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Bat Algorithm for Economic Emission Load Dispatch Problem

Thang Trung Nguyen and Sang Dang Ho*

Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, HCM City, Vietnam
19, Nguyen Huu Tho str., 7th dist., HCM City, Vietnam
nguyentrungthang@tdt.edu.vn, hsodangsang@tdt.edu.vn

Abstract

This paper presents a Bat Algorithm (BA) for solving economic emission dispatch (EELD) problem with quadratic fuel function. The BA is a new meta-heuristic algorithm which is a powerful optimal solution search algorithm owing easily selected control parameters and high successful rate as well as high ability for dealing with complex constraints. In addition to minimizing electricity generation fuel cost, emission released into the air from thermal plants is also another main objective needs to be minimized. In order to test the performance of the proposed BA one system with two load cases is employed. The obtained result by the BA compared to that from other methods has revealed that the proposed BA is a very promising meta-heuristic algorithm for solving economic emission load dispatch problem.

Keywords: *Bat algorithm, economic emission load dispatch, transmission losses, and quadratic fuel cost function.*

Nomenclature

$a_i,\ b_i,\ c_i$	Cost coefficients of thermal unit i
$d_i,\ e_i,\ f_i$	Emission coefficients of thermal unit i
$B_{ij},\ B_{0i},\ B_{00}$	Transmission loss formula coefficients
N	Number of online generating units
P_D	Total load demand of the system (MW)
P_L	Total network loss of the system (MW)
P_i	Output power of unit i (MW)
$P_{imin},\ P_{imax}$	Lower and upper generation limits of unit i (MW)
w_1, w_2	Weights corresponding to the fuel cost and emission objectives.
rand	Uniformly distributed random number in [0, 1]
P_{s1}	Power output of the slack thermal unit
P_{1max}, P_{1min}	Maximum and minimum power outputs of slack thermal unit 1
$P_s^{\lim}$	Limit for the slack unit 1
A	Loudness of pule for all bats.
r	rate of frequency
f_d	frequency of the *dth* Bat
$f_{dmin},\ f_{dmax}$	Lower and upper frequency of the *dth* Bat
PR	The price penalty factor.

1. Introduction

A power system mainly consists of thermal plants to supply electricity to load and the primary fuels using at the thermal plants for generating electricity from the

* Corresponding Author

thermal plant are so expensive and become in the near future. In addition, the thermal plants are one of the main resources producing emission in to the air, causing hotter temperature and climate change for the earth. Therefore, the main objective of the economic emission dispatch problem is to minimize both electricity generation fuel cost and emission [1].

Over decades, many artificial intelligence based methods have been applied for solving EELD problem such as Improved Hopfield Neural Network Model (IHNN) [2], Tabu Search (TS) [3], fuzzy logic controlled genetic algorithm (FCGA) [4], the Non-dominated Sorting Genetic Algorithm - II (NSGA-II) [5], Differential Evolution (DE) [6], biogeography-based optimization (BBO) [7], multi-objective differential evolution (MODE) [8], Hybrid Differential volution-sequential quadratic programming (DE-SQP) and Hybrid Particle Swarm optimization-sequential quadratic programming (PSO-SQP) [9], parallel synchronous PSO algorithm (PSPSO) [10], Cuckoo Search Algorithm (CSA) [11]. Among the methods, the application of IHNN to the EELD problem is the most limited because it can not deal with complicated problem with nonconvex fuel cost function of thermal units. Besides, the IHNN faces to the local optimization with high number of iteration for convergence. In [6] and [8], the EELD has been successfully solved by DE algorithm based methods. DE has been considered a strong tool for solving optimization problem in engineering fields since it could tackle the disadvantage of IHNN, namely considering nonconvex fuel cost function of thermal units; however, the methods requires a careful section of control parameters. Otherwise, the method can fall within the near optimal solution. The difference between DE in [6] and [8] is that MODE in [8] can determine the best compromise solution which can satisfy both cost and emission minimization requirement without using fuzzy mechanism like DE in [6]. The manner enables MODE to reduce the computing procedure and execution time as well. Two hybrid methods employed in [9], DE-SQP and PSO-SQP, are the combination between two individual methods. The advantage of the methods is that they can take advantage of each individual to enhance the solution approaching the global optimization; however, the methods have to cope with the high number of iterations and longer computational time. BBO has been widely and successfully used for solving the EELD problem and obtained superior results to other methods like NSGA-II and Tabu Search. PSO has become a popular method for over decades in electrical engineering especially power system optimization like load dispatch and optimal power flow. Nevertheless, the method needs more improvement performing on the conventional PSO to achieve higher solution. Compared to other meta-heuristic algorithms, CSA can be considered the most efficient method because it gets 100% convergence rate with higher performance than PSO, DE…

Bat Algorithm, a new meta-heuristic inspired from the behavior of Bat for searching food, was developed by Xin-She Yang in 2010 [12]. In the paper, the BA is successfully applied for solving EELD problem in which capacity of generator, power balance constraint are considered. The performance of the proposed BA has been validated by testing on different systems and compared to other methods consisting of FCGA [4], CGA [4] and CSA [11].

2. Problem Formulation

The optimal economic emission dispatch is to determine the power output of each thermal unit so that the both electricity generation fuel cost and released emission are minimized during the optimal horizon.

2.1. Economic Dispatch

At thermal power plants fossil fuel is burned to drive generator and produce electricity. In addition, the fuel is very expensive and becomes exhausted in the near future. Therefore, minimization of the fuel cost, economic dispatch, is one of the objectives during operation of thermal units. The objective is expressed as the following equation.

$$\text{Min} \sum_{i=1}^{N} F_{1i}(P_i) = \sum_{i=1}^{N} (c_i P_i^2 + b_i P_i + a_i) \tag{1}$$

2.2. Emission Objective Function

In addition to minimization of fuel cost, the emission produced from burning the fossil fuel released into the air, one of the factors causing to higher temperature, is also needed to be minimized during the operation. The emission objective is summarized in the following expression.

$$Min \sum_{i=1}^{N} F_{2i}(P_i) = \sum_{i=1}^{N} (f_i P_i^2 + e_i P_i + d_i) \tag{2}$$

2.3. Economic Emission Dispatch

As minimizing both fuel cost and emission, the problem is named economic emission dispatch (EED). The objective of the EED problem is as follows.

$$Min \sum_{i=1}^{N} F_i = \sum_{i=1}^{N} \left(w_1 F_{1i}(P_i) + w_2 .PR.F_{2i}(P_i) \right) \tag{3}$$

Subject to:

1. Power balance constraints:

$$\sum_{i=1}^{N} P_i - P_L - P_D = 0 \tag{4}$$

$$P_{Lk} = \sum_{i=1}^{N_1} \sum_{j=1}^{N_1} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{0i} P_i + B_{00} \tag{5}$$

2. Generator operating limits:

$$P_{i\min} \le P_i \le P_{i\max} \tag{6}$$

3. Bat Algorithm for EELD Problem

3.1. Calculation of Generation for Slack Thermal Unit

In order to satisfy equality constraints, most meta-heuristic algorithms used sack variables and obtained promising results [11]. In the paper, power output of thermal units excluding the first unit is initialized and newly generated whereas the first thermal unit generation is considered as a slack variable. Its value is determined by [11]:

$$P_{s1} = P_D + P_L - \sum_{i=2}^{N} P_i \tag{7}$$

3.2. Bat Algorithm

Bat algorithm is inspired from the behavior of Bat specie during their food search. The Bat algorithm is constructed by three idealized rules as below.

1) Each Bat *d* has a position X_d and a velocity V_d and it generates a pulse with frequency f_d and loudness A_d and rate r_d
2) The loudness A_d that a Bat generates is the largest value at the beginning of the search process and it reduces gradually and reaches the lowest one as approached to the food or prey.
3) During the search process, the frequency f_d is randomly produce meanwhile pule rate r_d and loudness *A* of each pule are automatically tuned.

Note that each bat with position represents a solution which will be improved gradually since the iteration is increased. The velocity represented as an increased value is used to determine the following position. Normally, the new position is better for searching food than the previous position. The fact means that normally the new solution tends to obtain better quality than the old one. However, sometimes the new solution is worse than the old. In this case, the better position of the bat is retained in stead of new position.

3.3. Bat Search Algorithm Implementation for the EED Problem

The main steps for the proposed BA for solving EELD problem are described as follows:

1) *Initialization:* Similar to other meta-heuristic algorithms, each position of each Bat in the population of Bat N_B is represented by a vector $X_d = [P_{d2}, \ldots\ldots, P_{dN}]$ $(d = 1, \ldots, N_B)$. Certainly, the upper and lower limits of each position are respectively $X_{dmin}=[P_{imin}]$ *and* $X_{dmax}=[P_{imin}]$. Consequently, each X_d is randomly initialized within the limits $P_{i,min} \le P_{i\,d} \le P_{i,max}$ $(i=2, \ldots, N_1)$ as follows.

$$X_d = X_{d\min} + rand * (X_{d\max} - X_{d\min}) \tag{8}$$

Fitness function is calculated to evaluate the quality of each solution. The value includes objective function value and the penalty value of the slack thermal unit 1. The detail of fitness function is as below.

$$FT_d = \sum_{i=1}^{N} \left(w_1 F_{1i}(P_{id}) + w_2 .PR.F_{2i}(P_{id}) \right) + K_s (P_{ds1} - P_{s1}^{\lim})^2 \tag{9}$$

where $P_{s1}^{\lim}$ is obtained by:

$$P_{s1}^{\lim} = \begin{cases} P_{s\max} & if\ P_{ds1} > P_{1\max} \\ P_{s\min} & if\ P_{ds1} < P_{1\min} \\ P_{ds1} & \text{otherwise} \end{cases} \tag{10}$$

The initial population of Bat is set to best value of each nest $Xbest_d$ ($d = 1, \ldots, N_d$) and the Bat with lowest fitness function value is the best Bat *Gbest* among all nests in the population.

2) *The first new solution generation*

The frequency and the velocity of each Bat are respectively newly randomized and updated as below.

$$f_d = f_{\min} + rand * (f_{\max} - f_{\min}) \tag{11}$$

$$V_d^{new} = V_d + rand.f_d.(Xbest - Gbest); d = 1,...,N_B \quad (12)$$

The first new solution generation is performed by the following equation.

$$X_d^{new} = Xbest_d + V_d^{new}; d = 1,...,N_B \quad (13)$$

3) The second new solution generation

If a random number is higher than the pules rate r_d, a new solution is generated by

$$X_d^{new} = \begin{cases} G_{best} + 0.01 * rand \ if \ rand > r_d \\ X_d^{new} \quad otherwise \end{cases}; d = 1,...,N_B \quad (14)$$

There is not criterion to assure that the new solutions are always exactly met their limit constraints. Therefore, the redefinition of the new solution is carried out by.

$$X_d^{new} = \begin{cases} X_{d\max} & \text{if} \quad X_d^{new} > X_{d\max} \\ X_{d\min} & \text{if} \quad X_d^{new} < X_{d\min} \\ X_d^{new} & otherwise \end{cases} \quad (15)$$

4) Evaluation and selection of the high quality solutions

The slack unit 1 is calculated by using (7) and the fitness function (9) is then determined. The new value of fitness function for each Bat is named FT_d^{new}.
The selection is performed to keep better position for each Bat.

$$X_d = \begin{cases} X_d^{new} & \text{if} \quad FT_d^{new} \le FT_d \ \& \ rand < A_d \\ Xbest_d & otherwise \end{cases} \quad (16)$$

5) Selection the best Bat with the lowest fitness function value.

Evaluate the quality of each Bat by using fitness function (9). The Bat with lowest value of the function is set to *Gbest* and others are set to *Xbest*.

6) Termination of the whole iterative algorithm

The whole iterative algorithm is terminated if the current iteration G is equal to the predetermined maximum number of iteration. Otherwise, set G=G+1 and update new value for the following parameters:

$$A = \alpha.A \quad (17)$$

$$r = r.[1 - \exp(\gamma.G)], \quad (18)$$

4. Three Dispatch Cases for the Problem

In the EELD problem, there are three cases of dispatch including economic dispatch, emission dispatch and economic emission dispatch. Depending on the value of w_1, w_2 and PR in equation (9), the kind of dispatch is decided as below.

1) Economic dispatch ($w_1=1, w_2=0$);
2) Emission dispatch ($w_1=0, w_2=1/PR$);
3) Combined economic and emission dispatch ($w_1=0, w_2=1, PR$ is a given value determined based on the load demand). The following steps are applied to determine the price penalty factor *PR* for a particular load over optimal interval [13].

Step 1: Calculate the average fuel cost for each MW of each thermal unit at full generation.

Step 2. Calculate the average emission for each MW of each thermal unit at full generation.

Step 3. Calculate the ratio of the average cost to average emission for each thermal unit and thus PR is obtained by

$$PR = \frac{F_1(P_{si\max})/P_{si\max}}{F_2(P_{si\max})/P_{si\max}} \ (\$/lb) \quad (16)$$

Step 4: Arrange the price penalty factor in ascending value order

Step 5: Gradually sum the maximum capacity of each unit ($P_{si,max}$), one at time, begging form full generation of thermal unit with the lowest value of the factor until the sum is equal or higher than the load demand.

Step 6: At the stage, the price penalty factor PR associated with the final unit in the process is the price penalty factor PR.

The values of the factor obtained in the study [13] have shown that *PR* depends on the load demand and note that there is only one value of the factor for each load demand.

5. Results and Discussions

The proposed BA is coded in Matlab 7.2 programming language and run on an Intel 1.7 GHz PC with 2 GB of Ram.

The Bat algorithm is tested on a system with two load cases, 1200 MW and 1800 MW and run fifty independent trials for each case of a set control parameter. The data of fuel cost and emission are respectively taken from [4] and [5]. Three dispatch cases including economic dispatch, emission dispatch and economic emission dispatch are performed. The values of loudness and pulse rate are in range from 0.9 to 0.1 with a step of 0.1 meanwhile the maximum iteration is set to 100. As a result, the best set of control parameters is selected based on the best minimum value and the standard deviation. The detail of the dispatches is as follow.

Case 1: Economic dispatch (w_1=1 and w_2=0)

The obtained results in terms of minimum cost, average cost, maximum cost, standard deviation cost and average computational time are given in Tables 1 and 2 respectively for 1200 MW and 1800 MW of load. As seen from the table, the best minimum cost of $/h 11477.5055 is obtained at A=0.3 and r=0.9 at 1200 MW of load and the best minimum cost at 1800 MW of load is also obtained at these values of loudness and pulse rate with $/h 16579.4671.

Table 1. The Obtained Results from by the Bat Algorithm at 1200 MW of Load for Economic Dispatch

A, r	Min. cost ($/h)	Aver. cost ($/h)	Max. cost ($/h)	Std. ($/h)	Aver. CPU time (s)
A=0.1, r=0.5	11477.7794	11494.55333	11513.7612	8.13	0.098
A=0.3, r=0.9	11477.5055	11492.00639	11516.158	9.46	0.098
A=0.4, r=0.7	11477.7615	11495.07175	11560.7097	13.74	0.097
A=0.4, r=0.9	11477.9653	11492.19408	11513.8196	8.51	0.098
A=0.5, r=0.6	11477.5633	11495.13866	11522.8696	11.19	0.102
A=0.9, r=0.6	11477.5092	11495.44575	11575.4074	15.69	0.098

Table 2. The Obtained Results from by the Bat Algorithm at 1800 MW of Load for Economic Dispatch

A, r	Min. cost ($/h)	Aver. cost ($/h)	Max. cost ($/h)	Std. ($/h)	Aver. CPU time (s)
A=0.1, r=0.8	16579.5140	16586.9433	16604.9831	5.3543	0.181
A=0.1, r=0.9	16579.5621	16588.1725	16604.8970	6.5717	0.098
A=0.3, r=0.9	16579.4671	16586.0248	16603.8679	5.4073	0.138
A=0.4, r=0.4	16579.5215	16589.4541	16613.0264	6.9605	0.12
A=0.5, r=0.5	16579.4746	16586.2551	16604.5006	4.7372	0.191
A=0.9, r=0.8	16579.4958	16586.9732	16601.3701	5.4100	0.192

Case 2: Emission dispatch (w_1=0 and w_2=1, PR obtained by section 4)

In emission dispatch, the control parameters are set to the same values with those from case 1. The obtained results are summarized in Tables 3 and 4. Clearly, the best emission is obtained at several values of control parameters at the two load cases.

Table 3. The Obtained Results from by the Bat Algorithm at 1200 MW of Load for Emission Dispatch

A, r	Min. emission (kg/h)	Aver. emission (kg/h)	Max. emission (kg/h)	Std. (kg/h)	Aver. CPU time (s)
A=0.4, r=0.8	1113.305	1123.827	1178.003	83.185	0.094
A=0.5, r=0.6	1113.302	1125.006	1159.159	102.291	0.095
A=0.5, r=0.7	1113.303	1125.552	1155.034	0.1	0.095
A=0.5, r=0.9	1113.301	1123.296	1171.102	478.057	0.101
A=0.6, r=0.8	1113.301	1125.732	1182.671	59.401	0.095
A=0.7, r=0.8	1113.302	1123.27	1161.922	79.042	0.095

Table 4. The Obtained Results from by the Bat Algorithm at 1800 MW of Load for Emission Dispatch

A, r	Min. emission (kg/h)	Aver. emission (kg/h)	Max. emission (kg/h)	Std. (kg/h)	Aver. CPU time (s)
A=0.5, r=0.9	2512.211	2544.875	2642.648	112.884	0.116
A=0.7, r=09	2511.965	2544.545	2648.485	290.328	0.115
A=0.8, r=0.9	2511.999	2545.902	2608.604	367.683	0.115
A=0.9, r=0.9	2512.353	2546.323	2619.633	29.038	0.118
A=0.5, r=0.9	2512.211	2544.875	2642.648	112.884	0.116
A=0.7, r=09	2511.965	2544.545	2648.485	290.328	0.115

Case 3: Economic Emission dispatch

In the economic emission dispatch, the values of w_1 *and* w_2 are set to one whereas the PR is set to 5.537 according the instruction described in section 4. The best values for fuel cost and emission are given in Table 5.

Table 5. The Obtained Results from by the Bat Algorithm at 1800 MW of Load for ECONOMIC EMISSION DISPATCH

Load (MW)	A, r	Min. cost ($/h)	Min. emission (kg/h)	Aver. CPU time (s)
1200	A=0.5, r=0.9	11593.104	1150.447	0.16
1800	A=0.5, r=0.9	16748.9247	2565.0974	0.15

The comparison of result obtained by the BA and other methods including FCGA [4], CGA [4] and CSA [11] are reported in Tables 6 and 7. Obviously, the BA obtains approximate solution quality with CSA in [11] and better solution than including FCGA [4], CGA [4]. On the other hand, the execution time form BA for searching optimal solution is around than 0.1 second although the execution time comparison can not be carried out because of other methods did not report their time excluding CSA in [11]. As compared to CSA, the BA is slower. Note that the CSA has been run on a stronger computer with 1.8 GHz and 4 GB of Ram. The optimal solution for economic dispatch and emission dispatch are given in Tables 8 and 9.

Table 6. Result Comparisons for System 2 for 1200 MW Load

Dispatch	Method	CGAs [4]	FCGAs [4]	CSA [11]	BA
Economic dispatch	Cost ($/h)	11493.74	11480.03	11477.09	11477.5055
	Cpu (s)	17.83	7.43	0.031	0.098
Emission dispatch	Emission (kg/h)	-	-	1113.3005	1113.301
	Cpu (s)			0.04	0.09
Economic emission dispatch	Cost ($/h)	-	-	11517.493	11593.104
	Emission (kg/h)	-	-	1306.6945	1150.447
	Cpu (s)	-	-	0.032	0.16

Table 7. Result Comparisons for System 2 for 1800 MW Load

Dispatch	Method	CGAs [4]	FCGAs [4]	CSA [11]	BA
Economic dispatch	Cost ($/h)	16589.05	16585.85	16579.33	16579.4671
	Cpu (s)	19.66	10.44	0.062	0.138
Emission dispatch	Emission (kg/h)	-	-	2511.9957	2511.965
	Cpu (s)	-	-	0.03	0.115
Economic emission dispatch	Cost ($/h)	-	-	16641.901	16748.9247
	Emission (kg/h)	-	-	2790.9434	2565.0974
	Cpu (s)	-	-	0.034	0.15

Table 8. Optimal Solution for Economic Dispatch

Generation (MW)	PD=1200 (MW)	PD=1800 (MW)
P_1	118.6076	250.8172
P_2	122.9112	221.3058
P_3	53.0916	76.1358
P_4	452.8588	579.9525
P_5	226.8743	335.739
P_6	225.6566	336.0497

Table 9. Optimal Solution for Emission Dispatch

Generation (MW)	PD=1200 (MW)	PD=1800 (MW)
P_1	120.4921	304.9304
P_2	207.6642	307.4582
P_3	121.2864	185.5768
P_4	224.3821	258.8224
P_5	244.971	372.2594
P_6	281.2042	370.9529

6. Conclusion and Future Work

In this paper, Bat Algorithm has been successfully applied for solving economic emission dispatch. The BA is known as a few control parameter algorithm with fast convergence and high quality solution. The method is tested on one system with two load cases with three dispatch cases including economic dispatch, emission dispatch and combined economic emission dispatch. In addition, the price penalty factor is employed to determine the best compromise solution for combined economic and emission dispatch. The obtained results from the BA compared to those from others have indicated that the BA is every efficient for the combine economic emission dispatch problem because it can obtain approximate or better solution quality than other methods.

In practical systems, a set of huge number of thermal units are operating to supply electricity to load. In addition, the pollutants produced at thermal plant include NOx, CO2 and SO2. Therefore, the method will be applied to economic emission dispatch where multi-thermal units and multi-pollutants are considered.

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Authors

Thang Trung Nguyen, he received his B.Eng. and M.Eng degrees in Electrical Engineering from University of Technical education Ho Chi Minh City, Ho Chi Minh city, Vietnam in 2008 and 2010, respectively. Now, he is teaching at department of electrical and electronics engineering, Ton Duc Thang University, Ho Chi Minh city, Vietnam. His research interests include optimization of power system, power system operation and control and Renewable Energy.

Sang Dang Ho, he received his B.Eng. and M.Eng degrees in Electrical Engineering from Ho Chi Minh University of Technology, Ho Chi Minh city, Vietnam in 2005 and 2008, respectively. Now, he is teaching at department of electrical and electronics engineering, Ton Duc Thang University, Ho Chi Minh city, Vietnam. His research interests include optimization of power system and electric machines control.

