Weighting Factor Scenarios for Assessing the Financial Balance of Pollutant Productions and Fuel Consumptions on the Power System Operation

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Abstract: - This paper presents an application of the novel evolutionary algorithm for assessing an economic power system operation throughout a combined economic and emission dispatch problem required by various technical limitations. Moreover, this problem considers pollutant production and fuel consumption problems for covering environmental protection and fuel usage aspects as a constrained objective function. Running out simulations show, minimum costs depend on various weighting factors implemented in the defined problem. Reducing the total fuel cost focused on the dispatching priority and the pollutant target based on the emission production have different implications as its contribution on the economic operation. The increased power demand leads to generated powers, costs and emission discharges associated with its parameters and schedules.

Key-Words: - economic dispatch, emission dispatch, intelligent computation, load demand, weighting factors

1 Introduction

Practically, a power system is developed using interconnected structures to deliver electric energy from generator sites to the some areas of loads with various scheduled capacities for existing the daily operation. In particular, separated load centers are normally supplied using operated electric power plants with a least fuel cost strategy considered several operational constraints for the power system operation. Moreover, the power system is divided into three sub sections covered in generation, transmission, distribution and utilization [1]. These sections are managed accurately for producing energy with suitable operating cost of the power system expressed in optimal fuel cost of generating stations throughout an economic dispatch (ED) due to a certain load.

In recent years, pollutant emission has become attention in combustions of fossil fuels at thermal power plants [2]. The fossil fuel combustion discharges pollutants in various types like CO, CO_2, SO_x and NO_x [3]. By considering pollutants, 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 problem of scheduled power outputs [4]. In the past years, many methods were proposed to solve power system problems with various type efforts to find out cases which have applied mathematical programming principles and optimization techniques [5]. There were proposed in traditional and evolutionary methods depend on the problem in what it would be solved. The traditionally method covers classically approaches such as linear programming, lambda iteration, quadratic programming, gradient search, Newton's method, interior point method, Lagrangian method [6], [7], [8]. On the other hand, the evolutionary method is consisted of several intelligent techniques, for examples, genetic algorithm, simulated annealing, evolutionary programming, ant colony algorithm, particles swarm optimization and neural network [9], [10], [11].

This paper focuses on dispatching problems modeled in a nonlinear objective function for integrating ED and EmD problems in a combined economic and emission dispatch (CEED) problem based on weighting factor scenarios. To carry out the CEED problem, this paper also concern in a harvest season artificial bee colony (HSABC) algorithm as a novel evolutionary method of bee's generation proposed in 2013 [12].

2 Pollutant and Fuel Problems

As mentioned before, the power system is commonly established using main sections covered in generation; transmission; distribution and utilization. In particular, the generation section is supported by various power plants for producing electric energy at certain locations with plotting in a balanced power output combination to meet a total demand at separated usage areas in all operating periods [12], [13]. Moreover, it should be generated economically during existing the interconnected structures to delivers electric energy from generator sites to energy users with considering technical constraints. Recently, it also conduct to control pollutant productions of thermal power plants. These problems have to take double attentions for reducing pollutant discharges as an environmental protection efforts and decreasing the operating budget as a reasonable operating cost [2], [14].

In this section, CEED problem 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 which are provided in single objective function in order to get a balanced result for the economic power system operation. Moreover, the CEED is expressed using nonlinear equation for providing electric energy from joined power stations and for assessing fuel consumptions and pollutant productions. In detail, CEED includes an including weighting factor for balancing ED and EmD problems in terms of compromised and penalty factors [3], [12], [15], [16]. This function can be formulated using following expression:

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

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

Minimize EmD: $E_t = \sum_{i=1}^{ng}\left(\gamma_i + \beta_i.P_i + \alpha_i.P_i^2\right)$, (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 power output 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 emission characteristics by the i^{th} generating unit.

3 Novel Intelligent Computation

For carrying out ED and EmD problems, an intelligent based computation is implemented to solve the CEED associated with a new evolutionary algorithm. In this section, HSABC algorithm is introduced clearly as an instrument for determining the optimal solution. As mentioned before, HSABC algorithm is a novel method consisted of multiple food sources (MFSs) to express many flowers located randomly at certain positions in the harvest season area [12]. The MFSs is consisted of the first food source (FFS) and the other food sources (OFSs) with each position of OFSs is directed by a harvest operator (ho) from the FFS. In general, HSABC has three agents for exploring the space area, 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 based on certain pseudo-codes covered generating population; food source exploration; food selection; and abandoned replacement, as detailed in [12], [15], [17].

In principles, 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 the parameter to be optimized, which is populated using equation (4). Moreover, structures and hierarchies of HSABC algorithm are discussed clearly in [17]. Mathematically, its main functions are developed using following main expressions:

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

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

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

here, x_{ij} is a current food, i is the i^{th} solution of the food source, $j \in \{1,2,3,\ldots,D\}$, D is the number o 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}, $k \in \{1,2,3,\ldots,SN\}$, SN is the number o solutions, $\emptyset_{i,j}$ is a random number within [-1,1], H_{iho} is the harvest season food position, $ho \in \{2,3,\ldots,FT\}$, FT is the total number of flowers for 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], and MR is the modified rate of probability food.

4 Tested System Model

The balanced value of ED and EmD problems is measured using the CEED applied to IEEE-30 bus system as a sample model as shown on Figure 1. Its data for simulations associated with generating units are listed respectively in Table 1, Table 2 and Table 3.

Table 1. 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

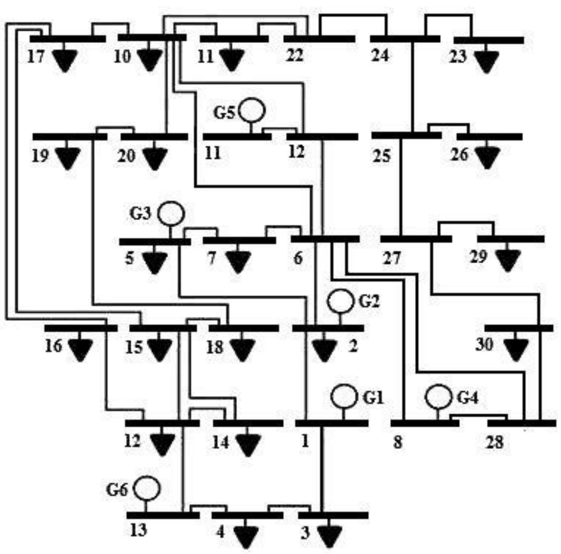

Figure 1. IEEE-30 bus system model

Table 2. 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 3. 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

5 Results

In this section, simulation results of CEED are demonstrated using weighting factor scenarios in Table 4. To show roles of dispatching components, the tested system model considers the total load 283.4 MW. Three case studies are used to assess 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 objective function, the 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 5, Table 6 and Table 7 for generated powers, costs and emissions.

Table 4. Weighting factor scenarios

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 5, Table 6 and Table 7 show the results of simulations. From these tables are known that pure ED neglects the pollutant emission 422.99 kg/hr and produces 292.67 MW of the power with 9.27 MW of the total loss. In contrast, pure EmD discharges 340.06 kg/hr of an accumulated emission and produces 288.71 MW of the power with the total loss is 5.31 MW. According to these tables, the full CEED has 345.55 kg/hr of the emission, 289.47 MW of the power and 6.07 MW of the total loss. In total, the operating payments are 1447.30 $/hr of the full CEED, 1558.87 $/hr of the pure ED and 1461.46 $/hr of the pure EmD. Based on various combinations w_{eco} and w_{emi}, the lowest cost is 1447.26 $/hr of $CEED_3$ using the weighting factor 0.5 as shown in Table 5.

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 a fluctuation of w_{emi} on the constant w_{eco}=1 of WF_2, the pollutant emission is climbed up. On the other hand, the pollutant increases 54.78% from $CEED_1$ to $CEED_5$.

Figure 2, Figure 3 and Figure 4 illustrate typical convergence speeds for determining the optimal solutions of assessments. Its convergences are quick and stable as shown in these figures. According to Figure 2, the pure ED has 26 iterations for obtaining the solution 801.72 $/hr of $CEED_1$ after starting at

810.71 \$/hr. The full CEED expressed on $CEED_5$ needs 38 iterations to remain 1447.30 \$/hr from 1460.68 \$/hr as shown on Figure 4. According to Figure 3, it is known that the optimal solution is obtained in 45 iterations to get 723.63 \$/hr from 730.03 \$/hr of the first point using 0.5 of the equal weighting factor.

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

Table 5. 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/hr)	422.99	355.60	345.55	341.54	340.06
CEED (\$/hr)	801.72	762.79	723.63	679.93	609.27
EmD cost (\$/hr)	757.15	637.10	619.10	611.90	609.27
ED cost (\$/hr)	801.72	816.66	828.15	838.67	852.20
Total cost (\$/hr)	1558.87	1453.75	1447.26	1450.57	1461.46

Table 6. 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/hr)	422.99	362.11	353.21	348.87	345.55
CEED (\$/hr)	801.72	1007.10	1135.00	1260.80	1447.30
EmD cost (\$/hr)	757.15	648.52	632.72	625.12	619.12
ED cost (\$/hr)	801.72	812.54	818.64	823.22	828.18
Total cost (\$/hr)	1558.87	1461.06	1451.36	1448.34	1447.30

In addition, this load condition also affects to the CEED for defining generating unit participations inline the system. In this section, the 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 5. Power demands are assumed to increase gradually at load buses as listed in Table 8. The simulation results are shown in Table 9 and Table 10.

Table 7. 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/hr)	340.06	340.85	341.98	343.33	345.55
CEED (\$/hr)	609.27	863.29	1031.20	1198.10	1447.30
EmD cost (\$/hr)	609.27	610.68	612.74	615.05	619.12
ED cost (\$/hr)	852.20	842.06	836.93	832.93	828.18
Total cost (\$/hr)	1461.47	1452.73	1449.67	1447.98	1447.30

Table 8. 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

Table 9. Summary results considered various loads

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

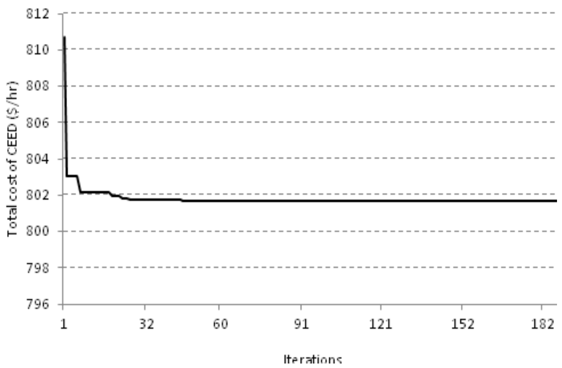

Figure 2. Convergence of $CEED_1$ with w_{eco}=1 and w_{emi}=0

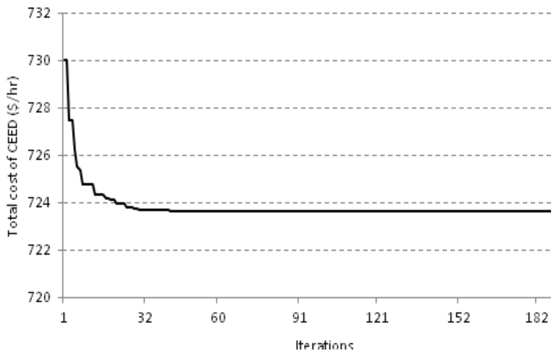

Figure 3. Convergence of $CEED_3$ with w_{eco}=0.5 and w_{emi}=0.5

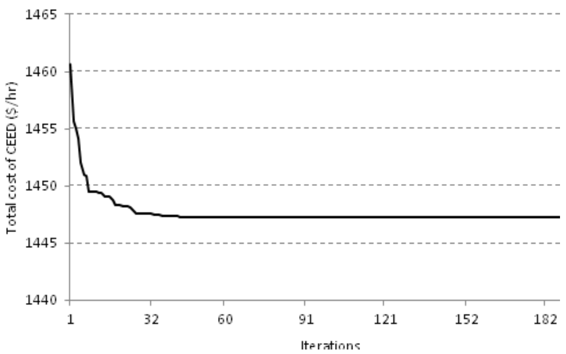

Figure 4. Convergence of $CEED_5$ with w_{eco}=1 and w_{emi}=1

Table 10. 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

Table 9 shows simulation results of generating units used NL_1 - NL_4 of loads. Six generators produce diferent power outputs to face to the load demand. Specifically G5 and G4 feed to the power system in the constant power 30 MW and 35 WM because of the upper limitation of operating powers. G1 increases from 137.13 MW to 182.73 MW associated with NL_1 to NL_4. In total, generating units deliver powers to the load demand from 319.00 MW to 409.71 MW with increasing losses from 7.26 MW to 12.95 MW.

Comparing result in Table 9 and $CEED_3$ in Table 5, percentage performances on various loads are shown in Table 10. The most interesting point is NL_4 because the increasing load demand is only changed up 40 % but the costs are passed 50 % and also losses are overed 100 %. According to these results, cost values are rose up, the fluctuation of total costs are ranged in 15% to 69%, the fuel costs are moved up from 13 % to 56% and the emission costs are paid more from 16% to 85% for increasing pollutans.

6 Conclusions

This paper presents the pollutant production and fuel consumption assessments throughout the CEED using various weighting factor scenarios, which is demonstrated clearly for determining a financial balance on IEEE-30 bus system. The simulation results show that the computation converged smoothly during assessment the minimum costs. The weighting factor scenarios for ED and EmD affect to the CEED. The increasing demands also give effects to the generated powers, emissions and costs. From these studies, the revealing convergence speed and a real test system are devoted to the future work on the higher implementation.

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