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Research paper



Combined Economic and Emission Dispatch Solution using Artificial Bee Colony Algorithm with Fuzzy Approach

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Abstract

The cost and emission minimization in power system operation become important issue in power dispatch due to increase of environmental pollution and fossil fuel price. Therefore, combined economic and emission dispatch (CEED) must be considered in generation scheduling in order to provide balanced solution for optimal cost and emissions level of power generation. In this paper, an Artificial Bee Colony (ABC) algorithm with Fuzzy best compromise solution is proposed to determine the optimal cost and emission level by converting the multi-objective (cost and emission) into single objective problem using weighted sum method approach. The best compromise solution among Pareto front solution was determined by fuzzy approach. The effectiveness of ABC algorithm has been validated in terms of the best solution, convergence behaviour and consistency for power system benchmark such as IEEE 30-bus 6-unit system and 10-unit system. The comparison study shows that ABC algorithm capable to obtain a better performance of minimizing the cost and emission level in power generation.

Keywords: *Artificial Bee Colony Algorithm; Best Compromise Solution; Combined Economic and Emission Dispatch; Fuzzy Approach*

1. Introduction

There is various type of energy resources can be used to generate electricity such as fossil fuels, wind power, hydropower, solar power and many others. Among those sources, fossil fuels which include coal, natural gas and oil ranked to be the most common sources for the electric generation [1]. In power system application, the two main optimization problems such as economic dispatch (EcD) and emission dispatch (EmD) problem should be considered.

EcD aims to determine the power output of the scheduled unit for a system in order to meet the power demand at the minimum operating cost and the constraints of the system are achieved regardless of the emission amount [2]. Due to increase awareness and concern about environmental pollution which will lead to a result of global warming has encouraged the power system planning to consider the emission dispatch into economic dispatch simultaneously. The use of fossil fuels to generate electricity accounted as one of the cause of global warming because some impurity gases like nitrogen oxides (NOx), carbon dioxide (COx) and sulphur oxides (SOx) will emit during the power generating process [3],[4]. Therefore, EmD plays an important role in power system operation with considerations concerning reduction of pollution.

The objective of EmD is to optimize the power output of the generating units so that the total emissions quantity released from generating unit can be minimized or controlled. In order to get an optimum solution that will provide a balanced result for minimization of both operating cost and emission level, a combined economic and emission dispatch (CEED) problem is considered [5,6]. Several algorithms have been applied to determine optimal results of CEED problem for different case studies such as particle swarm optimization (PSO) [7] and flower pollination algorithm (FPA) [8] where price penalty function is used to combined cost and emission to become single a objective function. In [9], both objectives are evaluated based on non-dominated and crowding distance to obtain Pareto front solution but programming become complicated. For constraints handling, an equality constraint is more complicated and difficult to handle. Most of the researchers are embedded the constraints with objective function with penalty function [10]. However, it required an extensive study to determine the proper selection values of penalty factor and may varies to the complexity of the problem. An efficient constraints handling approach has been proposed in [11] to satisfy the power balance without using the penalty factor. The weighted sum method (WSM) has been applied to transform a set of objectives function into a single objective while fuzzy-based mechanism plays the role to choose the best compromise solution that minimize both objectives in balanced condition [12],[13].

This paper proposes an ABC algorithm with efficient constraint handling in operating cost and emission level minimization of power generation. The fuzzy approach has been adopted in ABC algorithm to determine best compromise solution. The effectiveness and performance of ABC algorithm have been tested on 2 test systems which are IEEE 30-bus 6-unit system and 10-unit system in term of the optimal solution, convergence characteristics and robustness after 40 trials of 1000 iterations. The obtained optimal results were compared with some reported results found in the literature thus highlight the high performance of ABC since it is

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capable to get a better compromise result for fuel cost and emission level optimization.

2. Problem Formulation: Optimal Combined Economic and Emission Dispatch (CEED)

This section presents the mathematical formulation of EcD, EmD, CEED and constraints as follows:

2.1. Objective Function 1: Economic Dispatch (EcD)

The EcD aims to determine the power output of the generating unit in order to meet the load demand at the minimum cost while all the fulfilled the constraints. Considering the valve-point effects, the minimizing total fuel cost function for the *n* generating units can be modelled by a quadratic polynomial and sinusoidal functions as follows:

$$\begin{aligned} Min\ F_T &= \sum_{i=1}^{n} F_i(P_i) \\ &= \sum_{i=1}^{n}\left[a_i P_i^2 + b_i P_i + c_i + \left| e_i \sin(f_i (P_{i,\min} - P_i)) \right| \right] \end{aligned} \quad (1)$$

where F_T is the total fuel cost, $F_i(P_i)$ is the fuel cost function, P_i is the real output power of the i^{th} generating unit, n is the number of the generating unit, P_{min} is the lower power limit, a_i, b_i, c_i and are the cost function coefficients of i^{th} generating unit, e_i and f_i are the cost function coefficients considering valve-point effect [12],[14].

2.2. Objective Function 2: Emission Dispatch (EmD)

The EmD is to optimize the power output of the generating units so that the total emissions amount released from the system can be minimized or controlled**.** The quantity of emissions released by the operation of i^{th} generating unit can be expressed as follows:

$$\begin{aligned} Min\ E_T &= \sum_{i=1}^{n} E_i(P_i) \\ &= \sum_{i=1}^{n}\left[\left(\alpha_i P_i^2 + \beta_i P_i + \gamma_i + \xi_i \exp\left(\lambda_i P_i\right) \right) \right] \end{aligned} \quad (2)$$

where E_T is the total emission, $E_i(P_i)$ is the emission function if i^{th} generating unit, and α_i, β_i, γ_i, ξ_i and λ_i are the emission coefficients of i^{th} generating unit [12],[15].

2.3. Objective Function 3: Combined Economic and Emission Dispatch (CEED)

Since the objectives in (1) and (2) are optimized the cost and emission level of power generation separately, the CEED are required to solve the conflicts cost function and emission function as shown in Fig. 1. Thus, the main objective of CEED is to get an optimum solution of both operating cost and emission level simultaneously. The weighted sum method is adopted in this paper to convert these functions into a single objective. Therefore, the objctives function in (1) and (2) can be combined according to the formula [2],[12]:

$$FE_T = wF_T + (1-w)\sigma E_T \quad (3)$$

where FE_T is combined objectives of (1) and (2), w represents the weighted factor between 0 and 1 and σ is the price penalty factor. The factor σ is the ratio of the toal maximum fuel cost ($F_T(P_{max})$ to the total maximum emission (($E_T(P_{max})$) and can be calculated using following formula:

$$\sigma = \frac{F_T(P_{\max})}{E_T(P_{\max})} \quad (4)$$

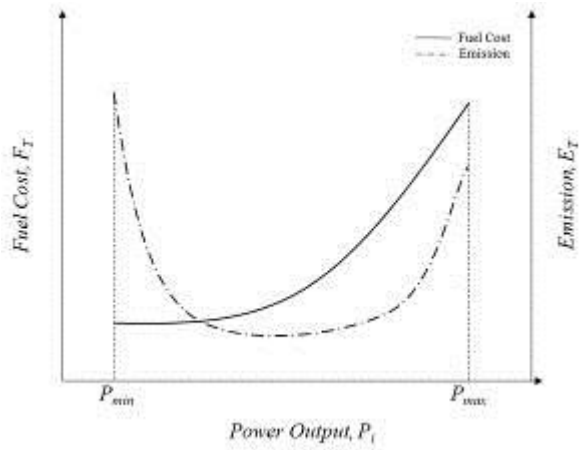


Fig. 1: Cost and emission characteristic of the thermal generator

2.4. Problem Constraints

The objection function of EcD, EmD and CEED in (1) to (3) are subjected to the following constraints:

2.4.1. Operating Power Limits

Operating power limits is one of the inequality constraints where the active power of i^{th} unit generator must be operated between the lower and upper limits as follows:

$$P_{i,\min} \le P_i \le P_{i,\max} \quad i = 1,2,\ldots,n \quad (5)$$

where $P_{i,min}$ and $P_{i,max}$ are the maximum lower and upper operating power limit of i^{th} generating unit.

2.4.2. Real Power Balance Constraints

Total power generated by i^{th} unit should be equal to the total of power demand and transmission line losses. The real power balance constraint can be calculated as follows:

$$\sum_{i=1}^{n} P_i = P_D + P_L \quad (6)$$

where P_D is the power demand in MW and P_L is the transmission line losses in MW.

Transmission line losses for a power generation system are quadratic functions in relation to variables P_i . The calculation of the transmission line losses can be used krons formula based on B-loss coefficients as follows:

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{0i} P_i + B_{00} \quad (7)$$

where B,B_0 and B_{00} are loss coefficients.

3. ABC Algorithm with Fuzzy for CEED Problem

Artificial Bee Colony (ABC) is a population based algorithm inspired by the intelligent food foraging behavior and communication of honey bee swarm to search for the optimal solution in the numerical optimization problem. Basically, the model of honey bee swarm intelligent forage selection consists of three groups of bees which named as employed bees, onlooker bees and scout bees and their three deeds are called as food source investigation, bees recruitment for the food source and food source dereliction [10],[16]. The fundamental ABC are as follows:

Step 1 (Initialization):
Determine the population size (*SN*) and calculate the possible food source x_i *(i=1,2,…,SN)*. Each food source is generated as follow:

$$x_{ij} = x_{j,\min} + rand[0,1](x_{j,\max} - x_{j,\min}) \quad (8)$$

Evaluate the fitness of food source with the following formula:

$$fitness_i = \begin{cases} \dfrac{1}{(1+F_i)}, if\ F_i \geq 0 \\ 1 + abs(F_i), otherwise \end{cases} \quad (9)$$

Step 2 (Employed bees phase):
Determine the new food source location, v_i according to the following equation:

$$v_{ij} = x_{ij} + \varphi_{ij}(x_{ij} - x_{kj}) \qquad i \neq k \quad (10)$$

When the new food source found is better than the reference food source, the reference food source will be replaced by the new food source. Otherwise, it will remain as the reference food source.

Step 3 (Onlooker bees phase):
Select the best food source according to the fitness value. The more amount of the nectar (fitness function), the higher probability (P_i) of being selected. The selection probability of a food source can be determined by:

$$p_i = \frac{fitness_i}{\sum_{k=1}^{SN} fitness_k} \quad (11)$$

Step 4 (Scout bees phase):
Find a new food source in replacement of the discarded food source, if the previous food source is being abandoned as it did not improve after reaching the visiting time. A new food source location can be selected based on (9).

The implementation flowchart of ABC algorithm for solving CEED is shown in Fig. 2. To satisfy the constraints in (5) to (7), the constraints handling based modified feasible solution has been implemented before updated the fitness solution. The details algorithm can be found in [11].

3.1. Fuzzy-Based Mechanism

In power dispatch optimization, economic dispatch and emission dispatch are opposing objectives which means the total fuel cost having a minimum value when the total emission is maximum and vice versa as shown in Fig. 1. In order to get the best compromise result that satisfies these two opposing objectives to some extent, the fuzzy-based mechanism is introduced. The linear membership function of each objective can be calculated as follows [3],[12]:

$$u_{ij} \begin{cases} 1 & f_j(X_i) \leq f_j^{\min} \\ \dfrac{f_i^{\max} - f_i(X_i)}{f_j^{\max} - f_j^{\min}} & f_j^{\min} \leq f_j(X_i) \leq f_j^{\max} \\ 0 & f_j(X_i) \leq f_j^{\max} \end{cases} \quad (12)$$

where f_j^{min} and f_j^{max} are the minimum and maximum value of the j^{th} objective function respectively, $f_j(X_i)$ is the value of the j^{th} objective function for the i^{th} solution. A normalized membership function needs to be determined so that best compromise solution will be selected among the non-dominated solution as follows:

$$u_i = \frac{\sum_{j=1}^{k} u_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{k} u_{ij}} \quad (13)$$

where *m* is the number of non-dominated solution and *k* is the number of the objective functions.
The non-dominated solution with the highest value of μ solution is selected as the best compromise solution for CEED problem.

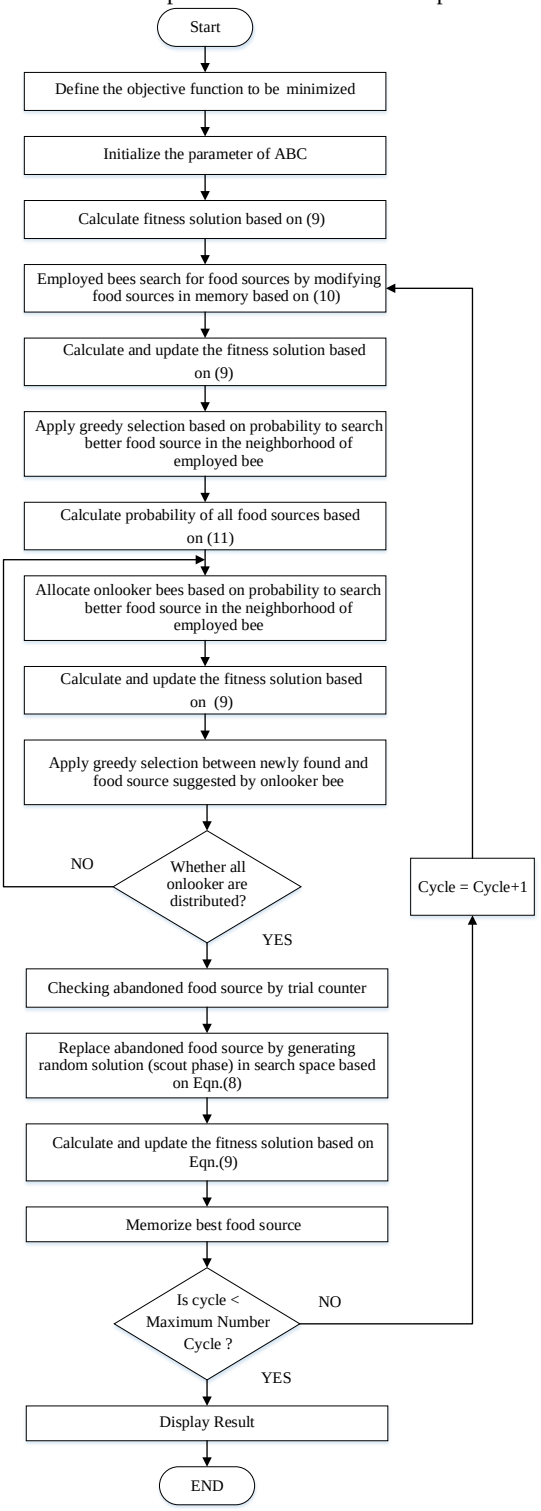


Fig. 2: Flowchart of Artificial Bee Colony for CEED

4. Results and Analysis

The simulation has been conducted using MATLAB R2018a software in order to investigate the performance of ABC algorithm with the fuzzy compromise solution for CEED problem. It has been tested two case studies; IEEE 30-bus 6-unit system and 10-unit system. Initially, both systems are used to minimize cost and emission individually. Then, the CEED with fuzzy compromise solution is considered. The simulation results have been analyzed in term of optimal solution, convergence characteristics and robustness after 40 trials of 1000 iterations. Finally, a comparison of ABC algorithm results with the reported results in literature has been conducted.

4.1. Case Study 1: IEEE 30-Bus 6-Unit System

Case Study 1 considered IEEE 30-bus 6-unit system with the power demand of 2.834 p.u. The input data of this case study are taken from [17] and the data are provided in per unit (p.u). The best optimal cost and emission solution produced by ABC are tabulated in Table 1. It found that the result of optimal cost (603.3509 $/h) obtained high emission amount (0.2032 ton/h) while optimal emission (0.1862 ton/h) obtained high emission amount (636.1508 $/h). The covergence characteristic of ABC for this case study has been plotted in Fig. 3. It can be seen that the ABC obtained minimum cost and emission within 100 iterations. To determine the consistency of ABC for fuel cost and emission minimization, the 40 runs are conducted in this case study and the result presented in Fig. 4.

For CEED problem, the Pareto front solution obtained by ABC after varying the weight factor (w) from 0 to 1 in step of 0.1 are shown in Table 2. Based on fuzzy approach, it found that the best compromise solution is located at w=0.7. Fig. 5 illustrates the Pareto front solutions obtained by ABC and the best compromise solution will be chosen among the Pareto members according to the fuzzy-based mechanism. In order to demonstrate the performance of ABC algorithm, the comparison between ABC and other algorithms such as Modified Bacterial Foraging Algorithm (MBFA) [18], Multi-objective Differential Evolution (MODE) [19] and Backtracking Search Algorithm (BSA) [12] are tabulated Tables 3 and 4. It found that ABC algorithm can provide optimal cost and emission compared to other algorithms. Therefore, it can be highlighted that ABC capable to obtain a better solution and it has good potential for solving CEED problems.

Table 1: Optimal Cost and Emission Level for Case Study 1

	Fuel Cost Minimization	Emission Minimization
P_1 (p.u.)	0.1506	0.3925
P_2 (p.u.)	0.2842	0.4953
P_3 (p.u.)	0.5784	0.5038
P_4 (p.u.)	0.9807	0.4552
P_5 (p.u.)	0.5051	0.5047
P_6 (p.u.)	0.3477	0.4948
P_T (p.u.)	2.8467	2.8462
P_L (p.u.)	0.0128	0.0121
Fuel cost ($/h)	**603.3509**	636.1508
Emission (ton/h)	0.2032	**0.1862**

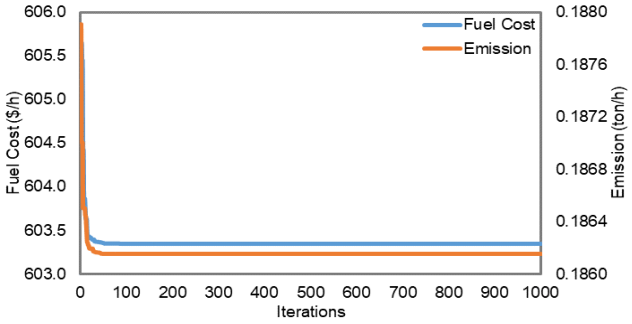


Fig. 3: Convergence Characteristic of ABC Algorithm for Case Study 1

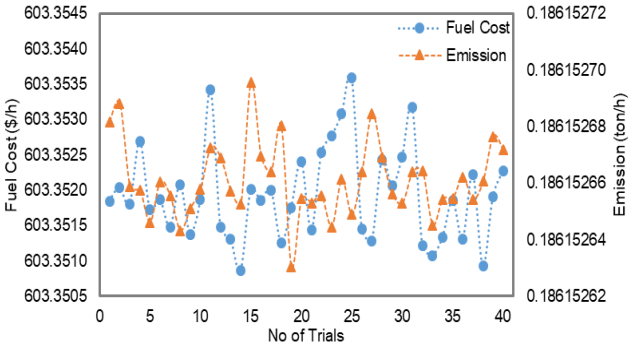


Fig 4: Robustness of ABC Algorithm for Case Study 1

Table 2: Optimal Solution for Different Weighted Value (w) and Normalized Membership Function (μ) for Case Study 1

w	Fuel Cost ($/h)	Emission (ton/h)	μ_{FC}	μ_{FE}	μ
0.0	636.1508	0.1862	0.0000	1.0000	0.0715
0.1	633.5427	0.1862	0.0795	0.9984	0.0771
0.2	630.7433	0.1863	0.1649	0.9927	0.0828
0.3	627.6406	0.1865	0.2595	0.9807	0.0887
0.4	624.3194	0.1868	0.3607	0.9601	0.0944
0.5	620.6817	0.1874	0.4716	0.9258	0.0999
0.6	616.8043	0.1883	0.5898	0.8712	0.1045
0.7	**612.6556**	**0.1899**	**0.7163**	**0.7821**	**0.1071**
0.8	608.6559	0.1922	0.8383	0.6431	0.1059
0.9	605.0572	0.1963	0.9480	0.4039	0.0967
1.0	603.3509	0.2032	1.0000	0.0000	0.0715

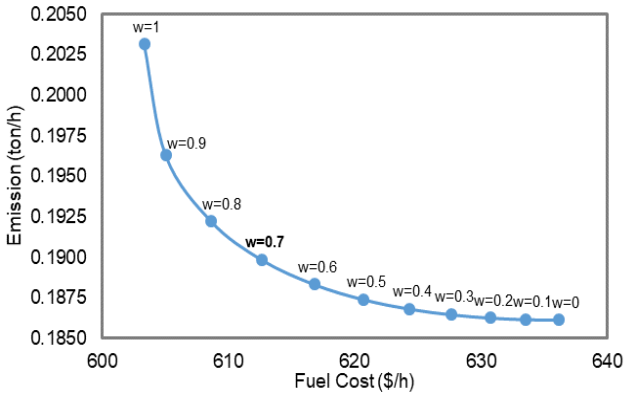


Fig. 5: Pareto Front Solutions Obtained by ABC Algorithm for Case Study 1

Table 3: Comparison of Fuel Cost and Emission Minimization between ABC and Other Algorithms for Case Study 1

Method	Fuel Cost Minimization		Emission Minimization	
	Fuel Cost ($/h)	Emission (ton/h)	Fuel Cost ($/h)	Emission (ton/h)
MBFA [18]	606.17	0.2174	643.84	0.1942
MODE [19]	606.126	0.2195	642.8490	0.1942
BSA [12]	605.9984	0.2207	646.2072	0.1942
ABC	**603.3509**	0.2032	636.1508	**0.1862**

Table 4: Comparison of Best Compromise Solution between ABC and Other Algorithms for Case Study 1

Method	Best Compromise Solution	
	Fuel Cost ($/h)	Emission (ton/h)
MBFA [18]	616.496	0.2002
MODE [19]	613.27	0.2026
BSA [12]	615.5878	0.2008
ABC	**612.6556**	**0.1899**

4.2. Case Study 2: 10-Unit System

In Case Study 2, the 10-unit system with the power demand of 2000MW is considered. The input data are taken from [12]. The best optimal solution for cost and emission level obtained by ABC are tabulated in Table 5. Fig. 6 presents the convergence characteristic of ABC for finding optimal cost and emission level during 1000 iteration. It clearly shows that the ABC obtained minimum value after 100 iterations and slightly decreased until 1000 iteration. After 40 different runs, the consistency result of cost and emission are shown in Fig. 7. ABC algorithm obtained the best solution after 40 runs but results are not consistent and fluctuated.

For CEED problem, the Pareto front solution obtained by ABC with varying the value of w is tabulated in Table 6. It can be seen that the cost is increased and emission decreased as the w increased in step of 0.1. These conflicting objectives can be seen in Fig. 8. From the figure, the best compromise solution is found at w=0.8 where the highest normalized value (μ) is selected as described in Section 3.1.

In order to demonstrate the performance of ABC algorithm, the optimal results of ABC and other algorithms such as Teaching Learning Based Optimization (TLBO) [20], Quasi-Oppositional Teaching Learning Based Optimization (QOTLBO) [20], Real Coded Chemical Reaction algorithm (RCCRO) [21] and Back-tracking Search Algorithm (BSA) [12] have been compared in Tables 7 and 8. For cost and emission minimization, it shows that ABC algorithm provided slightly smaller cost and emission amount compared to others. It should be noted that this study is conducted for one hour dispatch. Therefore, the saving can be obtained one month or year significantly.

Table 5: Optimal Solution of ABC Algorithm for Case Study 2

	Fuel Cost Minimization	Emission Minimization
P_1 (MWh)	55.0000	55.0000
P_2 (MWh)	80.0000	80.0000
P_3 (MWh)	106.9438	81.1427
P_4 (MWh)	100.5675	81.3574
P_5 (MWh)	81.5081	160.0000
P_6 (MWh)	83.0194	240.0000
P_7 (MWh)	300.0000	294.4674
P_8 (MWh)	340.0000	297.2791
P_9 (MWh)	470.0000	396.7730
P_{10} (MWh)	470.0000	395.5754
P_T (MWh)	2087.0388	2081.5951
P_L (MWh)	87.0389	81.5952
Fuel cost ($/h)	**111497.6240**	116412.3626
Emission (lb/h)	4572.1759	**3932.2429**

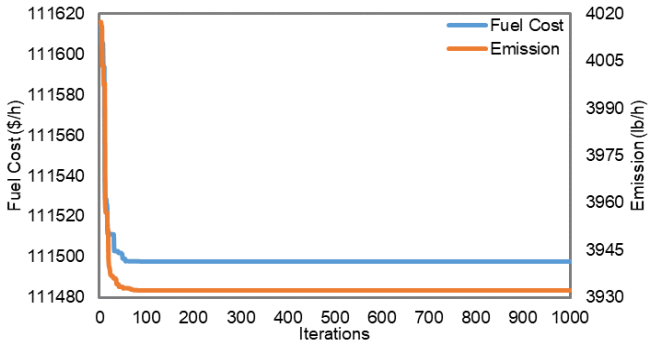


Fig. 6: Convergence Characteristic of ABC Algorithm for Case Study 2

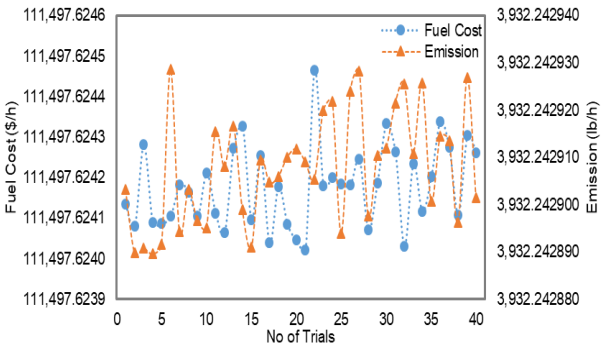


Fig. 7: Robustness of ABC Algorithm for Case Study 2

Table 6: Optimal Solution for Different Weighted Value (w) and Normalized Membership Function (μ) for Case Study 2

w	Fuel Cost ($/h)	Emission (lb/h)	μ_{FC}	μ_{FE}	μ
0.0	116412.3626	3932.2429	0.0000	1.0000	0.0823
0.1	116406.8240	3932.2553	0.0011	1.0000	0.0824
0.2	116400.5147	3932.3001	0.0024	0.9999	0.0825
0.3	116392.5583	3932.4058	0.0040	0.9997	0.0826
0.4	116383.0643	3932.6097	0.0060	0.9994	0.0827
0.5	115801.2251	3953.0844	0.1243	0.9674	0.0898
0.6	114856.4308	3998.8553	0.3166	0.8959	0.0998
0.7	113722.2224	4084.8297	0.5474	0.7616	0.1077
0.8	**112555.9001**	**4224.3401**	**0.7847**	**0.5436**	**0.1093**
0.9	111688.1184	4420.2634	0.9612	0.2374	0.0986
1.0	111497.6240	4572.1759	1.0000	0.0000	0.0823

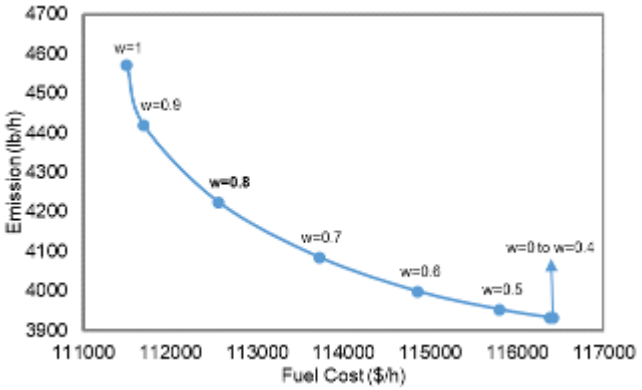


Fig. 8: Pareto Front Solutions Obtained by ABC Algorithm for Case Study 2

Table 7: Comparison of Fuel Cost and Emission Minimization between ABC and Other Algorithms for Case Study 2

Method	Fuel Cost Minimization		Emission Minimization	
	Fuel Cost ($/h)	Emission (lb/h)	Fuel Cost ($/h)	Emission (lb/h)
TLBO [20]	111500	4563.3	116412	3932.2
QOTLBO [20]	111498	4568.7	116412	3932.2
RCCRO [21]	111497.6319	4571.9552	116412.4441	3932.2433
BSA [12]	111497.6276	4572.2607	116412.3843	3932.2432
ABC	**111497.6240**	4572.1759	116412.3626	**3932.2429**

Table 8: Comparison of Best Compromise Solution between ABC and Other Algorithms for Case Study 2

Method	Best Compromise Solution	
	Fuel Cost ($/h)	Emission (lb/h)
TLBO [20]	113471	4113.5
QOTLBO [20]	113460	4110.2
RCCRO [21]	113355.7454	4121.0684
BSA [12]	112559.8061	4223.7248
ABC	**112555.9001**	**4224.3401**

5. Conclusion

In this paper, an Artificial Bee Colony (ABC) algorithm is proposed to solve a combined economic and emission (CEED) problem in power generation system. The CEED problem is a multi-objective optimization problem where both fuel cost and emission objectives are against each other. Thus, weighted sum method is used to solve CEED problem after solving it individually. The best compromise result is selected by using fuzzy-based mechanism. The proposed ABC algorithm has been applied to two case studies consists of IEEE 30-bus 6-unit system and 10-unit system in order to investigate the performance and effectiveness of ABC in term of the optimal solution, convergence characteristics and robustness. Moreover, the comparison has been conducted with some results of the same case studies reported in the literature. From the limited study, it found that ABC algorithm with fuzzy-based mechanism provided better performance for solving CEED problem.

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