Financial Assessment Considered Weighting Factor Scenarios for the Optimal Combination of Power Plants on the Power System Operation

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Abstract— *This paper presents an application of the novel evolutionary algorithm for assessing financially an economic power system operation throughout a combined economic and emission dispatch problem required by various technical limitations. In detail, this problem considers two dispatches for fuel and environmental aspects as a constrained objective function associated with weighting factor scenarios. Running out simulations show that minimum costs are depended on weighting factors, which implemented on the combination of the problem. Reducing the total fuel cost focused on the dispatching priority and the pollutant target based on the emission production have difference implications as its contribution to the economic operation, the increasing load demand leads to generated powers, costs and emission discharges associated with its parameters and power schedules.*

Keywords—Economic dispatch, emission dispatch, financial assessment, weighting factors.

I. INTRODUCTION

Practically, a power system is developed using interconnected structures to delivers electric energy from generator sites to some areas of the load demand with various scheduled capacities for existing the daily operation. In particular, separated load centers are normally supplied by operated electric power plants with the least cost strategy considered several operational constraints for the whole operation. Moreover, the power system is divided into sub sections covered in generation, transmission, distribution and utilization. These sections are operated regularly for producing and transfering energy with suitable operating costs of the power system expressed in the optimal fuel cost of generating stations through an economic dispatch (ED) due to a load demand at a certain period time.

In recent years, a pollutant penetration has become ungently issues in combustions of fossil fuels at thermal power plants [1]. This combustion discharges pollutants in various types of particles and gasseous products like CO, CO_2, SO_x and NO_x [2], [3], [4], [5], [6]. By considering these contaminants, the ED becomes a complex problem with considering an emission dispatch (EmD). It also becomes a crucial task in the power system operation for determining economically the committed power outputs [7]. In the past years, many methods were proposed to solve power system problems with numerical efforts to find out cases which have applied mathematical programming principles and optimization techniques [8]. There were proposed in traditional and evolutionary methods depended on the problem in what it would be solved in order to assess the daily operation in a financial aspect as the whole performance during the period. Traditional methods cover classical approaches such as linear programming, lambda iteration, quadratic programming, gradient search, Newton's method, interior point method, Lagrangian method [9], [10], [11]. On the other hand, the evolutionary method is consisted of several intelligent techniques which are useful for selecting the optimal solution, for examples, genetic algorithm, simulated annealing, evolutionary programming, ant colony algorithm, particles swarm optimization, and neural network [12], [13], [14], [15], [16].

This paper is focused on the dispatching problem modeled in a nonlinear objective function for integrating ED and EmD problems in a combined economic and emission dispatch (CEED) problem. In addition, this paper is also concerned in the financial assessment for its problem using weighting factor scenarios. To carry out the problem, harvest season artificial bee colony (HSABC) algorithm will be applied for determining the optimal solution as an evolutionary method which was proposed in 2013 [6], [16], [17].

II. POLLUTANT AND FUEL PROBLEMS

As mentioned before, a power system is operated at main sections covered generation, transmission, distribution and utilization sections. In particular, the generation section is supported by various type power plants for producing electric energy in certain locations with a balanced power output combination to meet a total demand at separated user areas in all operating periods [17], [18]. Moreover, it should be generated economically during existing the interconnected structures to delivers electric energy from generator sites to customers under technical constraints. Recently, it also conducts to control pollutant productions of thermal power plants. These problems have to take double attentions for reducing pollutant discharges as environmental protection efforts and decreasing the reasonable operating cost [1], [15], [16], [19], [20], [21].

In this section, CEED is subjected to optimize the total operating cost considered several technical limitations for ED. CEED is also used to minimize emission discharges through EmD. In general, ED reduces the total fuel cost and EmD decreases the total emission discharge in single objective function in order to get a balanced result for the economic power system operation. Moreover, CEED is expressed using a nonlinear equation for providing electric energy from existed power stations. In detail, CEED includes a weighting factor for balancing ED and EmD problems in terms of compromised and penalty factors [2], [17], [22], [23]. This function can be formulated using following expression:

Optimize CEED: $\Phi_t = w_{eco}.F_t + w_{emi}.h.E_t$ (1)

Minimize ED: $F_t = \sum_{i=1}^{ng}(c_i + b_i.P_i + a_i.P_i^2)$ (2)

Minimize EmD: $E_t = \sum_{i=1}^{ng}(\gamma_i + \beta_i.P_i + \alpha_i.P_i^2)$ (3)

Where Φ_t is the CEED, w_{eco} and w_{emi} are weighting factors for ED and EmD, h is a factor penalty, F_t is the total fuel cost of generating units (\$/hr), a_i; b_i; c_i are coefficients of the quadratic fuel cost by the i^{th} generating unit, P_i is the output power of the i^{th} generating unit, ng is the number of generator, E_t is the total emission discharge of generating units (kg/hr), α_i; β_i; γ_i are coefficients of the emission characteristics by the i^{th} generating unit.

III. HSABC ALGORITHM

To find out ED and EmD problems, an intelligent based computation is implemented to assess the power system operation throughout the CEED problem associated with an evolutionary algorithm. In this section, HSABC algorithm is introduced clearly as an instrument for determining the optimal solution. In detail, HSABC algorithm is consisted of multiple food sources (MFSs) to express many flowers located randomly at certain positions in the harvest season area [17]. The MFSs are consisted of the first food source (FFS) and the other food sources (OFSs) with each position of OFSs directed by a harvest operator (ho) from the FFS. In general, HSABC algorithm has three agents for exploring the space area, those are employed bees; onlooker bees; and scout bees with each different tasks in the hierarchy. Each agent also has different abilities in the process and it is collaborated to obtain the best food based on certain pseudo-codes [17], [22], [24]. In principle, the sequencing computation of HSABC algorithm is distributed into several processes to select the optimal solution. By considering these processes, the pseudo-codes are presented as follows:

- Generating population: create initial population sets, evaluate initial population sets, and define the population.
- Food source exploration: produce the FFS, produce the OFSs, evaluate the MFSs, apply the greedy process, and calculate the probability value.
- Food selection: produce a new food, produce neighbor foods, evaluate foods, and apply the greedy process.
- Abandoned replacement: determine an abandoned food, replace with a new randomly one, and memorize the food.

In particular, a set of MFSs is prepared to provide candidate foods 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. A set initial population is generated and created randomly by considering objective constraints located at difference positions which is formed using (5) and (6) for the FSS and OFSs. For each solution, it is corresponded to the number of parameters to be optimized, which is populated using equation (4). Moreover, structures and hierarchies of HSABC algorithm are discussed clearly in [6], [17], [22], [24]. Mathematically, its main functions are developed using following main expressions:

$$x_{ij} = x_{minj} + rand(0,1) * (x_{maxj} - x_{minj}), \quad (4)$$

$$v_{ij} = x_{ij} + \emptyset_{ij}.(x_{ij} - x_{kj}), \quad (5)$$

$$H_{iho} = \begin{cases} x_{kj} + \emptyset_{ij}(x_{kj} - x_{fj}).(ho-1), & \text{for } R_j < MR \\ x_{kj}, & \text{otherwise} \end{cases}, \quad (6)$$

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, $\emptyset_{i,j}$ 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. TESTED MODEL

The balanced point of ED and EmD problems is assessed using the CEED problem applied to IEEE-30 bus system as shown on Fig. 1. Its data for simulations associated with each generating units are listed respectively in Table I, Table II and Table III.

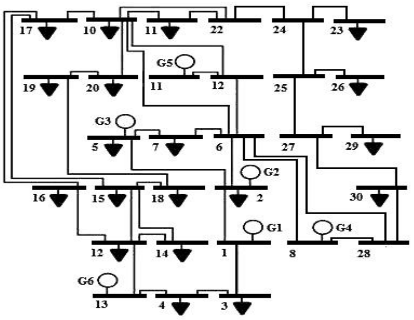

Fig. 1: IEEE-30 bus system model

Table I. Cost coefficients and power limits

Bus	Gen	a ($/MWh^2)	b ($/MWh)	c	P_{min} (MW)	P_{max} (MW)
1	G1	0.00375	2.00000	0	50	200
2	G2	0.01750	1.75000	0	20	80
5	G3	0.06250	1.00000	0	15	50
8	G4	0.00835	3.25000	0	10	35
11	G5	0.02500	3.00000	0	10	30
13	G6	0.02500	3.00000	0	12	40

Table II. Emission coefficients

Bus	Gen	α (kg/MWh^2)	β (kg/MWh)	γ
1	G1	0.0126	-1.1000	22.9830
2	G2	0.0200	-0.1000	25.3130
5	G3	0.0270	-0.0100	25.5050
8	G4	0.0291	-0.0050	24.9000
11	G5	0.0290	-0.0040	24.7000
13	G6	0.0271	-0.0055	25.3000

Table III. Load data for each bus

Bus No	MW	Mvar	Bus No	MW	Mvar
1	0.0	0.0	16	3.5	1.8
2	21.7	12.7	17	9.0	5.8
3	2.4	1.2	18	3.2	0.9
4	7.6	1.6	19	9.5	3.4
5	94.2	19.0	20	2.2	0.7
6	0.0	0.0	21	17.5	11.2
7	22.8	10.9	22	0.0	0.0
8	30.0	30.0	23	3.2	1.6
9	0.0	0.0	24	8.7	6.7
10	5.8	2.0	25	0.0	0.0
11	0.0	0.0	26	3.5	2.3
12	11.2	7.5	27	0.0	0.0
13	0.0	0.0	28	0.0	0.0
14	6.2	1.6	29	2.4	0.9
15	8.2	2.5	30	10.6	1.9

V. RESULTS AND DISCUSSIONS

In this section, simulation results of CEED are demonstrated using weighting factor scenarios in Table IV. To show roles of dispatching components, the tested system model considers the total load 283.4 MW. Three case studies are used to illustrate the performance of CEED using weighting factors. To show the domination of ED or EmD, CEED uses WF_1. To describe the component contribution of the objective function, simulations consider WF_2 and WF_3. In these studies, pure ED is expressed by $CEED_1$ used w_{eco}=1 and w_{emi}=0 in WF_1 and WF_2, but the pure EmD is expressed by $CEED_1$ used w_{eco}=0 and w_{emi}=1 in WF_3 or $CEED_5$ in WF_1. Assessing results are given in Table V, Table VI and Table VII for generated powers, costs and emissions.

Table IV. Weighting factors for ED and EmD

WF_1		WF_2		WF_3		Types
w_{eco}	w_{emi}	w_{eco}	w_{emi}	w_{eco}	w_{emi}	
1	0	1	0	0	1	$CEED_1$
0.7	0.3	1	0.3	0.3	1	$CEED_2$
0.5	0.5	1	0.5	0.5	1	$CEED_3$
0.3	0.7	1	0.7	0.7	1	$CEED_4$
0	1	1	1	1	1	$CEED_5$

Table V, Table VI and Table VII show the results of simulations. From these tables are known that pure ED neglects the pollutant emission 422.99 kg/h and produces 292.67 MW of the power output with 9.27 MW of the total power loss. In contrast, pure EmD discharges 340.06 kg/h of the accumulated emission and produces 288.71 MW of the power with a total loss is 5.31 MW. According to these tables, full CEED has 345.55 kg/h of the pollutant emission, 289.47 MW of the power output and 6.07 MW of the power loss.

In total, the operating payments are used for 1447.30 $/h of full CEED, 1558.87 $/h of pure ED and 1461.46 $/h of pure EmD. Based on various combination w_{eco} and w_{emi}, the lowest cost is 1447.26 $/h of $CEED_3$ using weighting factor 0.5 as shown in Table V.

Table V. Optimum results used WF_1

Subject	$CEED_1$	$CEED_2$	$CEED_3$	$CEED_4$	$CEED_5$
G1 (MW)	176.26	137.46	126.55	119.45	112.69
G2 (MW)	48.38	50.21	49.48	48.39	46.88

G3 (MW)	20.87	25.27	27.8	30.27	34.26
G4 (MW)	22.71	31.33	31.87	31.8	31.58
G5 (MW)	12.45	22.95	26.63	29.08	30.00
G6 (MW)	12.00	22.87	27.13	30.09	33.30
Total G (MW)	292.67	290.09	289.46	289.08	288.71
Loss (MW)	9.27	6.69	6.06	5.68	5.31
Emission (kg/h)	422.99	355.60	345.55	341.54	340.06
CEED ($/h)	801.72	762.79	723.63	679.93	609.27
EmD cost ($/h)	757.15	637.10	619.10	611.90	609.27
ED cost ($/h)	801.72	816.66	828.15	838.67	852.20
Total cost ($/h)	1558.87	1453.75	1447.26	1450.57	1461.46

In detail, by using a constant w_{emi}=1 of WF_3, the increasing of w_{eco} gives an effect on the decreasing pollutant emission. The pollutant reduces 18.25% from $CEED_1$ to $CEED_5$. In contrast, by considering the fluctuation of w_{emi} on the constant w_{eco}=1 of WF_2, the pollutant emission is climbed up. In detail, the pollutant increases 54.78% from $CEED_1$ to $CEED_5$.

Table VI. Optimum result used WF_2

Subject	$CEED_1$	$CEED_2$	$CEED_3$	$CEED_4$	$CEED_5$
G1 (MW)	176.26	142.85	135.24	130.72	126.56
G2 (MW)	48.38	50.27	50.13	49.87	49.48
G3 (MW)	20.87	24.36	25.70	26.70	27.80
G4 (MW)	22.71	30.78	31.51	31.76	31.87
G5 (MW)	12.45	21.23	23.68	25.20	26.63
G6 (MW)	12.00	20.94	23.70	25.45	27.13
Total G (MW)	292.67	290.43	289.96	289.7	289.47
Loss (MW)	9.27	7.03	6.56	6.30	6.07
Emission (kg/h)	422.99	362.11	353.21	348.87	345.55
CEED ($/h)	801.72	1007.10	1135.00	1260.80	1447.30
EmD cost ($/h)	757.15	648.52	632.72	625.12	619.12
ED cost ($/h)	801.72	812.54	818.64	823.22	828.18
Total cost ($/h)	1558.87	1461.06	1451.36	1448.34	1447.30

Table VII. Optimum result used WF_3

Subject	$CEED_1$	$CEED_2$	$CEED_3$	$CEED_4$	$CEED_5$
G1 (MW)	112.69	117.5	120.46	123.09	126.56
G2 (MW)	46.88	47.98	48.58	49.03	49.48
G3 (MW)	34.26	31.12	29.85	28.89	27.80
G4 (MW)	31.58	31.72	31.83	31.88	31.87
G5 (MW)	30.00	29.73	28.73	27.83	26.63
G6 (MW)	33.3	30.91	29.67	28.56	27.13
Total G (MW)	288.71	288.96	289.12	289.28	289.47
Loss (MW)	5.31	5.56	5.72	5.88	6.07
Emission (kg/h)	340.06	340.85	341.98	343.33	345.55
CEED ($/h)	609.27	863.29	1031.20	1198.10	1447.30
EmD cost ($/h)	609.27	610.68	612.74	615.05	619.12
ED cost ($/h)	852.20	842.06	836.93	832.93	828.18
Total cost ($/h)	1461.47	1452.73	1449.67	1447.98	1447.30

Fig. 2, Fig. 3 and Fig. 4 illustrate typical convergence speeds for determining the optimal solutions of the assessments. Its convergences are quick and stable as shown in these figures. According to Fig. 2, pure ED, the computation has 26 iterations for obtaining the solution 801.72 $/h of $CEED_1$ after starting at 810.71 $/h. The full CEED expressed on $CEED_5$ needs 38 iterations to remain 1447.30 $/h from 1460.68 $/h as shown on Fig. 4. According to Fig. 3, it is known that the optimal solution is obtained in 45 iterations to get 723.63 $/h from 730.03 $/h of the first point using 0.5 of the weighting factor.

Practically, power output profiles of generating units are associated with load demand behaviors at a certain time to set fixed schedules of power outputs. The least operating cost becomes very crucial decision caused by a fluctuation of the load demand. To perform these effects on the increasing load demand and to assess it on the total cost, this section provides the assessments.

Table VIII. Increased load assumptions

Load	Increased load		New load
	%	(MW)	(MW)
NL_1	10	28.34	311.74
NL_2	20	56.68	340.08
NL_3	30	85.02	368.42
NL_4	40	113.36	396.76

In addition, this load condition also affects to the CEED for defining generating units inline the system. In this section, weighting factors are compromised in 0.5 for an equality contribution of ED and EmD because of the

CEED for this case is minimum as given in Table V. Then, power demands are assumed to increase gradually at load buses as listed in Table VIII. The simulation results are shown in Table IX and Table X.

Table IX shows simulation results of generating units used NL_1 - NL_4 of loads. Six generators produce different power outputs to face to the load demand. Specifically G5 and G4 feed to the power system in constant power outputs of 30 MW and 35 WM because of the upper limits of this operation for producing power outputs. G1 increases from 137.13 MW to 182.73 MW associated with NL_1 to NL_4 as the impact of load demand changes. In total, generating units deliver power to the load center from 319.00 MW to 409.71 MW with increasing losses from 7.26 MW to 12.95 MW. This production is associated with customer usages for energy as presented in the cost, lost and emission. The increasing load demand will conduct to these aspects, or in reverse for it.

Table IX. Summary results considered various loads

Subject	Loads			
	NL_1	NL_2	NL_3	NL_4
G1 (MW)	137.13	150.84	165.76	182.73
G2 (MW)	54.95	62.08	69.86	78.78
G3 (MW)	30.70	34.44	38.53	43.20
G4 (MW)	35.00	35.00	35.00	35.00
G5 (MW)	30.00	30.00	30.00	30.00
G6 (MW)	31.22	36.59	40.00	40.00
Total G (MW)	319.00	348.95	379.15	409.71
Total Loss (MW)	7.26	8.87	10.73	12.95
Total emission (kg/h)	402.53	469.55	547.48	639.21
CEED ($/h)	829.20	946.30	1075.45	1219.33
Total emission cost ($/h)	720.52	841.24	980.89	1145.20
Total fuel cost ($/h)	937.88	1051.37	1170.00	1293.45
Total cost ($/h)	1658.40	1892.61	2150.89	2438.65

Table X. Percentage Result on Various Loads

Subjects	Percentage Increased results (%)			
	NL_1	NL_2	NL_3	NL_4
G1	8	19	31	44
G2	11	25	41	59
G3	10	24	39	55
G4	10	10	10	10
G5	13	13	13	13
G6	15	35	47	47
Total G	10	21	31	42
Loss	20	46	77	114
Total emission	16	36	58	85
CEED	15	31	49	69
Total emission cost	16	36	58	85
Total fuel cost	13	27	41	56
Total cost	15	31	49	69

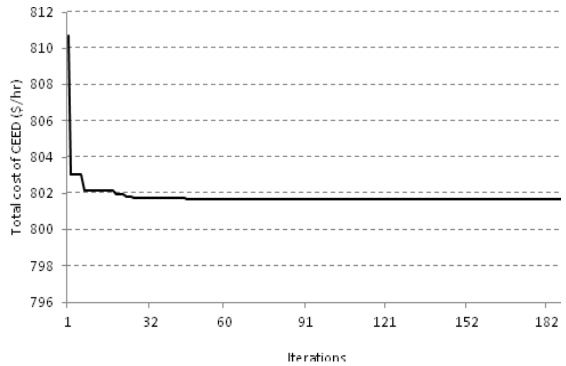

Fig. 2: Convergence of $CEED_1$ with w_{eco}=1 and w_{emi}=0

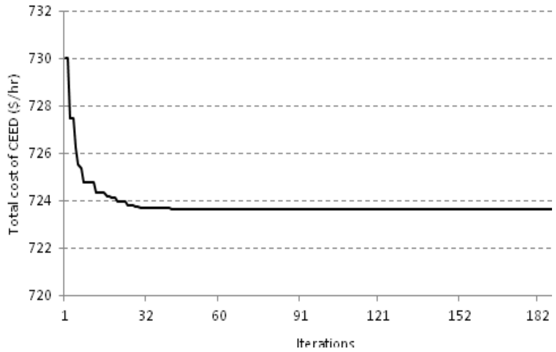

Fig. 3: Convergence of $CEED_3$ with w_{eco}=0.5 and w_{emi}=0.5

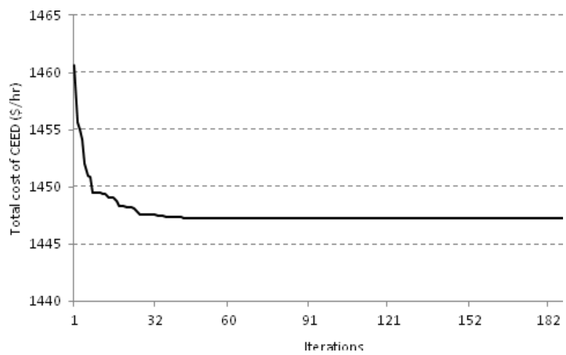

Fig. 4: Convergence of $CEED_5$ with w_{eco}=1 and w_{emi}=1

Comparing results in Table IX and $CEED_3$ in Table V, percentage performances on various loads are shown in Table X. The most interesting point is NL_4 because the increasing load demand is only changed up 40 % but costs passed 50 % and also the loss overed 100 %.

According to these results, cost values are rose up, the fluctuation of total costs are ranged in 15% to 69%, fuel costs are moved up from 13 % to 56% and emission costs are paid more from 16% to 85% for increasing pollutans.

VI. CONCLUSIONS

This paper presents a financial assessment for the CEED problem using various weighting factor scenarios, which is demonstrated clearly using IEEE-30 bus system for determining the balanced operating cost. The simulation results show that the computation converged smoothly during assessment to get minimum costs. In addition, weighting factor scenarios for ED and EmD affected to the CEED. Increasing load demands gave effects to generated powers, emissions and costs. From these studies, the revealing convergence speed up and real test are devoted to the future work on the real system application.

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