Optimal Solution of the EPED Problem Considering Space Areas of HSABC on the Power System Operation

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Abstract—Recently, the emission problem and economic dispatch (EPED) becomes crucial aspects in the power system operation. These aspects are measured technically using financial payments as the total operating cost based on pollutant productions and fuel consumptions throughout individual costs of generating units based on a committed power output to meet a load demand. This paper introduces the newest artificial intelligent computation, harvest season artificial bee colony (HSABC) algorithm, for determining the optimal solution of the EPED based on the operating cost function using IEEE-62 bus system with various operational constraints. Results obtained show that HSABC has short time computations and fast convergences while space areas give different implications on performances. The optimal solution produces various individual power outputs, pollutants, and costs.

Keyword- Economic dispatch, emission problem, HSABC, power system

I. INTRODUCTION

Currently, increasing public awareness of the environmental protection for reducing atmospheric emissions and the Clean Air Act Amendments of 1990 have forced the power system operation to modify operational strategies of thermal power plants considered a pollutant emission for decreasing air contaminants. In particular, the environmental protection requirements have also forced to consider the pollutant production from combustions of fossil fuels at thermal power plants in the power system operation. In detail, combustions of fossil fuels have contributed to produce chemical parts, such as, CO; CO2; SOx; and NOx [1], [2], [3]. By considering the pollutant problem, the power system operation is very important to optimize for determining suitable sharing power productions under operational limitations with in order to reach the economical budget.

Practically, the economic operation of the power system is managed using cost strategies for providing electric energy from generator sites to supply load demand areas. These strategies are subjected to decide the minimum total cost for producing power outputs to meet a total load demand. In addition, a minimum total operating cost is obtained using a total fuel cost minimization of generating units throughout an economic dispatch [4], [5], [6]. The classical views cannot meet the environmental protection requirements, since the economic dispatch only considers a total fuel cost. Moreover, the emission problem makes the economic dispatch become a complex case under various technical constraints for the power system operation and environmental situations. In detail, the economic dispatch is oriented for reducing the total fuel cost while the emission problem must be decreased as the environmental protection efforts from the power system operation throughout thermal power plants [7].

To cover these conditions, the pollutant and cost have become an important task to optimize based on the total cost of fuel consumptions and the total pollutant production [8], [9]. These objectives treat impacts of the environmental protection and fuel consumptions as competing targets in the optimization problem, which requires some constraints to reach the optimal solution in feasible ranges of operations [10]. In these works, both targets are transformed into single objective function of the optimization problem as an emission problem and economic dispatch (EPED) for determining a committed power output of generating units during decreasing the total fuel cost and reducing the pollutant production for the power system operation as the balance between pollutant and economic aspects.

As an optimization problem, the power system operation can be solved economically using various techniques. Many methods have been proposed to solve the economic operation in various topics using traditional and evolutionary methods [1], [3], [5], [7], [8], [11]. Evolutionary methods have been frequent used to obtain the optimal solution because of traditional methods suffer for large systems and multi dimension spaces. For a couple of years, evolutionary methods are more popular than traditional methods with supporting by many algorithms using natural inspirations for constructing its hierarchies. In this works, the latest generation of the evolutionary algorithm is used to solve the EPED. This algorithm was introduced in 2013 namely harvest season artificial bee colony (HSABC) algorithm based on bee's behaviours and the harvest situation [12]. In addition, HSABC will be used to search the optimal solution of the EPED under several operational constraints on the IEEE standard model of the power system.

II. EPED PROBLEM

Financially, the power system is measured using a minimum total cost for establishing the whole operations based on technical and non technical sections. Technically, this budget is optimized using an operating cost function considered operational constraints to obtain the optimal solution of the total operating cost for the better combination of scheduled power outputs for generating units [8], [9], [10]. Basically, the economic operation only considers a total fuel cost as shown in (1) with an individual fuel cost of each generating unit online the power system. By considering the environmental protection, the emission problem is also included in the generating unit operation [8], [9]. Its discharge is formed for measuring the pollutant and the minimized function of the total pollutant production is given in (2) as the emission problem.

Currently, fuel costs and pollutant productions become an important thing in the power system operation. These points are combined in the EPED using penalty and compromised factors. The penalty factor is performed to show the coefficient rate of each generating unit at its maximum output for the given load [10]. A compromised factor shows the contribution of the economic dispatch and emission problem in the objective function [12]. Specifically, The EPED is expressed in (3) and this single objective function is constrained using equations (4) – (11), as given in fallowing mathematical expressions for these studies:

Cost function: $F_{tc} = \sum_{i=1}^{ng}(c_i + b_i.P_i + a_i.P_i^2)$, (1)

Emission function: $E_t = \sum_{i=1}^{ng}(\gamma_i + \beta_i.P_i + \alpha_i.P_i^2)$, (2)

EPED function: $\Phi = w.F_{tc} + (1 - w).h.E_t$, (3)

$$\sum_{i=1}^{ng} P_i = P_D + P_L, \quad (4)$$

$$P_{Gp} = P_{Dp} + V_p \sum_{q=1}^{nBus} V_q \left(G_{pq}.\cos\theta_{pq} + B_{pq}.\sin\theta_{pq}\right), \quad (5)$$

$$Q_{Gp} = Q_{Dp} + V_p \sum_{q=1}^{nBus} V_q \left(G_{pq}.\sin\theta_{pq} - B_{pq}.\cos\theta_{pq}\right), \quad (6)$$

$$P_L = \sum_{p=1}^{ng}\sum_{q=1}^{ng} P_p.B_{pq}.P_q + \sum_{p=1}^{ng} B_{0p}.P_p + B_{00}, \quad (7)$$

$$P_i^{min} \le P_i \le P_i^{max}, \quad (8)$$

$$Q_i^{min} \le Q_i \le Q_i^{max}, \quad (9)$$

$$V_p^{min} \le V_p \le V_p^{max}, \quad (10)$$

$$S_{pq} \le S_{pq}^{max}, \quad (11)$$

where P_i is a output power of the i^{th} generating unit, a_i, b_i, c_i are fuel cost coefficients of the i^{th} generating unit, F_{tc} is a total fuel cost, α_i, β_i, γ_i are emission coefficients of the i^{th} generating unit, E_t is a total emission production of generating units (kg/h), E_{tc} is a total emission cost ($/h), Φ is the EPED ($/h), w is the compromised factor, h is the penalty factor ($/kg), ng is the number of generators, P_i^{min} is a minimum output power of the i^{th} generating unit, P_i^{max} is a maximum output power of the i^{th} generating unit, P_D is the total demand, P_L is the total transmission loss, P_p and P_q are power injections at bus p and q, P_{Gp} and Q_{Gp} are active and reactice power injections at bus p from generator, P_{Dp} and Q_{Dp} are load demands 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 the i^{th} generating unit, V_p^{max} and V_p^{min} are maximum and minimum voltages at bus p, S_{pq} is a total power transfer between bus p and q, S_{pq}^{max} is a limit of power transfer between bus p and q.

III.HSABC ALGORITHM

As mentioned before, HSABC is a new artificial intelligent which is consisted of multiple food sources (MFSs) to express many flowers located randomly at certain positions in the harvest season area [12], [13]. These food sources are explored by agents to search foods in the space area (SA). In HSABC, the MFSs is consisted of the first food source (FFS) and the other food sources (OFSs). Each position of OFSs is directed by a harvest operator (ho) from the FFS. In general, HSABC has three agents for exploring the SA, those are employed bees, onlooker bees and scout bees with each different tasks for the hierarchy. Each agent also has different abilities in the process and it is collaborated to obtain the best food in the SA based on certain pseudo-codes covered generating population; food source exploration; food selection; and abandoned replacement [14], [15].

In HSABC, a set of MFSs is prepared to provide candidate foods in the SA for every foraging cycle. The foraging for foods is preceded by searching the FSS and it will be accompanied by OFSs located randomly at different positions in the SA. A set initial population is generated and created randomly by considering objective constraints located at difference positions in the SA which is formed using (13) and (14) for the FSS and OFSs. For each solution, it is corresponded to the number of the parameter to be optimized, which is populated using equation (12). In these works, the nectar quality is evaluated for defining foods and the probability of each food source is determined for exploring each position. Moreover, each position of the candidate food is searched for the FSS and OFSs. Mathematically, HSABC is developed using following main expressions:

$$x_{ij} = x_{minj} + rand(0,1) * (x_{maxj} - x_{minj}), \quad (12)$$

$$v_{ij} = x_{ij} + \emptyset_{ij}.\left(x_{ij} - x_{kj}\right), \quad (13)$$

$$H_{iho} = \begin{cases} x_{kj} + \emptyset_{ij}\left(x_{kj} - x_{fj}\right).(ho - 1), & \text{for } R_j < MR \\ x_{kj}, & \text{otherwise} \end{cases}, \quad (14)$$

here, x_{ij} is a current food, i is the i^th^ solution of the food source, j∈{1,2,3,…,D}, D is the number of variables of the problem, x_{minj} is a minimum limit of x_{ij}, x_{maxj} is a maximum limit of x_{ij}, v_{ij} is the food position, x_{kj} is a random neighbor of x_{ij}, k∈{1,2,3,…,SN}, SN is the number of solutions, $Ø_{i,j}$ is a random number within [-1,1], H_{iho} is the harvest season food position, ho∈{2,3,…,FT}, FT is the total number of flowers for harvest season, x_{fj} is a random harvest neighbor of x_{kj}, f ∈{1,2,3,…,SN}, R_j is a randomly chosen real number within [0,1], and MR is the modified rate of probability food.

IV. PROCEDURES

In these studies, a standard model IEEE-62 bus system is adopted as a sample of the power system as shown in Fig. 1 consisted of 62 buses; 89 lines; and 32 load buses. Fig. 1 also shows locations of generating units and loads in the power system. Economical data of this system are provided in Table I. HSABC's parameter uses the colony size = 100, food sources = 50, foraging cycles = 100. Main procedures for HSABC are illustrated in Fig. 2 as the sequencing computations for searching the optimal solution based on the EPED.

HSABC's procedures are consisted of several steps. The first step is an objective function formation for computing a minimum total cost for every foraging cycle. The second step is an algorithm composition using generating population; food source exploration; food selection; and abandoned replacement, for searching the optimal solution. The third step is programming developments divided into three categories of subprograms in terms of data input program; EPED program; and algorithm program.

TABLE I. Fuel Cost and Emission Coefficients of Generating Units

Bus	Gen	a, x10^{-3} (\$/MWh^2)	b (\$/MWh)	c	α (kg/MWh^2)	β (kg/MWh)	γ	Real (MW)		Reactive (MVar)	
								Min	Max	Min	Min
1	G1	7.00	6.80	95	0.0180	-1.8100	24.300	50	300	0	450
2	G2	5.50	4.00	30	0.0330	-2.5000	27.023	50	450	0	500
5	G3	5.50	4.00	45	0.0330	-2.5000	27.023	50	450	-50	500
9	G4	2.50	0.85	10	0.0136	-1.3000	22.070	0	100	0	150
14	G5	6.00	4.60	20	0.0180	-1.8100	24.300	50	300	-50	300
17	G6	5.50	4.00	90	0.0330	-2.5000	27.023	50	450	-50	500
23	G7	6.50	4.70	42	0.0126	-1.3600	23.040	50	200	-50	250
25	G8	7.50	5.00	46	0.0360	-3.0000	29.030	50	500	-100	600
32	G9	8.50	6.00	55	0.0400	-3.2000	27.050	0	600	-100	550
33	G10	2.00	0.50	58	0.0136	-1.3000	22.070	0	100	0	150
34	G11	4.50	1.60	65	0.0139	-1.2500	23.010	50	150	-50	200
37	G12	2.50	0.85	78	0.0121	-1.2700	21.090	0	50	0	75
49	G13	5.00	1.80	75	0.0180	-1.8100	24.300	50	300	-50	300
50	G14	4.50	1.60	85	0.0140	-1.2000	23.060	0	150	-50	200

51	G15	6.50	4.70	80	0.0360	-3.0000	29.000	0	500	-50	550
52	G16	4.50	1.40	90	0.0139	-1.2500	23.010	50	150	-50	200
54	G17	2.50	0.85	10	0.0136	-1.3000	22.070	0	100	0	150
57	G18	4.50	1.60	25	0.0180	-1.8100	24.300	50	300	-50	400
58	G19	8.00	5.50	90	0.0400	-3.000	27.010	100	600	-100	600

In general, the data input program is consisted of a set data input of parameters, such as generating units; transmission lines; loads and constraints. The EPED program is created to compute an objective function under operational constraints and the number of CEED's variable is associated with exploring limits of the food source. The algorithm program is developed for searching the optimal solution based on HSABC's hierarchies. In these programs, three types of agents are collaborated to explore food sources in the SA for controlling the placements and the programs are executed together for choosing the best food as the optimal solution.

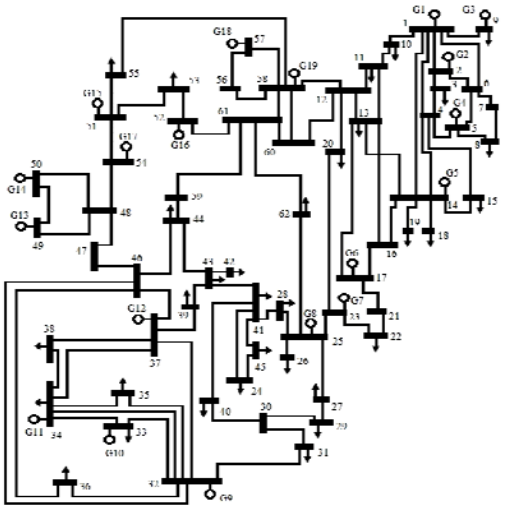

Fig. 1. IEEE-62 bus system

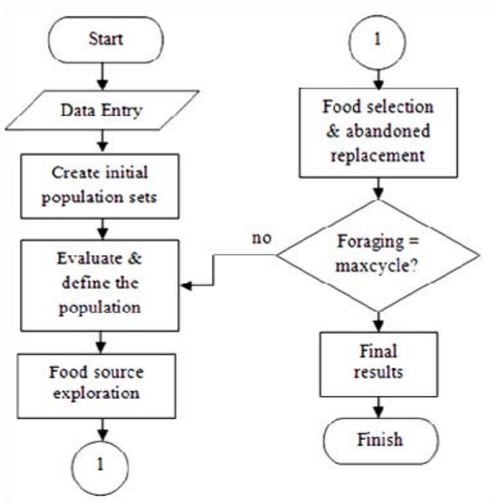

Fig. 2. Solution sequencing order

V. Results

In this section, the computation is addressed to determine the optimal solution of the EPED considered operational constraints. HSABC uses three food sources and the SA is demonstrated using four size scenarios for 100%, 75%, 50% and 45%. A set population is given in Figure 3 for candidate foods considering power constraints of generating units. The population is created for 50 candidate solutions for G1 to G19 in every foraging cycle with convergence speeds as illustrated in Fig. 4. Fig. 4 shows characteristics of the problem solving using 45%, 50%, 75% and 100% of the SA and its ability is detailed in Table II for time consumptions and optimal cycles. Solution's positions in the areas are illustrated in Fig. 7 and Fig. 8 for random positions and over locations in the SA.

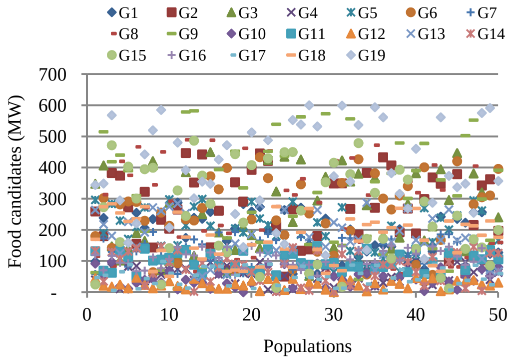

Fig. 3. Initial generated population

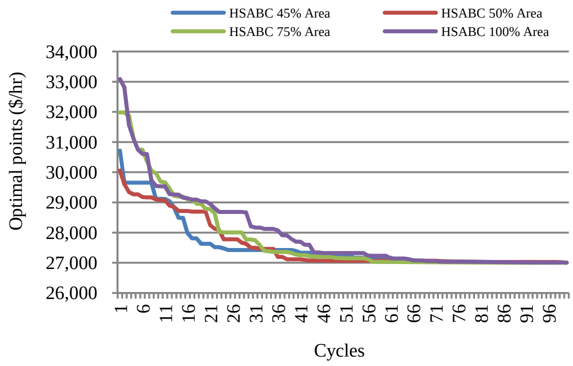

Fig. 4. Convergence speeds of HSABC

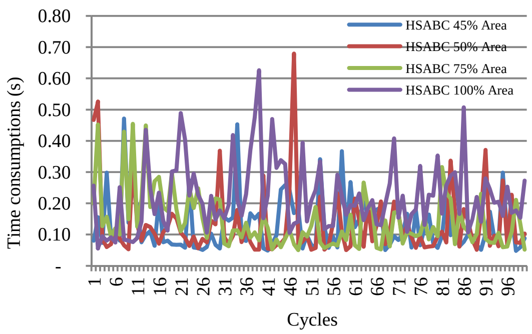

Fig. 5. Time consumptions

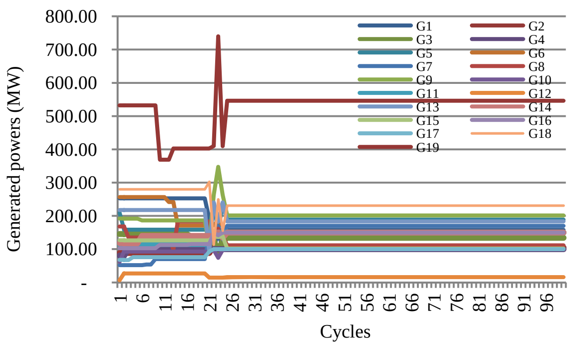

Fig. 6. Progressing power outputs

TABLE II. Numerical and Statistical Results

Para meters	Space areas				Parameters	Space areas			
	45%	50%	75%	100%		45%	50%	75%	100%
Max	30,299.16	29,601.37	31,625.36	32,773.61	Optimal time (s)	3.31	4.43	7.63	10.86
Min	27,005.93	27,005.93	27,005.93	27,005.93	Total time (s)	12.91	13.02	19.27	22.03
Range	3,293.24	2,595.44	4,619.43	5,767.68	Cycle improvement	23	16	5	0
Mean	27,319.18	27,361.65	27,625.08	27,767.72	Cycle improvement (%)	47.92	33.33	10.42	0
Median	27,005.93	27,005.93	27,005.93	27,005.93	Time improvement (s)	7.55	6.43	3.23	0
Mode	27,005.93	27,005.93	27,005.93	27,005.93	Time improvement (%)	69.52	59.21	29.74	0
Std.dev.	725.08	652.78	1,146.61	1,212.39	Total time improvement	9.12	9.01	2.76	0
Optimal cycle	25	32	43	48	Total time improvement (%)	41.40	40.90	12.53	0

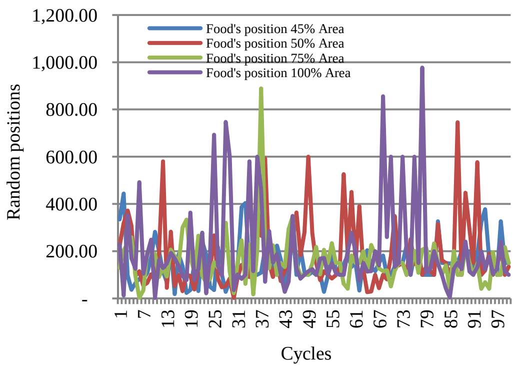

Fig. 7. Food's positions in the area

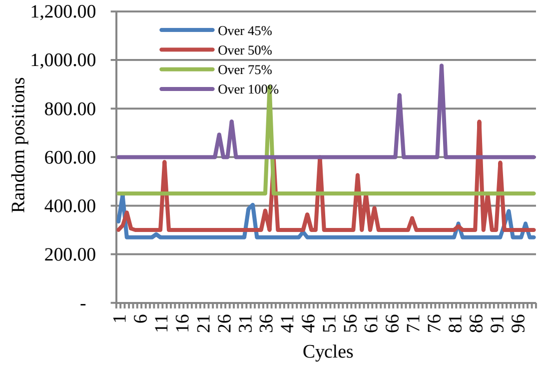

Fig. 8. Over limits of positions

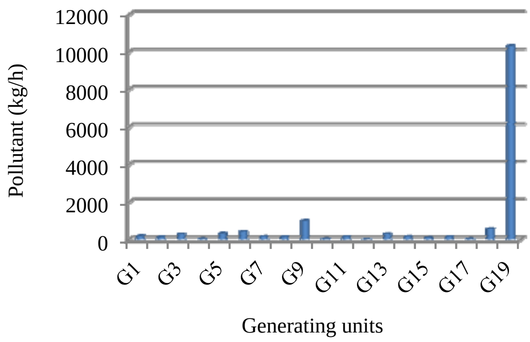

Fig. 9. Pollutant productions of generating units

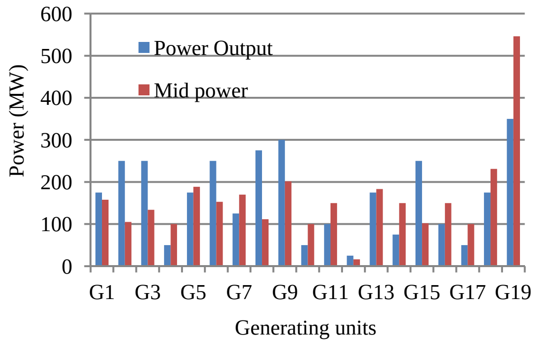

Fig. 10. Committed powers of generating units

From Fig. 4, it is known that the convergence speed of HSABC using 45% of SA is faster than others. This characteristic is demonstrated in 25 iterations for searching a minimum solution of the EPED after pointing at 30,299.16 $/h at the first cycle. HSABC using 50% of SA is started at 29,601.37 $/h and it is converged to the minimum value in 32 cycles. The HSABC using 75% of SA needs 43 cycles to reach 27,005.93 $/h of the EPED from 31,625.36 $/h at the first cycle. The largest size of SA produces 48 of cycles for the convergence speed and 32,773.61 $/h of the initial cost for the HSABC. Concerning in the number of time executions, Table II also provides time consumptions of HSABC using each area. This table shows the time consumption for obtaining minimum total costs and completing the running out programs in 100 foraging cycles. From Table II, it is known that various sizes of the SA affect to performances. In detail, by using 45% of the SA, the minimum result is searched in 3.31 minutes. This computation is completed in 12.91 minutes for 100 foraging cycles with various running times of the execution as shown in Fig. 5. Moreover, a smaller area gives the better effects to the performances as listed in Table II. In detail, statistical results are also given in Table II. This table lists the results in terms of max and min points; ranges; means; medians; modes; and standard deviations.

TABLE III. Costs of Generating Units online the Power System Operation

Bus	Gen.	Cost ($/h)			Bus	Gen.	Cost ($/h)		
		Emis.	Emis.	Emis.			Emis.	Fuel	Total
1	G1	480.95	480.95	480.95	34	G11	381.06	406.25	787.31
2	G2	328.73	328.73	328.73	37	G12	9.91	92.25	102.16
5	G3	729.34	729.34	729.34	49	G13	764.73	573.11	1,337.84
9	G4	72.15	72.15	72.15	50	G14	406.25	426.25	832.50
14	G5	831.59	831.59	831.59	51	G15	251.25	627.32	878.57
17	G6	1,070.43	1,070.43	1,070.43	52	G16	381.06	401.25	782.31
23	G7	400.90	400.90	400.90	54	G17	72.15	120.00	192.15
25	G8	365.57	365.57	365.57	57	G18	1,455.01	634.40	2,089.41
32	G9	2,582.51	2,582.51	2,582.51	58	G19	26,546.49	5,483.15	32,029.64
33	G10	72.15	72.15	72.15	Total		37,202.23	37,202.23	37,202.23

Progressing power outputs of computations are presented in Fig. 6 with its levels on the optimal solution are illustrated in Fig. 10. This figure is performed using 45% of the SA for G1 to G19 to meet a total load demand. This figure has been also evaluated using a newton raphson load flow analysis and power output constraints to meet all technical requirements for the operation. The final economic results based on the EPED are listed in Table III for the operational costs. These final results covers for producing the total power output around 3,049.83 MW for supplying 2,912 MW of the total load while releasing the total pollution around 14,474.45 kg/h from generating units with individual emissions as given in Fig. 9. In addition, the total payment for existing the power system is 54,011.85 \$/h contributed by 16,809.62 \$/h of the total fuel cost and 37,202.23 \$/h of the total emission cost with individual fees of generating units are listed in Table III.

VI. CONCLUSIONS

This paper introduces the latest intelligent computation, HSABC algorithm, to obtain committed power outputs of generating units based on the minimum total cost considered the EPED. By using various areas, the small size area produces better results in terms of the time consumption and convergence speed. Refers to applications of the SA, the size of harvest season area can be used to control EPED's performances. From these works, the evaluation of positions and placements are devoted to future works.

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