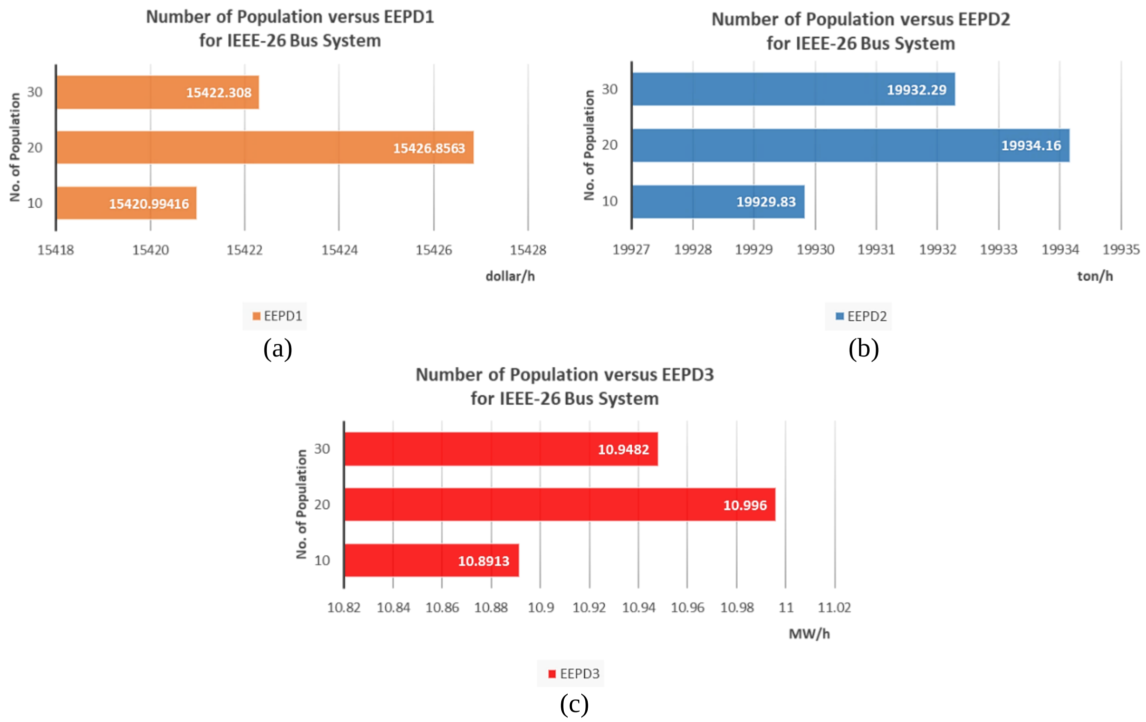


Figure 2. The comparison graph of EEPD against number of populations for IEEE 26 bus system: a) EEPD1, (b) EEPD2, and (c) EEPD3

From Figure 2(a), the best possible result for the minimum total cost was obtained at 15420.99 dollar/h. The solution is generated through 10 number of populations for EEPD1 that calculated from the mathematical formulation as in (1) using the corresponding cost coefficient and within their capacity limit. Then, the ABC algorithm is implemented for EEPD2 solution using the similar number of populations as done for EEPD1. As mentioned previously, all related parameters were used to obtain the EEPD2 as formulated in (2). The results achieved is presented by a graph in Figure 2(b). The graph highlighted the smallest emission produced was only at 19929.83 ton/h. Similarly, the least EEPD2 results when using the ABC algorithm with 10 populations. The EEPD3 solution is executed using the ABC algorithm with 10, 20, and 30 numbers of populations differently. A graph records the results as in Figure 2(c) displayed that the lowest system loss was 10.89 MW/h which again obtained by applying the 10 number of populations for the ABC algorithm. Based on the analysis of the attained result, the appropriate number of populations is by using the 10 number of populations in getting the best suitable solution for EEPD1, EEPD2, and EEPD3. Besides, Table 1 displayed the respective generating units produced to achieve the best possible solution for the EEPD1, EEPD2, and EEPD3 problems.

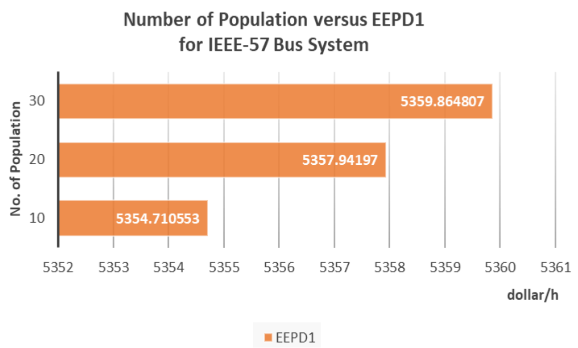
3.2. Result for standard IEEE 57 bus system

The ABC algorithm was also tested for the standard IEEE 57 bus system. Similarly, the EEPD1, EEPD2, and EEPD3 were simulated for different populations, which are 10, 20, and 30 population number of the identical algorithm as presented in Figure 3. EEPD1 is calculated using (1) during the simulation process, and the result is shown in Figure 3(a).

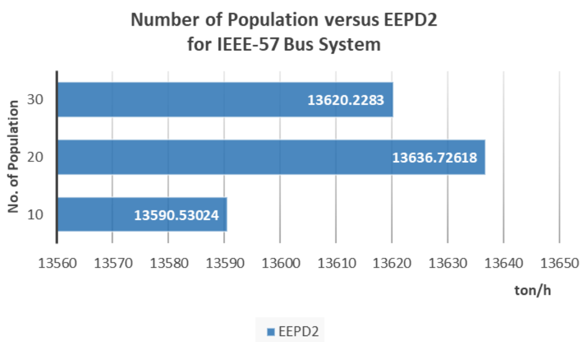
As referred to the graph in Figure 3(a), the best possible result was obtained at 5354.71 dollar/h for the EEPD1 function. The result is achieved when the ABC algorithm is applied with 10 number of populations. The next objective function tested was the EEPD2 formulated by (2) among 10, 20, and 30 number populations for the ABC algorithm application. The simulation results gained from the experiment are presented in the following Figure 3(b).

The graph highlighted the lowest emission for the bus system was 13590.53 ton/h that simulated from 10 number populations compared with the implementation of 20 and 30 number of populations. The other crucial objective function which is to reduce the total system loss or named as EEPD3 is also tested using the ABC algorithm. The algorithm was simulated among different number of populations like 10, 20 and 30 populations as well. Thus, the results obtained are illustrated by the graph as in Figure 3(c). From the plotted graph, the minimum total loss for EEPD3 is showed at 10.89 MW. Again, the lowest system loss is produced by using the 10 number of populations during the ABC algorithm deployment.

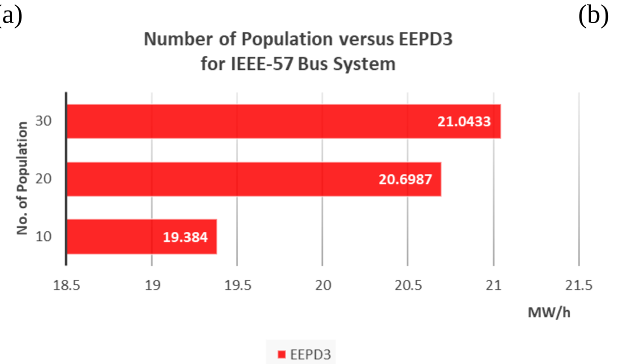
Throughout the analysis, the implementation of the ABC algorithm for standard IEEE 57 bus system also showed a better performance when using the 10 number of populations compared with a bigger number of populations. Earlier, a similar number of populations was also verified as the successful tool implementation for the in standard IEEE 26 bus system. Hence, Table 2 bring out the corresponding generator units simulated to attain the best possible result for the EEPD1, EEPD2 and EEPD3 problem.



(a)



(b)



(c)

Figure 3. The comparison graph of EEPD against number of populations for IEEE 57 bus system: (a) EEPD1, (b) EEPD2, and (c) EEPD3

3.3. Comparison between standard IEEE 26 bus and IEEE 57 bus system

The contrast between the standard IEEE 26 bus system and the standard IEEE 57 bus system is measured in terms of the deviation and percentage of the deviation compared with the base case value, respectively. The results obtained from the ABC algorithm with the 10 populations are taken because of the best possible solution. Accordingly, the following Table 3 simplified the results getting from the tested IEEE bus system as mentioned.

Table 1. The corresponding generator units using 10 number of populations for IEEE 26 bus system

	EEPD1	EEPD2	EEPD3
Pg1(MW)	449.101	441.542	445.656
Pg2(MW)	171.379	171.451	171.386
Pg3(MW)	261.952	261.786	262.011
Pg4(MW)	134.182	135.207	135.076
Pg5(MW)	173.931	175.950	175.539
Pg26(MW)	83.3337	84.475	84.223
$\sum \boldsymbol{Pg}$ (MW)	1273.882	1270.411	1273.891
Total demand (MW)	1263	1263	1263

Table 2. The corresponding generator units using 10 numbers of populations for IEEE 57 bus system

	EEPD1	EEPD2	EEPD3
Pg1(MW)	238.800	240.897	245.537
Pg2(MW)	100.000	99.991	100.000
Pg3(MW)	140.000	140.000	140.000
Pg6(MW)	99.990	100.000	100.000
Pg8(MW)	194.000	194.000	193.208
Pg9(MW)	100.000	100.000	100.000
Pg12(MW)	356.574	353.787	352.671
$\sum \boldsymbol{Pg}$ (MW)	1229.365	1228.674	1231.416
Total demand (MW)	1250.8	1250.8	1250.8

Overall, the results displayed in Table 3 saw that the ABC algorithm solved the less amount for all three individual functions named EEPD1, EEPD2, and EEPD3 referred to the base value simulated with the simple gradient approach of Newton Raphson load flow method. Furthermore, the deviation is calculated and highlighted in percentage as well, that presented in Table 4. For IEEE 26 bus system, the improvement between the base case and ABC algorithm is about 20.11 dollar/h for the EEPD1 solution. The percentage of the deviation is then calculated at 0.13% using (10). Whilst the EEPD2 resulted by the ABC algorithm showed less about 203.27 ton/h of emission polluted compared with the base case quantity. The corresponding percentage of improvement is 1.01% based on the calculation. The ABC algorithm's enhancement also referred to reducing the system losses as matched with the base value. In sequence, the significant percentage of deviation is determined as equal to 19.96% overall. Then, the fewer expenses for EEPD1 in the standard IEEE 57 bus system about 1.39 dollar/h are gained through the ABC simulation. Thus, the mild percentage of deviation calculated only about 0.02% as referred to base value total cost. The significant improvement in finding the EEPD2 for the bus system which is about 9044.1 ton/h can be reduced using the ABC algorithm approach. From the calculation is found that the percentage of deviation for EEPD2 is 39.88%. The EEPD3 for IEEE 57 bus system also showed a reduction by 10.98 W/h for losses when applying the ABC algorithm. The calculated deviation percentage is about 34.29% as compared with the base case system loss produced.

Table 3. The comparison results obtained between the gradient method (base value) and the ABC Algorithm for EEPD1, EEPD2, and EEPD3

	EEPD objective	Gradient method	ABC algorithm	Elapsed time (s)
IEEE 26 bus system	EEPD1 (dollar/h)	15441.100	15420.990	31.35
	EEPD2 (ton/h)	20133.100	19929.830	
	EEPD3 (MW/h)	13.607	10.891	
IEEE 57 bus system	EEPD1 (dollar/h)	5356.100	5354.710	53.86
	EEPD2 (ton/h)	22681.000	13636.090	
	EEPD3 (MW/h)	32.018	21.040	

Table 4. The deviation and the percentage calculation between the gradient method (base value) and the ABC Algorithm for EEPD1, EEPD2, and EEPD3

	EEPD objective	Deviation	Percentage of deviation %
IEEE 26 bus system	EEPD1 (dollar/h)	20.110	0.13
	EEPD2 (ton/h)	203.270	1.01
	EEPD3 (MW/h)	2.716	19.96
IEEE 57 bus system	EEPD1 (dollar/h)	1.390	0.02
	EEPD2 (ton/h)	9044.910	39.88
	EEPD3 (MW/h)	10.978	34.29

Thoroughly, the ABC algorithm showed better performance based on the deviation measurement. In addition, the calculated deviation percentage also indicated the improvement using the ABC even though not significantly elevated in EEPD1 for both IEEE bus systems. However, the most significant improvement of the introduced algorithm is provided for EEPD3 solutions.

4. CONCLUSION

This research was presented the minimization and objective functions for solving the singular objective functions of the EEPD problem, which is identified as EEPD1, EEPD2, and EEPD3 using the ABC algorithm. Upon the completion, the proper population used was chosen as 10 number of the population due to the best possible outcome of every single objective of the EEPD. The measurement in terms of the deviation and its percentage is calculated as well to verify the ABC algorithm performance that referred to the base value has shown an improvement. Moreover, the benefit of employing the ABC algorithm is more significant for EEPD3 due to the percentage of the deviation result for the above two standard bus systems. In conclusion, the ABC swarming algorithm is verified as an effective simulation tool to overcome the complexity of the identified singular objective functions of the EEPD problem and needed less than 60 seconds to complete the solution for 100 iterations of looping stopping criteria.

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