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Hybrid method for solving the non smooth cost function economic dispatch problem

Wanchai Khamsen[1], **Chiraphon Takeang**[2], **Patiphat Aunban**[3]
[1,2]Department of Electrical Engineering, Rajamangala University of Technology Lanna, Thailand
[3]Chiangmai Municipality, Thailand

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ABSTRACT

This article is focused on hybrid method for solving the non-smooth cost function economic dispatch problem. The techniques were divided into two parts according to: the incremental cost rates are used to find the initial solution and bee colony optimization is used to find the optimal solution. The constraints of economic dispatch are power losses, load demand and practical operation constraints of generators. To verify the performance of the proposed algorithm, it is operated by the simulation on the MATLAB program and tests three case studies; three, six and thirteen generator units which compared to particle swarm optimization, cuckoo search algorithm, bat algorithm, firefly algorithm and bee colony optimization. The results show that the proposed algorithm is able to obtain higher quality solution efficiently than the others methods.

Corresponding Author:

Wanchai Khamsen,
Department of Electrical Engineering,
Rajamangala University of Technology Lanna,
200 Moo17 Pichai Subdistrict Mueang District Lampang Province, 52000, Thailand.
Email: wanchai_kh@rmutl.ac.th

1. INTRODUCTION

The electricity power generation enough with the demand. It is an important for security and reliability of electrical power system. Fuel is a factor that affects the production of electricity. It requires a production plan to minimize the total fuel cost of electrical power generation which satisfied constraints. That is the economic dispatch problem (ED). The objective function of economic dispatch is to minimize the total fuel cost of power plant which satisfied the constraints of load demand and power loss. The fuel cost function of electrical power generation divided into two types. The first type is smooth cost function represented by a single quadratic function, under the assumption that the incremental cost curves of the power plant are increasing piecewise linear functions. The second type is non-smooth cost function represented higher order nonlinear function and discontinuities which complex and non-convex characteristics with many constraints. While, most power plants are non-smooth cost function. The power output of the generator is controlled by multiple valves [1]. When steam admission valves in thermal units are first opened, a losses occurs rapidly. This is the valve-point loading characteristics. The economic dispatch problem with valve-point effects is difficulty of finding the global or near optimum.

There are many methods of meta heuristic optimization techniques to solving the non-smooth cost economic dispatch problem such as simulated annealing (SA) [2-5], genetic algorithm (GA) [6-7] and tabu search (TS) [8-9], particle swarm optimization (PSO) [10-13], ant colony optimization (ACO) [14-17], cuckoo search algorithm (CSA) [18-20], bat algorithm (BAT) [21-22], firefly algorithm (FFA) [23-24] and bee colony optimization (BCO) [25-29]. There are probabilistic heuristic algorithms which have been successfully used to solve the economic problem. While, BCO is very simple and robust stochastic optimization algorithm. The solution quality and computational efficiency of BCO is better than other algorithm. However, the initial population of all meta heuristic optimization techniques are obtained randomly, as a result more time to computational efficiency. That is the problem of this article.

The goal of this paper is to develop the hybrid method for solving the ED problem with non-smooth cost functions that good solution quality and computational efficiency. The incremental costs rates are used to find the initial solution for reduce the scope of the search and BCO to finding the global or near optimum around the initial solution. The constraints of economic dispatch are power losses, load demand and practical operation constraints of generators. Results from previous methods in terms of solution quality and computational efficiency are compared in this paper.

2. RESEARCH METHOD

The objective of the economic dispatch problem is to minimize the total generation cost of the individual dispatchable generating power units that satisfying the constraints.

2.1. Objective function

The objective function of ED problem can be formulated as a quadratic cost function:

$$Minimize: TC = \sum_{i=1}^{N} F_i(P_i) = a_i + b_i P_i + c_i P_i^2 + \left| e_i \times \sin\left(f_i \times \left(P_{i,\min} - P_i \right) \right) \right| \tag{1}$$

where TC is the total generation cost; N is the number of generating units; $F_i(P_i)$ is the total fuel cost of generation; P is the power output of the i^{th} generator and a_i, b_i, c_i, e_i and f_i are the cost coefficient of the i^{th} generator.

2.2. Constrains

The objective function represented in (1) is subject to the following equality and inequality constraints of the ED problems.

2.2.1. Power balance constraint

The sum of power output of all generator units must be equal to the sum of the total power demand and total power transmission losses as given below.

$$\sum_{i=1}^{N} (P_i) = P_D + P_{loss} \tag{2}$$

where P_D and P_{loss} are the total power demand and total power transmission losses respectively. The transmission losses are expressed as a function of the real power and B coefficient matrix as given below.

$$P_{loss} = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{j=1}^{N} B_{io} P_i + B_{00} \tag{3}$$

where B_{00}, B_{i0} and B_{ij} are the loss coefficient of the transmission line that assumed to be constant under the normal operating condition.

2.2.2. Generator rating constraint

The power output of each generator units must be operate within lower and upper operating limit which defined as:

$$P_{i,\min} \le P_i \le P_{i,\max} \tag{4}$$

where $P_{i,min}$ and $P_{i,max}$ are the minimum and maximum power output of the i^{th} generator unit.

2.3. Hybrid method (HBCO)

In this section, a new approach to implement the hybrid algorithm will be described in solving the ED problems. The hybrid algorithm techniques combination of two methods. The first one is the incremental cost rates (λ) which used to find the initial solution. The approach could provide local optimum solution. The second method is used BCO to find the optimal solution of initial neighborhood. Therefore, hybrid algorithm is obtained the incremental cost rates and BCO (HBCO). The constraints of ED are power losses, load demand and practical operation constraints of generators. To verify the performance of the proposed algorithm, it is operated by the simulation on the MATLAB program and tests three case studies; three, six and thirteen generator units with losses and without transmission losses. The process of the hybrid method is summarized as follows:

Step 1: Specify the HBCO parameters as shown in Table 1.

Step 2: Calculate the incremental cost rates (λ) using the following:

$$\lambda = \frac{P_D + \sum_{i=1}^{N} \frac{b_i}{c_i}}{\sum_{i=1}^{N} \frac{1}{c_i}} \tag{5}$$

Step 3: Calculate the power output of the i^{th} generator (P_i) with incremental cost rates that the initial solutions as following:

$$P_i = \frac{\lambda - b_i}{c_i} \tag{6}$$

Step 4: Find boundary of the power output of the i^{th} generator using the following:

$$P_{i,lower} = P_i\left(1 - rank\right) \tag{7}$$

and

$$P_{i,upper} = P_i\left(1 + rank\right) \tag{8}$$

where $P_{i,lower}$ and $P_{i,upper}$ are the minimum and maximum power output of the i^{th} generator unit; *rank* is rank size of power output generation.

Step 5: Create the populations (N) of the power output of the i^{th} generator that satisfied the constraints can be expresses as:

$$P_i = P_{i,lower} + \left(\left(P_{i,upper} - P_{i,lower}\right) \bullet rand(0,1)\right) \tag{9}$$

Step 6: Evaluate the fitness value of the populations and arrange the fitness in ascending order.

Step 7: Select S best solutions for the neighborhood search and separate the S best solutions into two groups (E, S-E).

Step 8: Determine the size of neighborhood for each best solution. Note that neighborhood sizes are equal to NE for solution group E and NO for solution group (S-E).

Step 9: Generate solutions around the selected solutions within the neighborhood sizes (NE, NO) and evaluate the fitness value from each patch. Then, select the best solution from each patch.

Step 10: Check the stopping criterion. If no, increase the iteration.

Step 11: Assign the new population (N-S) to generate new power output of the i^{th} generator. Then, return to Step 5.

Table 1. The HBCO parameters

Parameters	Number
Population size (*N*)	20
Number of selected sites (*S*)	14
Number of best sites (*E*)	10
Number of bees around best sites (*NE*)	20
Number of bees around other sites (*NO*)	10
Rank size (*rank*)	0.2

3. RESULTS AND ANALYSIS

The aim of this paper is to develop the hybrid method for solving the ED problem with non-smooth cost functions that good solution quality and computational efficiency. In this study, the three difference test cases are considered for verifying the effectiveness of the proposed approach.

3.1. Test case 1: three units system

This case study is the simple system with three generators and a total load demand of 850 MW. The system data is shown in Table 2. The simulation results from the proposed HBCO, PSO, CSA, BAT, FFA, and BSO algorithms are compared in Table 3. The results indicate that the proposed HBCO succeeds in finding the best solution of total generation cost. The convergence characteristics of the proposed HBCO in comparison with BCO methods are shown in Figure 1. Clearly, the HBCO converges to the optimal solution faster than BCO methods.

Table 2. Generator data for case 1

Unit No.	1	2	3
a_i	0.001562	0.00194	0.00482
b_i	7.92	7.85	7.97
c_i	561	310	78
e_i	300	200	150
f_i	0.315	0.42	0.63
$P_{i,max}$	600	400	200
$P_{i,min}$	100	100	50

Table 3. Comparison of the best results of each method for case 1

Unit No.	PSO [13]	CSA [20]	BAT [21]	FFA [24]	BCO [27]	HBCO
1	481	498.62	384.423	384.423	300.266	386.083
2	279	101.319	151.643	151.643	149.734	339.361
3	90	250.061	313.934	313.934	400.000	125.946
Total *P* (MW)	850	850	850	850	850.000	851.390
Total Cost ($/hr)	8217	8248.2	8253.1	8253.1	8234.07	8210

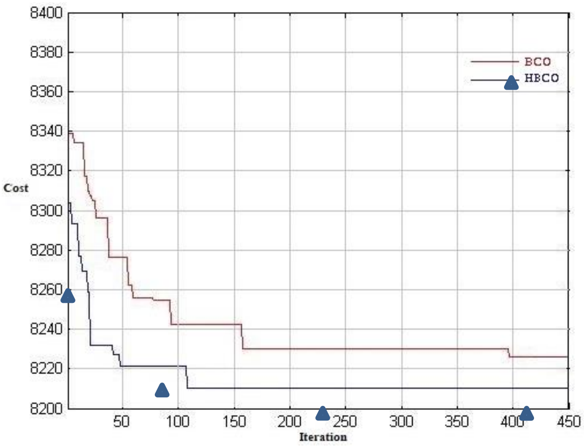

Figure 1. Solution convergence of proposed method (HBCO) and BCO for case 1

3.2. Test case 2: six units system

In this case, the system consists of six generators. The characteristic of all thermal generating units with valve point effect are given in Table 4. The total load demand is 1263 MW and loss coefficients matrix as follow:

$$B_{ij} = 1\times10^{-5}\begin{bmatrix} 0.17 & 1.2 & 0.7 & -0.1 & -0.5 & -0.2 \\ 1.2 & 1.4 & 0.9 & 0.1 & -0.6 & -0.1 \\ 0.7 & 0.9 & 3.1 & 0 & -1.0 & -0.6 \\ -0.1 & 0.1 & 0 & 2.4 & -0.6 & -0.8 \\ -0.5 & -0.6 & -1 & -0.6 & 12.9 & -0.2 \\ -0.2 & -0.1 & -0.6 & -0.8 & -0.2 & 15.0 \end{bmatrix}$$

$$B_{0i} = 1\times10^{-5}\left[-3.908 \quad -1.297 \quad 7.047 \quad 0.591 \quad 2.161 \quad -6.635\right] \qquad B_{00} = [0.056]$$

Table 5 show the summarized result of all the existing algorithms along with proposed method (HBCO) for test case 2. The simulation results from the proposed HBCO, MPSO, CSA, MABC, and IASFLA algorithms are compared. The results indicate that HBCO can provide a better solution than the other approaches in total generation cost and convergence efficiently. The convergence characteristics of the proposed HBCO in comparison with BCO methods are shown in Figure 2.

Table 4. Generator data for case 2

Unit No.	1	2	3	4	5	6
a_i	0.0070	0.0095	0.0090	0.0090	0.0080	0.0075
b_i	7.0	10	8.5	11	10.5	12
c_i	240	200	220	200	220	190
e_i	300	200	400	159	150	150
f_i	0.035	0.042	0.042	0.063	0.063	0.063
$P_{i,max}$	500	200	300	150	200	120
$P_{i,min}$	100	50	80	50	50	50

Table 5. Comparison of the best results of each method for case 2

Unit No.	MPSO [12]	CSA [18]	MABC [26]	IASFLA [30]	HBCO
1	447.187	447.4768	449.839	446.721	470.31
2	173.506	173.223	173.380	175.777	151.839
3	260.955	263.379	257.037	264.612	268.437
4	144.058	138.952	142.346	140.286	105.79
5	163.216	165.412	161.724	160.934	177.008
6	86.293	87.002	90.58	87.100	99.533
Total P (MW)	1275.22	1275.45	1274.91	1275.43	1272.92
Total Cost ($/hr)	15,441	15,443	15,438	15,442	15,430
Power losses (MW)	12.216	12.447	11.907	12.33	9.74

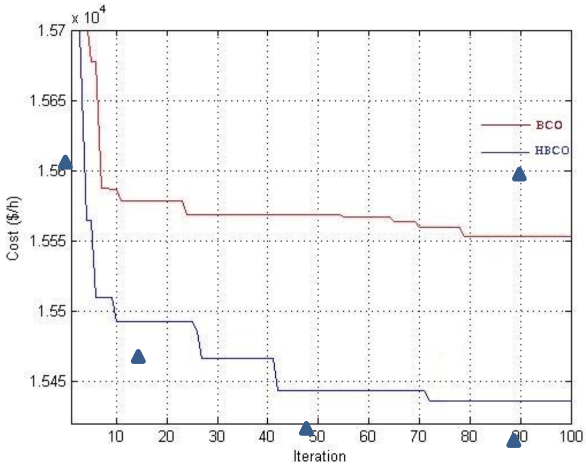

Figure 2. Solution convergence of proposed method (HBCO) and BCO for case 2

3.3. Test case 3: thirteen units system

In this case, the system consists of 13 generating units. The characteristic of all thermal generating units with valve point effect are given in Table 6. In order to validate the proposed HBCO method, it is tested with 13-unit system having non-convex solution spaces and total load demands of 1800 MW. Table 7 shows the comparison of results with different methodologies. The results indicate that optimal value of fuel cost obtained by HBCO algorithm is much less that FAPSO-VDE, CSA, FA and ABC. The convergence characteristics of the proposed HBCO in comparison with BCO methods are shown in Figure 3 Clearly, the HBCO converges to the optimal solution faster than BCO methods.

Table 6. Generator data for case 3

Unit No.	a_i	b_i	c_i	e_i	f_i	$P_{i,max}$	$P_{i,min}$
1	0.00028	8.10	550	300	0.035	680	0
2	0.00056	8.10	309	200	0.042	360	0
3	0.00056	8.10	307	200	0.042	360	0
4	0.00324	7.74	240	150	0.063	180	60
5	0.00324	7.74	240	150	0.063	180	60
6	0.00324	7.74	240	150	0.063	180	60
7	0.00324	7.74	240	150	0.063	180	60
8	0.00324	7.74	240	150	0.063	180	60
9	0.00324	7.74	240	150	0.063	180	60
10	0.00284	8.60	120	100	0.084	120	40
11	0.00284	8.60	120	100	0.084	120	40
12	0.00284	8.60	120	100	0.084	120	55
13	0.00284	8.60	120	100	0.084	120	55

Table 7. Comparison of the best results of each method for case 3

Unit No.	FAPSO-VDE [11]	CSA [20]	FA [23]	ABC [27]	HBCO
1	628.319	369.055	628.319	628.277	502.641
2	227.749	227.735	149.599	148.882	326.124
3	149.599	62.177	222.749	223.616	251.768
4	60	108.771	109.867	60	88.218
5	109.867	107.438	109.867	109.853	88.263
6	109.867	120	109.867	109.84	88.27
7	109.867	163.739	109.867	109.861	88.24
8	109.867	156.243	60	109.855	88.162
9	109.867	138.671	109.867	109.826	88.165
10	40	108.807	40	40	40
11	40	115.757	40	40	40
12	55	62.259	55	55	40
13	55	59.349	55	55	55
Total *P* (MW)	1800	1800	1800	1800	1800
Total Cost ($/hr)	17963.82	18809	17,963.83	17962.43	17,946.55

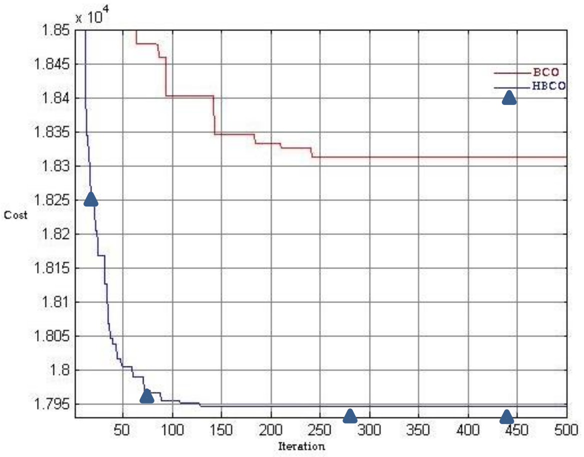

Figure 3. Solution convergence of proposed method (HBCO) and BCO for case 3

4. CONCLUSION

This paper proposes a methodology for solving the ED problem with non-smooth cost functions using hybrid method with taking various generator constraints. Three case systems are tested evaluates the performance proposed approach. The HBCO shown that algorithm is robust and can provide good solution quality and computational efficiency. The studied results confirm the HBCO proposed approach are indeed capable of obtaining higher quality solution, computation time and convergence characteristic in comparison with other method. The aim of this paper is to develop the hybrid method for solving the ED problem with non-smooth cost functions that good solution quality and computational efficiency.

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BIOGRAPHIES OF AUTHORS

Wanchai Khamsen was born in Lampang, Thailand in 1974. He graduated from Rajamamgla Institute of Technology with a Bachelor’s degree in Technical Education in 1997, King Mongkut’s Institute of Technology North Bangkok with a Master’s degree in Electrical Engineering in 2003 and Ph.D. in Electrical and Computer Engineering of Mahasarakam University. Currently, he is Associate Professor at Faculty of Engineering, Rajamangala University of Technology Lanna Lampang. His research interests include ac choppers, converter systems for improving power quality, economic dispatch and optimization technique.

Chiraphon Takeang was born in Chiangrai Thailand in 1978. He received his B.TechED. Degree in Electrical Engineering from the King Mongkut’s Institute of Technology North Bangkok in 2002 and the M.Eng. Degree in Electrical Engineering from the Rajamangala University of Technology Lanna in 2014. Currently, he is lecture at Faculty of Engineering, Rajamangala University of Technology Lanna Lampang. His research interests include economic dispatch and optimization technique.

Patiphat Aunban was born in Chiangrai Thailand in 1981. He received his B.Eng. and M.Eng. Degree in Electrical Engineering from the Rajamangala University of Technology Lanna, Thailand in 2005 and 2018. Currently, he is engineering at Chiangmai Municipality, Chiangmai. His research interests include economic dispatch and optimization technique.