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Combined Economic Emission Dispatch Solution using Modified Artificial Bee Colony Algorithm

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ABSTRACT: In this paper, a new approach is proposed to solve combined economic emission dispatch (CEED) problem in power systems using modified artificial bee colony (MABC) algorithm considering the power limits. The CEED is to minimize both the operating fuel cost and emission level simultaneously while satisfying the load demand and operational constraints. A novel best mechanism algorithm based on ABC algorithm, in which a new mutation strategy inspired from the differential evolution (DE) is introduced in order to improve the exploitation process. The effectiveness of the proposed algorithm has been tested on IEEE 30-bus test system and the results were compared with other methods reported in recent literature. The simulation results show that the proposed algorithm outperforms previous optimization methods.

KEYWORDS: Economic dispatch, emission dispatch, combined economic emission dispatch, modified artificial bee colony algorithm, differential evolution.

I. INTRODUCTION

Economic dispatch (ED) is one of the most fundamental issues in power system operation and control for allocating generation among the committed units. The objective of the ED problem is to determine the amount of real power contributed by online thermal generators satisfying load demand at any time subject to unit and system constraints so as the total generation cost is minimized. Therefore, it is very important to solve the problem as quickly and precisely as possible [1, 2]. Therefore, recently most of the researchers made studies for finding the most suitable power values produced by the generators depending on fuel costs. In these studies, they produced successful results by using various optimization algorithms [3-5]. Despite the fact that the traditional ED can optimize generator fuel costs, it still can not produce a solution for environmental pollution due to the excessive emission of fossil fuels.

Currently, a large part of energy production is done with thermal sources. Thermal power plant is one of the most important sources of carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x) which create atmospheric pollution [6]. Emission control has received increasing attention owing to increased concern over environmental pollution caused by fossil based generating units and the enforcement of environmental regulations in recent years [7]. Numerous studies have emphasized the importance of controlling pollution in electrical power systems [8].

Combined economic and emission dispatch (CEED) has been proposed in the field of power generation dispatch, which simultaneously minimizes both fuel cost and pollutant emissions. When the emission is minimized the fuel cost may be unacceptably high or when the fuel cost is minimized the emission may be high. A number of methods have been presented to solve CEED problems such as simplified recursive method [9], genetic algorithm [10-12], simulated annealing [13], biogeography based optimization [14], particle swarm optimization [15, 16], and artificial bee colony algorithm [17, 18].

In this paper, we propose a novel best search mechanism to improve original ABC algorithm. In this way, the newly generated candidate solutions are always around the random solutions of the previous iteration. Moreover, a controlled parameter is introduced to control the frequency of perturbation. By combing these methods, a modified algorithm as

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called MABC is proposed. Combined economic emission dispatch (CEED) solution which was performed using MABC algorithm was tested over a standard IEEE 30-bus test system which consisted of six generators. The results were compared to those reported in the literature.

II. PROBLEM FORMULATIONS

The EED problem targets to find the optimal combination of load dispatch of generating units and minimizes both fuel cost and emission while satisfying the total power demand. Therefore, EED consists of two objective functions, which are economic and emission dispatches. Then these two functions are combined to solve the problem. The EED problem can be formulated as follows [11]:

$$F_T = Min\ f\left(FC, EC\right) \qquad (1)$$

where F_T is the total generation cost of the system, *FC* is the total fuel cost of generators and *EC* is the total emission of generators.

2.1 Economic Dispatch (ED)

The ED problem targets to find the optimal combination of power generation by minimizing the total fuel cost of all generator units while satisfying the total demand. The ED problem can be formulated in a quadratic form as follows [11]:

$$F_C = \sum_{i=1}^{N}\left(a_i P_i^2 + b_i P_i + c_i\right) \qquad (2)$$

where P_i is the power generation of the *i*th unit; a_i, b_i, and c_i are fuel cost coefficients of the *i* th generating unit and *N* is the number of generating units.

2.2 Emission Dispatch (ED)

The classical ED problem can be obtained by the amount of active power to be generated by the generating units at minimum fuel cost, but it is not considered as the amount of emissions released from the burning of fossil fuels. Total amount of emissions such as SO2 or NOx depends on the amount of power generated by until and it can be defined as the sum of a quadratic function as follows [11]:

$$EC = \sum_{i=1}^{N}\left(\alpha_i P_i^2 + \beta_i P_i + \gamma_i\right) \qquad (3)$$

where α_i ,β_i and γ_i are emission coefficients of the *i*th generating unit.

2.3 Combined Economic Emission Dispatch (CEED)

CEED is a multi-objective problem, which is a combination of both economic and environmental dispatches that individually make up different single problems. At this point, this multi-objective problem needs to be converted into single-objective form in order to fulfill optimization. The conversion process can be done by using the price penalty factor. However, the single-objective EED can be formulated as shown in equation (4) [11, 18]:

$$Min\ \ F_T = \sum_{i=1}^{N}\left(\left(a_i P_i^2 + b_i P_i + c_i\right) + h_i\left(\alpha_i P_i^2 + \beta_i P_i + \gamma_i\right)\right)\ (\$/h) \qquad (4)$$

where h_i is the price penalty factor, and is formulated as follows:

$$h_i = \frac{a_i P_{i\max}^2 + b_i P_{i\max} + c_i}{\alpha_i P_{i\max}^2 + \beta_i P_{i\max} + \gamma_i} \qquad (5)$$

where $P_{i\ max}$ is the maximum power generation of the *i*th unit in MW.

2.4 Problem Constraints

There are two constraints in the EED problem which are power balance constraint and maximum and minimum limits of power generation output constraint.

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Power balance constraint:

$$\sum_{i=1}^{N} P_i = P_D + P_L \tag{6}$$

$$P_L = \sum_{i}^{N} \sum_{j}^{N} B_{ij} P_i P_j \tag{7}$$

Generating capacity constraint:

$$P_{i\min} \le P_i \le P_{i\max} \tag{8}$$

where P_D is total demand of the system (MW), and P_L is total power loss (MW). P_{imin}, $P_{imax,}$ and B_{ij} are minimum generation of unit i (MW), maximum generation of unit i (MW), and coefficients of transmission losses respectively.

III. ARTIFICIAL BEE COLONY (ABC) ALGORITHM

Artificial bee colony is one of the most recently defined algorithms by Karaboga in 2005, motivated by the intelligent behaviour of honey bees [19, 20]. In the ABC system, artificial bees fly around in the search space, and some (employed and onlooker bees) choose food sources depending on the experience of themselves and their nest mates, and adjust their positions. Some (scouts) fly and choose the food sources randomly without using experience. If the nectar amount of a new source is higher than that of the previous one in their memory, they memorize the new position and forget the previous one [20]. Thus, the ABC system combines local search methods, carried out by employed and onlooker bees, with global search methods, managed by onlookers and scouts, attempting to balance exploration and exploitation process.

In the ABC algorithm, the colony of artificial bees consists of three groups of bees: employed bees, onlooker bees, and scout bees. The main steps of the ABC algorithm are described as follows:

- Initialize.
- REPEAT.
  - (a) Place the employed bees on the food sources in the memory;
  - (b) Place the onlooker bees on the food sources in the memory;
  - (c) Send the scouts to the search area for discovering new food sources;
  - (d) Memorize the best food source found so far.
- UNTIL (requirements are met).

In the ABC algorithm, each cycle of the search consists of three steps: moving the employed and onlooker bees onto the food sources, calculating their nectar amounts respectively, and then determining the scout bees and moving them randomly onto the possible food source. Here, a food source stands for a potential solution of the problem to be optimized. The ABC algorithm is an iterative algorithm, starting by associating all employed bees with randomly generated food solutions. The initial population of solutions is filled with *SN* number of randomly generated *D* dimensions. Let $X_i = \{x_{i1}, x_{i2}, \ldots, x_{iD}\}$ represent the *i*th food source in the population, *SN* is the number of food source equal to the number of the employed bees and onlooker bees. *D* is the number of optimization parameters. Each employed bee x_{ij} generates a new food source v_{ij} in the neighborhood of its currently associated food source by (9), and computes the nectar amount of this new food source as follows:

$$v_{ij} = x_{ij} + \varphi_{ij}\left(x_{ij} - x_{kj}\right) \tag{9}$$

where $\varphi_{ij} = (\text{rand} - 0.5) \times 2$ is a uniformly distributed real random number within the range [-1, 1], $i \in \{1, 2, \ldots, SN\}$, $k = \text{int}(\text{rand} * SN) + 1$ and $k \ne i$, and $j \in \{1, 2, \ldots, D\}$ are randomly chosen indexes. The new solution v_i will be accepted as a new basic solution, if the objective fitness of v_i is smaller than the fitness of x_i, otherwise x_i would be obtained.

When all employed bees finish this process, an onlooker bee can obtain the information of the food sources from all employed bees and choose a food source according to the probability value associated with the food source, using the following expression:

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$$p_i = \alpha \times \frac{fit_i}{\max(fit_i)} + \beta; \quad \alpha + \beta = 1 \tag{10}$$

where fit_i is the fitness value of the solution *i* evaluated by its employed bee. Obviously, when the maximum value of the food source decreases, the probability with the preferred source of an onlooker bee decreases proportionally. Then the onlooker bee produces a new source according to (9). The new source will be evaluated and compared with the primary food solution, and it will be accepted if it has a better nectar amount than the primary food solution.

After all onlookers have finished this process, sources are checked to determine whether they are to be abandoned. If the food source does not improve after a determined number of the trails "limit", the food source is abandoned. Its employed bee will become a scout and then will search for a food source randomly as follows:

$$x_{ij} = x_{j\min} + \mathrm{rand}(0,1) * \left(x_{j\max} - x_{j\min}\right) \tag{11}$$

where $x_{j\,min}$ and $x_{j\,max}$ are lower and upper bounds for the dimension *j* respectively.

After the new source is produced, another iteration of the ABC algorithm will begin. The whole process repeats again till the termination condition is met.

IV. MODIFIED ARTIFICIAL BEE COLONY (MABC) ALGORITHM

Following this spirit, a modified ABC algorithm inspired from differential evolution (DE) to optimize the objective function of the ED problems. Differential evolution is an evolutionary algorithm first introduced by Storn and Price [23, 24]. Similar to other evolutionary algorithms, particularly genetic algorithm, DE uses some evolutionary operators like selection recombination and mutation operators. Different from genetic algorithm, DE uses distance and direction information from the current population to guide the search process. The crucial idea behind DE is a scheme for producing trial vectors according to the manipulation of target vector and difference vector. If the trail vector yields a lower fitness than a predetermined population member, the newly trail vector will be accepted and be compared in the following generation. Currently, there are several variants of DE. The particular variant used throughout this investigation is the DE/rand/1 scheme. The differential mutation strategy is described by the following equation:

$$v_i = x_a + F\left(x_b - x_c\right) \tag{12}$$

where $a, b, c \in SN$ are randomly chosen and mutually different and also different from the current index *i*. $F \in (0,1)$ is constant called scaling factor which controls amplification of the differential variation of $x_{bj} - x_{cj}$.

Based on DE and the property of ABC algorithm, we modify the search solution described by (13) as follows:

$$v_{ij} = x_{aj} + \varphi_{ij}\left(x_{ij} - x_{bj}\right) \tag{13}$$

The new search method can generate the new candidate solutions only around the random solutions of the previous iteration.

Akay and Karaboga [21] proposed a modified artificial bee colony (MABC) algorithm by controlling the frequency of perturbation. Inspired by this algorithm, we also use a control parameter, i.e., modification rate (*MR*). In order to produce a candidate food position v_{ij} from the current memorized x_{ij}, improved ABC algorithm uses the following expression [21, 22]:

$$v_{ij} = \begin{cases} x_{aj} + \varphi_{ij}(x_{ij} - x_{bj}), \text{if} \quad R_{ij} \le MR \\ x_{ij} \qquad\qquad\qquad \text{otherwise} \end{cases} \tag{14}$$

where R_{ij} is a uniformly distributed real random number within the range [0, 1]. The pseudo-code of the MABC algorithm is given below:

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Initialize the population of solutions x_{ij}, $i = 1. . .SN$; $j = 1. . .D$, $trial_i = 0$; $trial_i$ is the non-improvement number of the solution x_i, used for abandonment
Evaluate the population
cycle = 1
repeat
{--- Produce a new food source population for employed bee ---}
for $i = 1$ to SN **do**
Produce a new food source v_i for the employed bee of the food source x_i by using (14) and evaluate its quality:
Select randomly $a \neq b \neq i$

$$v_{ij} = \begin{cases} x_{aj} + \varphi_{ij}(x_{ij} - x_{bj}), \text{if} \quad R_{ij} \leq MR \\ x_{ij} \quad \text{otherwise} \end{cases}$$

Apply a greedy selection process between v_i and x_i and select the better one. If solution x_i does not improve $trial_i = trial_i + 1$, otherwise $trial_i = 0$
end for
Calculate the probability values p_i by (10) for the solutions using fitness values:

$$p_i = \alpha \times \frac{fit_i}{\max(fit_i)} + \beta; \quad \alpha + \beta = 1$$

{--- Produce a new food source population for onlooker bee ---}
$t = 0$, $i = 1$
repeat
if random < p_i **then**
Produce a new v_{ij} food source by (14) for the onlooker bee:
Select randomly $a \neq b \neq i$

$$v_{ij} = \begin{cases} x_{aj} + \varphi_{ij}(x_{ij} - x_{bj}), \text{if} \quad R_{ij} \leq MR \\ x_{ij} \quad \text{otherwise} \end{cases}$$

Apply a greedy selection process between v_i and x_i and select the better one. If solution x_i does not improve $trial_i = trial_i + 1$, otherwise $trial_i = 0$
$t = t + 1$
end if
until ($t = SN$)
{--- Determine scout bee ---}
if max ($trial_i$) > limit **then**
Replace x_i with a new randomly produced solution by (11)

$$x_{ij} = x_{j\min} + \text{rand}(0,1) * \left(x_{j\max} - x_{j\min}\right)$$

end if
Memorize the best solution achieved so far
cycle = cycle+1
until (cycle = Maximum Cycle Number)

V. SIMULATION RESULTS AND DISCUSSION

In the study of experiment, MABC algorithm is tested over standard IEEE 30-bus power system with six generating units as shown in Fig. 1. The parameters of all thermal units are presented in Table 1, followed by *B*-loss coefficient [9, 11, 18]. The values of MABC algorithm for solving CEED problem in this paper are designated as follow:

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The number of colony size, NP = 20; the number of cycles for aging, maxCycle = 300; the number of variables, NV = 6; and limit = 100.

The proposed technique is applied for CEED problem with load demands 500 MW, 700 MW, and 900 MW, respectively and it is compared with FCGA and NSGA-II [25]. Minimum fuel cost solution for CEED problem with all load demands are considered respectively in Table 2, Table 3, and Table 4. Minimum NO_x emission effect solution for CEED problem with all load demands are considered respectively in Table 5, Table 6, and Table 7. The best compromise solution for CEED problem with all load demands are considered respectively in Table 8, Table 9, and Table 10.

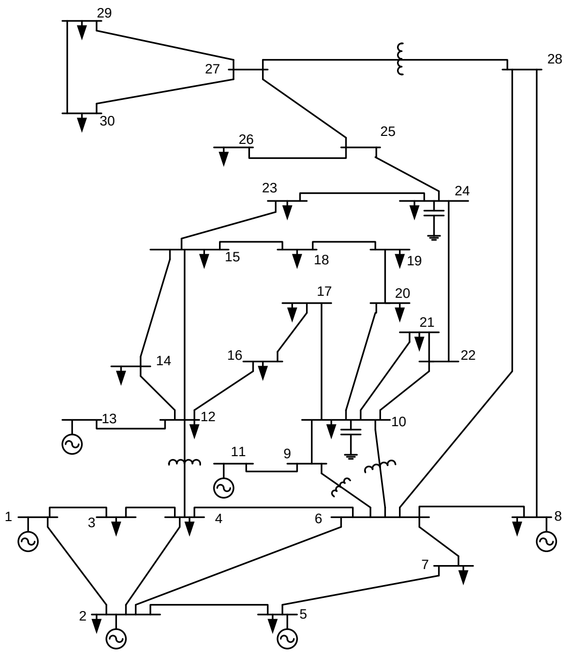

Fig. 1 Single-line diagram of IEEE 30-bus test system [18]

Table 1 Generator capacity limits, fuel cost and emission coefficients for IEEE 30-bus test system

Unit	P_i^{min} (MW)	P_i^{max} (MW)	a_i ($/MW^2)	b_i ($/MW)	c_i ($)	α_i ($/MW^2)	β_i ($/MW)	γ_i ($)
1	10	125	0.15240	38.53973	756.79886	0.00419	0.32767	13.85932
2	10	150	0.10587	46.15916	451.32513	0.00419	0.32767	13.85932
3	35	225	0.02803	40.39655	1049.9977	0.00683	-0.54551	40.26690
4	35	210	0.03546	38.30553	1243.5311	0.00683	-0.54551	40.26690
5	130	325	0.02111	36.32782	1658.5596	0.00461	-0.51116	42.89553
6	125	315	0.01799	38.27041	1356.6592	0.00461	-0.51116	42.89553

$$B_{ij} = \begin{bmatrix} 0.002022 & -0.000286 & -0.000534 & -0.000565 & -0.000454 & -0.000103 \\ -0.000286 & 0.003243 & 0.000016 & -0.000307 & -0.000422 & -0.000147 \\ -0.000534 & 0.000016 & 0.002085 & 0.000831 & 0.000023 & -0.000270 \\ -0.000565 & -0.000307 & 0.000831 & 0.001129 & 0.000113 & -0.000295 \\ -0.000454 & -0.000422 & 0.000023 & 0.000113 & 0.000460 & -0.000153 \\ -0.000103 & -0.000147 & -0.000270 & -0.000295 & -0.000153 & 0.000898 \end{bmatrix}$$

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Table 2 Best fuel cost for 6-generator system (P_D = 500 MW)

Unit Output	FCGA	NSGA-II	**MABC**
P1 (MW)	49.47	50.836	52.1024
P2 (MW)	29.40	31.806	29.0471
P3 (MW)	35.31	35.12	40.0000
P4 (MW)	70.42	73.44	68.0901
P5 (MW)	199.03	191.988	191.4150
P6 (MW)	135.22	135.019	136.4637
Fuel cost ($/h)	28150.80	28150.834	28086.9456
Emission (kg/h)	314.53	309.04	306.3324
Power losses (MW)	18.86	18.208	17.1183
Total Capacity (MW)	518.86	518.208	517.1183

Table 3 Best fuel cost for 6-generator system (P_D = 700 MW)

Unit Output	FCGA	NSGA-II	**MABC**
P1 (MW)	72.14	76.179	76.0897
P2 (MW)	50.02	51.81	49.0586
P3 (MW)	46.47	49.82	45.3525
P4 (MW)	99.33	103.407	102.7347
P5 (MW)	264.60	267.984	266.3914
P6 (MW)	203.58	184.734	191.3422
Fuel cost ($/h)	38384.09	38370.746	38207.5910
Emission (kg/h)	543.48	534.924	532.6970
Power losses (MW)	36.15	33.934	30.9692
Total Capacity (MW)	736.14	733.934	730.9692

Table 4 Best fuel cost for 6-generator system (P_D = 900 MW)

Unit Output	FCGA	NSGA-II	**MABC**
P1 (MW)	101.11	102.963	103.4811
P2 (MW)	67.64	74.235	70.1005
P3 (MW)	50.39	66.003	60.6818
P4 (MW)	158.80	140.316	139.5618
P5 (MW)	324.08	324.888	325.0000
P6 (MW)	256.56	248.416	251.7912
Fuel cost ($/h)	49655.40	49620.824	49297.9331
Emission (kg/h)	877.61	849.326	845.6922
Power losses (MW)	58.58	56.822	50.6162
Total Capacity (MW)	958.57	956.822	950.662

Table 5 Best emission effects for 6-generator system (P_D = 500 MW)

Unit Output	FCGA	NSGA-II	**MABC**
P1 (MW)	81.08	56.931	58.0644
P2 (MW)	13.93	41.542	43.7211
P3 (MW)	66.37	73.896	75.7252
P4 (MW)	85.58	84.931	83.9750
P5 (MW)	141.70	136.502	133.4545
P6 (MW)	135.93	131.328	128.7771
Fuel cost ($/h)	28756.71	28641.078	28626.5205
Emission (kg/h)	286.59	275.544	274.2547
Power losses (MW)	24.61	25.129	23.7172
Total Capacity (MW)	524.61	525.129	523.7172

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Table 6 Best emission effects for 6-generator system (P_D = 700 MW)

Unit Output	FCGA	NSGA-II	**MABC**
P1 (MW)	120.16	103.078	105.3292
P2 (MW)	21.36	73.505	76.4086
P3 (MW)	62.09	91.556	92.9206
P4 (MW)	128.05	110.787	109.8345
P5 (MW)	209.65	187.869	183.1928
P6 (MW)	201.12	174.289	170.0132
Fuel cost ($/h)	39455.00	39473.433	39433.4776
Emission (kg/h)	516.55	467.388	462.7169
Power losses (MW)	42.44	41.083	37.6990
Total Capacity (MW)	742.44	741.083	737.6990

Table 7 Best emission effects for 6-generator system (P_D = 900 MW)

Unit Output	FCGA	NSGA-II	**MABC**
P1 (MW)	133.31	124.998	124.9894
P2 (MW)	110.00	109.893	88.3224
P3 (MW)	100.38	111.081	123.9540
P4 (MW)	119.27	141.961	134.8330
P5 (MW)	250.79	254.36	274.6471
P6 (MW)	251.25	226.578	215.4800
Fuel cost ($/h)	53299.64	51254.195	50517.6331
Emission (kg/h)	785.64	760.052	751.2743
Power losses (MW)	65.00	68.87	62.2260
Total Capacity (MW)	965.00	968.87	962.2260

Table 8 Best compromise solution for 6-generator system (P_D = 500 MW)

Unit Output	FCGA	NSGA-II	**MABC**
P1 (MW)	65.23	54.048	54.7203
P2 (MW)	24.29	34.250	32.5975
P3 (MW)	40.44	54.497	49.2279
P4 (MW)	74.22	80.413	77.7303
P5 (MW)	187.75	161.874	166.3428
P6 (MW)	125.48	135.426	137.2141
Fuel cost ($/h)	28231.06	28291.119	28164.7430
Emission (kg/h)	304.90	284.362	282.4029
Power losses (MW)	17.41	20.508	17.1428
Total Capacity (MW)	517.41	520.508	517.1428

Table 9 Best compromise solution for 6-generator system (P_D = 700 MW)

Unit Output	FCGA	NSGA-II	**MABC**
P1 (MW)	80.16	86.286	84.1509
P2 (MW)	53.71	60.288	55.6554
P3 (MW)	40.93	73.064	66.0050
P4 (MW)	116.23	109.036	107.2668
P5 (MW)	251.20	223.448	230.9310
P6 (MW)	190.62	184.111	187.6477
Fuel cost ($/h)	38408.82	38671.813	38371.8924
Emission (kg/h)	527.46	484.931	476.5373
Power losses (MW)	32.85	36.234	31.6568
Total Capacity (MW)	732.85	736.234	731.6568

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Table 10 Best compromise solution for 6-generator system (P_D = 900 MW)

Unit Output	FCGA	NSGA-II	**MABC**
P1 (MW)	111.40	120.052	115.2769
P2 (MW)	69.33	85.203	78.8093
P3 (MW)	59.43	89.565	81.3885
P4 (MW)	143.26	140.278	137.3458
P5 (MW)	319.40	288.614	298.6779
P6 (MW)	252.11	233.687	238.1785
Fuel cost ($/h)	49674.28	50126.059	49553.8355
Emission (kg/h)	850.29	784.696	772.4565
Power losses (MW)	54.92	57.405	49.6769
Total Capacity (MW)	954.92	957.405	949.6769

Summary of the results in Table 2 to Table 10 for the best completion of MABC method compared with NSGA-II in order to reduce fuel costs, emissions, and power losses are shown in Table 11. After comparing the simulation results with the others method, it is obviously seen that proposed MABC algorithm give more powerful results than other algorithms.

Table 11 Summary of MABC VS NSGA-II for 6-generator system

	Load (MW)		
	500	**700**	**900**
Best fuel cost			
Fuel cost ($/h)	63.8884	163.1550	322.8909
Emission (kg/h)	2.7076	2.2270	3.6338
Power losses (MW)	1.0897	2.9648	6.2058
Best emission			
Fuel cost ($/h)	14.5575	39.9554	736.5619
Emission (kg/h)	1.2893	4.6711	8.7777
Power losses (MW)	1.4118	3.3840	6.6440
Best compromise			
Fuel cost ($/h)	126.3760	299.9206	572.2235
Emission (kg/h)	1.9591	8.3937	12.2395
Power losses (MW)	3.3652	4.5772	7.7281

VI. CONCLUSION

This paper has presented a new optimization algorithm to solve the combined economic emission dispatch problem considering linear equality and inequality constraints and also considering transmission losses. Economic and emission dispatch is a multi-objective problem. But the present approach makes use of only one objective function and depending upon the problem such as economic, emission or combined economic and emission dispatch, only the coefficients of the objective function has to be changed. The feasibility of the proposed method for solving CEED problems is demonstrated using IEEE 30-bus test system with six generating units. The comparison of the results with other methods reported in the literature shows the superiority of the proposed method and its potential for solving CEED problems in a power system. From the results obtained, it can be concluded that the MABC algorithm is a promising technique for solving complex optimization problems in power system operation.

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