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Solving Combined Economic and Emission Dispatch Using Harvest Season Artificial Bee Colony Algorithm Considering Food Source Placements and Modified Rates

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Abstract: This paper presents performances of a harvest season artificial bee colony (HSABC) algorithm for obtaining the best solution of a combined economic and emission dispatch (CEED). Two strategies of placement are applied to IEEE-30 bus system for solving the CEED problem under some constraints. Modified rates and various distances are also used to demonstrate HSABC's performances. Simulation results show that two placement strategies have different implications for the CEED, application of various modified rates and distances affect to convergence speeds, minimum results are searched in different starting points at the first iteration and the total number of food sources gives effects to the HSABC's performances.

Keywords: Bee, cost, food, solution.

1. Introduction

Power system is constructed by generation subsystem, transmission and sub-transmission subsystem, distribution and utilization subsystem. Practically, it uses interconnected systems for transferring electric energy from generating sites to the some areas of load demand. One purpose of this strategy is to reduce the total technical operating cost through the combination various types of generating units. An operating cost reduction is determined by sharing amount of a total power for each generating unit due to total load demand, which is expressed by an Economic Load Dispatch (ELD). ELD's primary objective is to schedule the committed generating unit outputs at a minimum total cost under some operational constraints [1].

Since the public awareness of the environmental protection have been increased to reduce atmospheric emissions, the ELD considers pollutant emissions in the air from combustions of fossil fuels at thermal power plants [2]. This situation has forced the power system operation to modify the operational strategies of the thermal power plants considered an Emission Dispatch (EmD). By considering an EmD, the ELD problem has become a crucial task to optimize a fuel cost with reducing pollutants for scheduling generating unit outputs on the minimum total cost [3]. The ELD and EmD are transformed into single objective function as a Combined Economic and Emission Dispatch (CEED) for collaborating both components.

Many previous works have been successfully applied to solve the CEED problem. Recently, evolutionary computational approaches are frequently used to solve optimization problems of the CEED. Evolutionary computations are commonly composed to mimic swarm behaviors of entities in nature by optimization principles for finding solutions. Evolutionary computations are developed to improve the performances of classical approaches [4]. The classical approaches cover many methods for searching solutions using mathematical programs [5], [6], [7], [8], [3], [9]. These methods are accurate but suffer for nonlinear search spaces and large scale systems. These approaches also need a long time for determining solutions. Many natural swarm behaviors have been adopted to create the evolutionary methods for improving classical performances, which are applied to carry out the optimization problems [10], [1], [11], [12], [13], [14], [2], [15]. Several evolutionary computation methods based on swarm behaviors are ant colony, cuckoo search, neural network and particles swarm.

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The newest evolutionary computation imitated a natural swarm behavior is an Artificial Bee Colony (ABC) algorithm. In 2005, this method was introduced to solve a numerical optimization based on a natural behavior of honeybees [4]. The ABC is consisted by employed bees, onlooker bees and scout bees. Each group of bees has different tasks to search food sources during foraging for the foods. In 2007, the ABC was evaluated to show its powerful and efficient compared with other evolutionary methods for optimization problems [16]. Many previous works have used ABC algorithm for analyzing the related problems.

At present years, ABC algorithm has been advancing to increase its performances in various names. These improvements are proposed in different years for each ABC's generation. Several types of ABC's generation are Parallel ABC, Smart Flight ABC, Multiple Onlooker ABC, Modified ABC and Improved ABC. According to these developments are known that main advantages are better abilities to get out of optimal results and superior performances for finding solutions [10], [17], [18], [19], [20], [21], [2]. From these works are devoted to the future studies in convergence speeds, searching mechanisms and real applications.

The latest generation of the ABC is a Harvest Season Artificial Bee Colony (HSABC) algorithm as a novel evolutionary method. This algorithm is introduced in 2013 and it is composed by multiple food sources (MFS) to mimics flowers of a harvest season situation for providing candidate solutions of the problem [22]. As the newest algorithm, this paper presents an application of HSABC for solving a CEED problem considered food source placements and modified rates (MR) to IEEE-30 bus system.

2. Harvest Season Artificial Bee Colony

Moving behaviors of entities in nature can be composed by using random walks [23], [7], [24], [25], [26]. Bees, as one of entities, fly randomly during foraging for the foods. The position moves from a selected current food source to one others for exploiting a large number of food sources [4], [19]. A large number of food sources is expressed by many flowers and it is provided in the harvest season area with a certain quality of nectars. In the HSABC, this situation is performed by using MFS to presents many flowers of a harvest season situation as the food sources. All food sources at certain positions collaborate to provide the best food [22]. Specifically, HSABC modifies a searching mechanism and a greedy process (GP) of the ABC. The GP is improved by using the fitness comparison and the searching mechanism is improved by generating random directions for the MFS. In the HSABC, the MFS is consisted by the first food source (FFS) and the other food sources (OFS). Each OFS is directed from the FFS by a harvest operator (ho). The FFS is accommodated from the ABC and it is followed by a creation of the OFS in random places around the FFS. The OFS can be arranged by using uncontrolled distance placements (UDP) and controlled distance placements (CDP). The UDP is position generations of OFS in random distances from the FSS for every foraging cycle and the CDP is position generations of OFS considered a certain distance from the FSS for each food source in every foraging cycle.

The HSABC is executed by following phases. The Initial Population Phase is a set population generation of candidate solutions. This population is created randomly by considering some constraints. Population's size is associated with a total employed bee. Each solution is corresponded to the number of parameters to be optimized which populated using equation (1). The Employed Bees Phase is a searching mechanism of neighbor food sources. Each food source chosen represents a possible solution to the problem. The OFS is created for expressing the harvest season situation after the FFS is found by bee. The Onlooker Bees Phase is food selections for the best food. A nectar quality of each food source is evaluated by using equation (4) and probability of food source is determined by using equation (5). The position of food candidate is searched by using equation (2) for the FSS and it is accompanied by OFS using equation (3). The best food is selected by using a greedy process considered a certain MR for every foraging cycle. The Scout Bees Phase is a random replacement of an abandoned food source with a new one.

In general, rules of the HSABC are MFS is consisted by FFS and OFS, OFS is preceded by the FFS, every food source is located at a different position, all food sources stay in the harvest season area, colony size is consisted by employed bees and onlooker bees, an employed bee of an abandoned food source becomes a scout bee. By mathematical expressions, the HSABC are composed as following expressions:

$$x_{ij} = x_{minj} + \mathrm{rand}(0,1) * (x_{maxj} - x_{minj}), \tag{1}$$

$$v_{ij} = x_{ij} + \emptyset_{ij}.(x_{ij} - x_{kj}), \tag{2}$$

$$H_{iho} = \begin{cases} x_{kj} + \emptyset_{ij}(x_{kj} - x_{fj}).(ho - 1), \text{ for } R_j < MR \\ x_{kj}, \text{otherwise} \end{cases}, \tag{3}$$

$$fit_i = \begin{cases} \frac{1}{1+F_i}, \text{for } F_i \geq 0 \\ 1 + abs(F_i), \text{if } F_i \leq 0 \end{cases}, \tag{4}$$

$$p_i = \frac{fit_i}{\sum_{i=1}^{SN} fit_i}, \tag{5}$$

where x_{ij} is a current food, i is the i^{th} solution of the food source, $j \in \{1,2,3,\ldots,D\}$, D is the number of variables of the problem, x_{minj} is the minimum limit of x_{ij}, x_{maxj} is the maximum limit of x_{ij}, v_{ij} is a food position, x_{kj} is a random neighbor of x_{ij}, $k \in \{1,2,3,\ldots,SN\}$, SN is the number of solutions, $\emptyset_{i,j}$ is a random number within [-1,1], H_{iho} is a harvest season food position, $ho \in \{2,3,\ldots,FT\}$, FT is the total number of flowers for the harvest season, x_{fj} is a random harvest neighbor of x_{kj}, $f \in \{1,2,3,\ldots,SN\}$, R_j is a randomly chosen real number within [0,1], MR is a modified rate of probability food, F_i is an objective function of the i^{th} solution of the food, fit_i is a fitness value of the i^{th} solution and p_i is the probability of the i^{th} quality of food.

3. Combined Economic and Emission Dispatch

One real problem of power system operation is an ELD. The ELD is used to schedule committed generating unit outputs by a minimizing total cost under some constraints [5], [10], [12], [3], [27]. The ELD is expressed by using a total fuel cost and it is formulated by equation (6). Specifically, real problems often have unique characteristics that make them difficult to obtain solutions and these chases are often constrained by operational limitations to pose desired solutions in the feasible space. In the power system operation, various pollutants have been produced from a burning of fossil fuels in the thermal power plants. Recently, these pollutants are considered as limitations in the ELD [27], [3], [28].

The pollutant discharge of generating units is minimized by using equation (7) as an EmD. By reducing pollutant emissions, the CEED is composed from ELD and EmD with including a penalty factor and a compromised factor. A penalty factor shows the rate coefficient of each generating unit at its maximum output for the given load. A compromised factor shows the contribution of ELD and EmD in the computations. The CEED is expressed by equation (9) as single objective function. To show CEED's performances, it is constrained by several limitations in equation (10) to (17). For obtaining a minimum solution, dispatching problem of the CEED is formulated by mathematical functions as follows:

$$\text{ELD minimize } F_{tc} = \sum_{i=1}^{ng}(c_i + b_i.P_i + a_i.P_i^2), \tag{6}$$

$$\text{EmD minimize } E_t = \sum_{i=1}^{ng}\left(\gamma_i + \beta_i.P_i + \alpha_i.P_i^2\right), \tag{7}$$

$$h_i = \frac{F_i(P_i^{max})/P_i^{max}}{E_j(P_j^{max})/P_j^{max}}, \tag{8}$$

$$\text{CEED minimize } \Phi = w.F_{tc} + (1-w).h.E_t , \tag{9}$$

$$\sum_{i=1}^{ng} P_i = P_D + P_L , \tag{10}$$

$$P_{Gp} = P_{Dp} + V_p \sum_{q=1}^{nBus} V_q \left(G_{pq}.\cos\theta_{pq} + B_{pq}.\sin\theta_{pq}\right), \tag{11}$$

$$Q_{Gp} = Q_{Dp} + V_p \sum_{q=1}^{nBus} V_q \left(G_{pq}.\sin\theta_{pq} - B_{pq}.\cos\theta_{pq}\right), \tag{12}$$

$$P_L = \sum_{p=1}^{ng}\sum_{q=1}^{ng} P_p.B_{pq}.P_q + \sum_{p=1}^{ng} B_{0p}.P_p + B_{00} , \tag{13}$$

$$P_i^{min} \le P_i \le P_i^{max} , \tag{14}$$

$$Q_i^{min} \le Q_i \le Q_i^{max} , \tag{15}$$

$$V_p^{min} \le V_p \le V_p^{max}, \tag{16}$$

$$S_{pq} \le S_{pq}^{max}, \tag{17}$$

where P_i is power outputs of i^{th}generating unit (MW), a_i, b_i, c_i are fuel cost coefficients of i^{th} generating unit, F_{tc} is the total fuel cost (\$/hr), α_i, β_i, γ_i are emission coefficients of i^{th} generating unit, E_t is a total emission of generating units (kg/hr), h_i is each penalty factor of i^{th} generating units, h is penalty factor from asceding order of h_i , P_i^{min} is a minimum power output of i^{th} generating unit, P_i^{max} is a maximum output power of i^{th} generating unit, Φ is the CEED (\$/hr), w is a compromised factor, ng is a number of generators, P_D is a total load, P_L is a total power loss, P_p and P_q are power injections at bus p and q, P_{Gp} and Q_{Gp} are power injections of load flow at bus p, P_{Dp} and Q_{Dp} are load demands of load flow at bus p, V_p and V_q are voltages at bus p and q, Q_i^{max} and Q_i^{min} are maximum and minimum reactive powers of i^{th} generating unit, V_p^{max} and V_p^{min} are maximum and minimum voltages at bus p, S_{pq} is the power transfer between bus p and q, S_{pq}^{max} is a limit of power transfer between bus p and q.

4. Sample system and Simulation Steps

The IEEE 30-bus system is adopted as a sample system for demonstrating HSABC's abilities using parameters as shown in Table 1 to Table 4. The simulations use 304 MW of total load, ± 5% of voltage limit, 0.5 of compromised factor and 90% of transmission transfer capability. The objective function of CEED is composed by contributing ELD and EmD. This objective function is subjected to operational constraints to meet a certain load demand using IEEE-30 bus system.

Table 1. Fuel Cost Coefficients of Generators

Bus	Gen	a, x10^{-3} (\$/MWh^2)	b (\$/MWh)	c
1	G1	3.75	2.00	0
2	G2	17.50	1.75	0
5	G3	62.50	1.00	0
8	G4	8.35	3.25	0
11	G5	25.00	3.00	0
13	G6	25.00	3.00	0

Table 2. Emission Coefficients of Generating Units

Bus	Gen	α, x10^{-2} (kg/MWh^2)	β, x10^{-2} (kg/MWh)	γ
1	G1	1.26	-110	22.98
2	G2	2.00	-10	25.31
5	G3	2.70	-1.00	25.51
8	G4	2.91	-0.50	24.90
11	G5	2.90	-0.40	24.70
13	G6	2.71	-0.55	25.30

Table 3. Power Limits of Generating Units

No	Bus	Gen	P_{min} (MW)	P_{max} (MW)	Q_{min} (Mvar)	Q_{max} (Mvar)
1	1	G1	50	200	100	-100
2	2	G2	20	80	60	-60
3	5	G3	15	50	65	-15
4	8	G4	10	35	50	-15
5	11	G5	10	30	40	-10
6	13	G6	12	40	15	-15

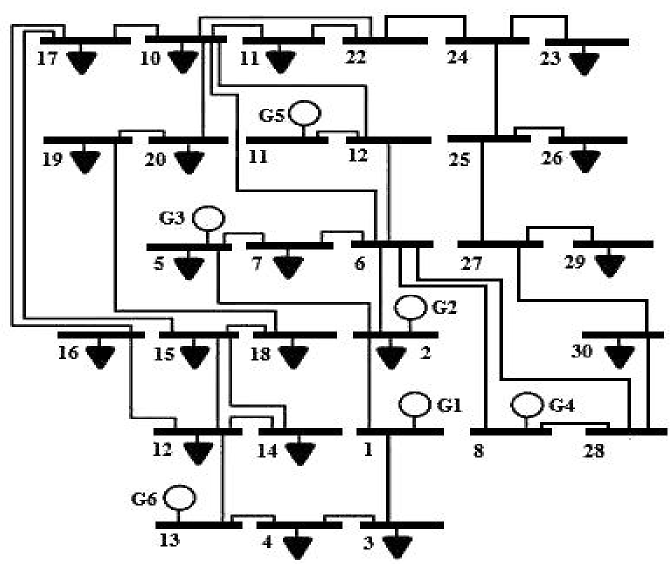

Figure 1. Single line diagram of IEEE 30-bus system

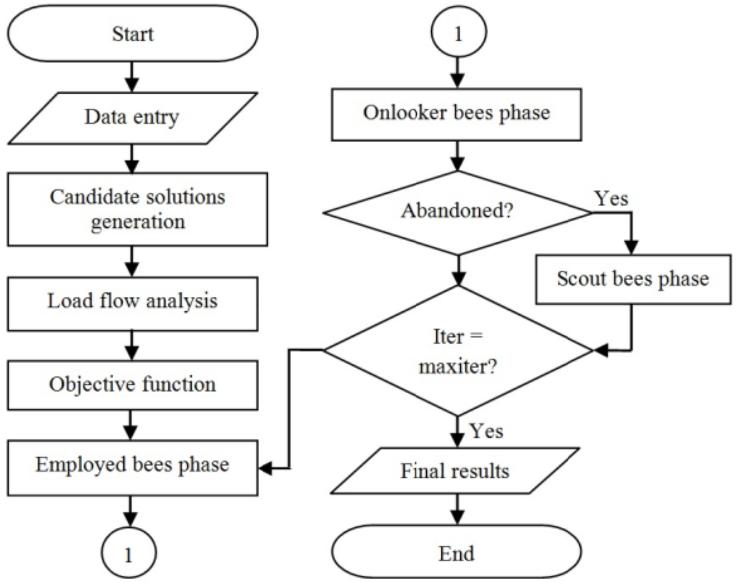

Figure 2. Flow chart of HSABC for solving CEED problem

Table 4. Bus Data of the Sample System

Bus	MW	Mvar	Bus	MW	Mvar
1	0	0	16	5.5	2.8
2	31.7	22.7	17	9	5.8
3	3.4	2.2	18	5.2	2.9
4	7.6	1.6	19	9.5	3.4
5	94.2	19	20	2.2	0.7
6	0	0	21	17.5	11.2
7	22.8	10.9	22	0	0
8	30	30	23	3.2	1.6
9	0	0	24	8.7	6.7
10	7.8	4	25	0	0
11	0	0	26	3.5	2.3
12	11.8	7.5	27	0	0
13	0	0	28	0	0
14	6.2	1.6	29	5.4	2.9
15	8.2	2.5	30	10.6	1.9
Total	**223.7**	**102**	**Total**	**80.3**	**42.2**

Table 5. Bee's Parameters

No	Parameters	quantity
1	Colony size	100
2	Food number	50
3	Limit food	50
4	Foraging cycles	100

Designed programs of the HSABC for solving CEED problem are created by considering several steps as shown in Figure 2. The designed programs are categorized into three subprograms. The Data Input Program is consisted by a set data of parameters for generating units, transmission lines, loads, constraints, CEED's parameters and HSABC's parameters. The CEED Program is designed for computing a total minimum cost based on the objective function. The HSABC Program is developed by using HSABC's steps for searching the best solution of the CEED. In additional, all designed programs are executed together for every foraging cycle as following executions. Firstly, a set population is generated as candidate solutions based on power limits. Power limits are also used to create x_{maxj}, x_{minj} and x_{ij}. A set population is evaluated by using an objective function and a load flow analysis. Secondly, food sources are located at random positions considered a current solution and neighbor food sources at certain distances. Thirdly, the best food is searched from a selected food source as the best solution of the CEED problem. The best solution is selected by using a greedy process based on the highest fitness and a probability value. Fourthly, an abandoned condition of the solution is replaced by a new one.

5. Simulation Results and Discussions

By considering power constraints, a set initial population is shown in Figure 3 as food candidates for G1 to G6. 50 of candidate solutions for generating units are provided in the population. According to this figure, it is known that food candidates are populated in different values in the population for G1 to G6.

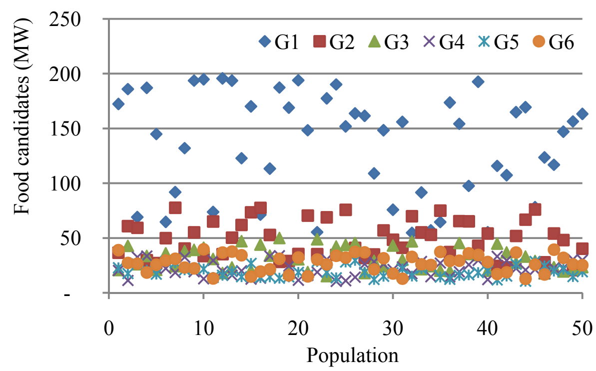

Figure 3. Population of food candidates

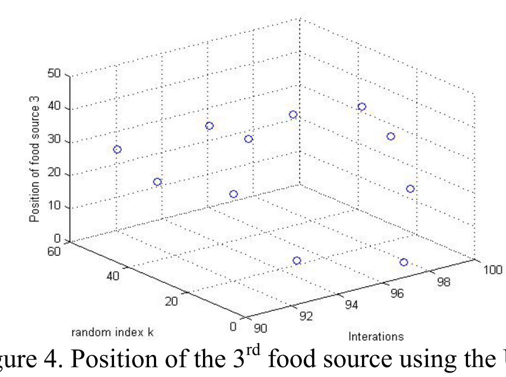

Figure 4. Position of the 3[rd] food source using the UDP

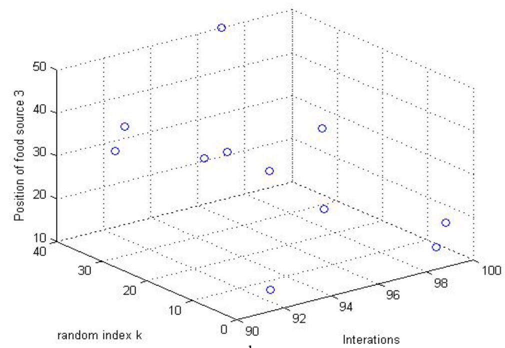

Figure 5. Position of the 3rd food source using the CDP

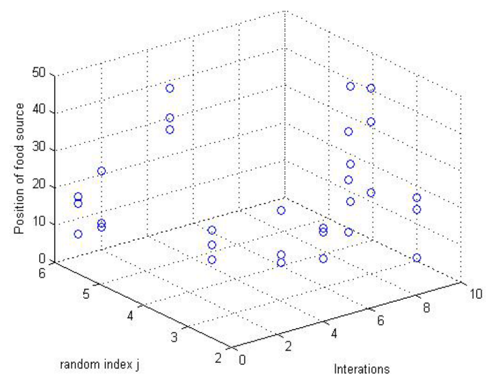

Figure 6. Collaboration of food sources using UDP

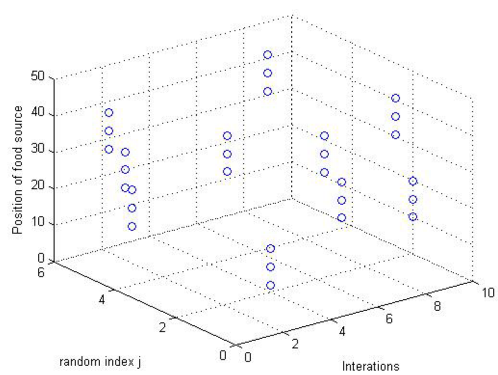

Figure 7. Collaboration of food sources using CDP

Captured within 11 cycles before finishing iteration on 90th cycle to 100th cycle, Figure 4 and Figure 5 show the positions of food sources, such as the 3rd food source. The collaboration of three food sources used UDP and CDP are performed in Figure 6 and Figure 7 for tenth iterations. These figures illustrate the involvement of the FFS and the OFS for determining solutions. HSABC's performances used MFS are shown in Figure 8 and Figure 9. Figure 8 expresses a fitness comparison of both placement strategies.

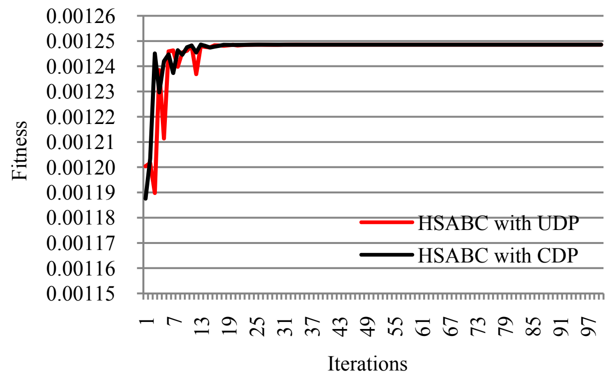

Figure 8. Greedy process comparison of the HSABC

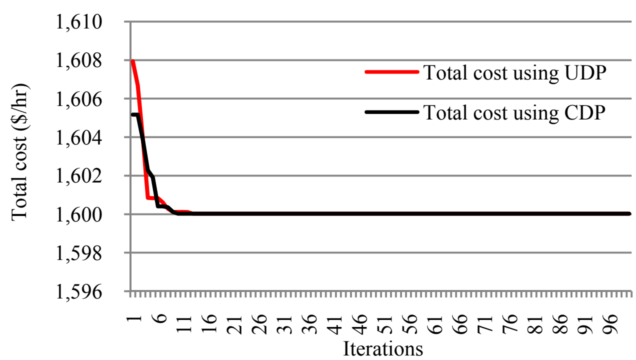

Figure 9. Convergence speed of HSABC

Figure 9 describes the convergence speeds to gets the minimum total cost of the CEED in the computations. The HSABC used CDP is faster than using UDP and it has 13 iterations for obtaining a minimum point. The minimum total cost is 1,600 $/hr contributed by 908.6 $/hr of fuel cost and 691.4 $/hr of emission cost. The HSABC used CDP has 1,605.2 $/hr of starting point and by using UDP the HSABC is started at 1,607.9 $/hr. Progressing committed powers of generating units are shown in Figure 10. This figure considers CDP strategy in the HSABC. Final real power results based on CEED problem are given in Table 6. According to this table, it is known that G4 is scheduled at its maximum limit but other generating units are operated over the middle of its power limits. The highest power is produced by G1 for committing to the load demand.

Table 6. Numerical Results of Simulations

Units	Power (MW)	Emission (Kg/hr)	Fuel cost ($/hr)	Emission cost ($/hr)
G1	133.1	99.7	332.6	178.7
G2	53.4	77.1	143.5	138.2
G3	30.3	49.9	87.4	89.4
G4	35.0	60.4	124.0	108.2
G5	29.3	49.4	109.3	88.6
G6	29.8	49.3	111.8	88.3
Total	**310.9**	**385.8**	**908.6**	**691.4**

Table 7. Comparing Simulation's Results

Subjects	Modified rates		
	0.2	**0.4**	**0.6**
Convergence speed	13	16	19
Starting points ($/hr)	803.31	801.91	802.75

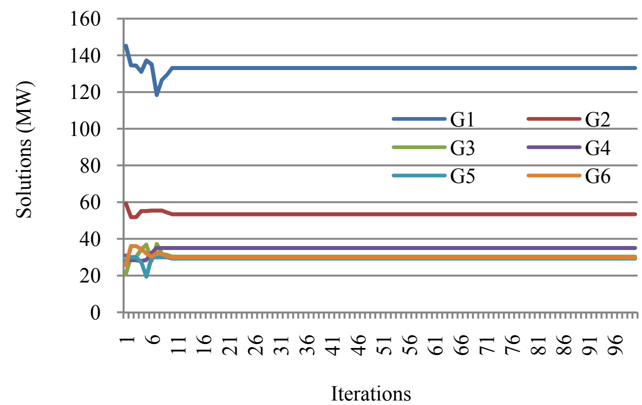

Figure 10. Progressing power in the HSABC using CDP

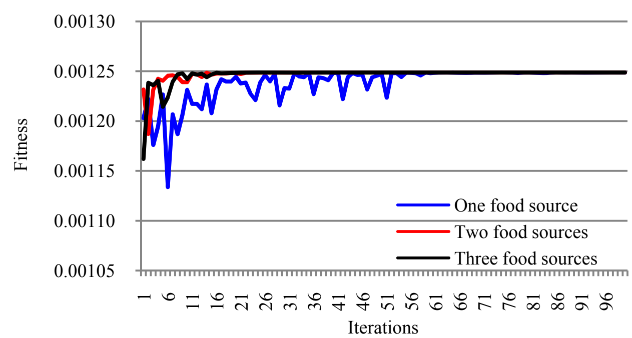

Figure 11. Comparison of greedy process

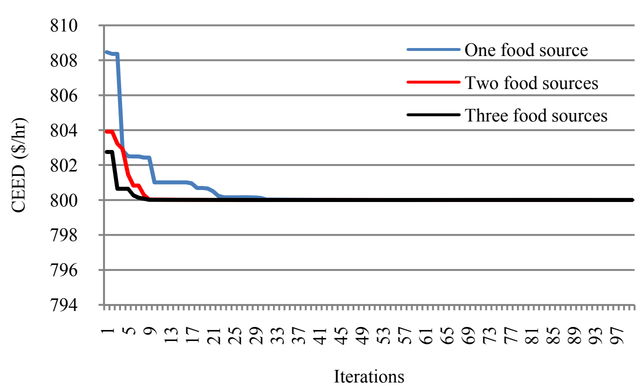

Figure 12. Comparison of convergence speed

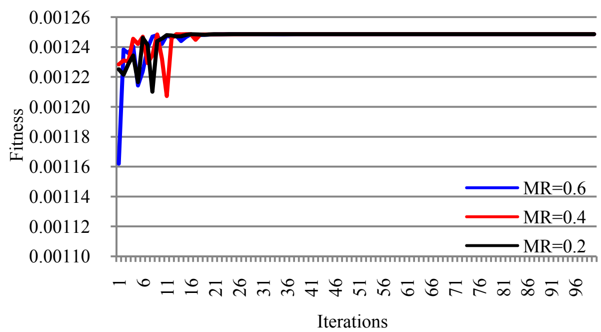

Figure 13. Greedy process using various modified rates

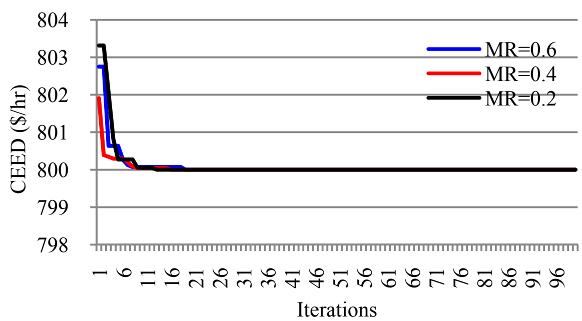

Figure 14. Convergence speeds on various MR

In the HSABC, the MFS is consisted by FFS and OFS. The number of food sources gives impacts on the CEED's solutions as performed in Figure 11 and Figure 12. According to both figures, there are known that better performances are given by HSABC used three food sources. These results indicate that the fastest computation of the CEED problem is obtained by higher number of food sources. A convergence speed of the HSABC used three food sources is demonstrated in 10 iterations for searching the minimum cost of CEED after pointing at 802.75 $/hr at the first iteration but the HSABC used two food sources is started at 803.91 $/hr before remaining a minimum value at 13 iterations. The HSABC needs 38 iterations to reach a minimum point after beginning at 808.46 $/hr at the first iteration using one food source. Contrasted to the HSABC used one food source, it is known that the convergence speed is rose up around 71.05% using three food sources and the HSABC used two food sources has a speeding up around 65.79%.

The best food is selected by using GP from all available food sources. The GP is executed to select the highest fitness from multiple positions considered MR. By considering 0.2, 0.4 and 0.6 of MR, its effects are shown in Figure 13 and Figure 14. Figure 13 illustrates the fitness selections of the GP for obtaining the best food and Figure 14 illustrates the convergence speeds for determining a minimum cost of the CEED problem. Each MR has different implications as listed in Table 7 and the lowest MR presents the shortest iteration.

6. Conclusions

This paper performs an application of HSABC for solving CEED problem using IEEE-30 bus system. Through the results obtained, it is concluded that HSABC used a CDP strategy is able to produce better performances, both placement strategies demonstrated in smooth convergence speeds, HSABC used CDP is faster than one of UDP, better results are also performed by the lowest value of MR and higher number of total food sources gives better performances. From these works are devoted to the future studies in space limits of harvest season area and real power system applications.

7. Acknowledgment

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