ECONOMIC LOAD DISPATCH PROBLEM WITH VALVE - POINT EFFECT USING A BANARY BAT ALGORITHM

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Abstract:

This paper proposes application of BAT algorithm for solving economic load dispatch problem. BAT algorithm is based on the echolocation characteristics of micro bats. The proposed approach has been examined and tested with the numerical results of economic load dispatch problems with three and five generating units with valve point loading without considering prohibited operating zones and ramp rate limits. The results of the proposed BAT algorithm are compared with that of other techniques such as lambda iteration, GA, PSO, APSO and ABC. For both the cases, the proposed algorithm outperforms the solution reported for the existing algorithms. In addition, the promising results show the robustness, fast convergence and efficiency of the proposed technique.

Keywords: Economic dispatch, BAT algorithm, Combined economic and emission dispatch, Mathematical modelling

1 INTRODUCTION

Economic load dispatch (ED) is an important task in the power plants operation which aims to allocate power generations to match load demand at minimal possible cost while satisfying all the power units and system constraints [3]. The complexity of the problem is due to the nonlinear and non-smooth characteristics of the input-output curves of the generators, because of valve-point effect, ramp rate limits and prohibited operating zones. The mathematical programming based optimization methods such as lambda iteration, base point participation method, Gradient and Newton's methods can solve successfully the convex ED problems [4]. But unfortunately, these methods are ineffective to handle the non convex ED problems with non-differentiable characteristics due to high complexity. Dynamic programming can solve such type of problem, but it suffers from curse of dimensionality. Hence for optimal solution this problem needs a fast, robust and accurate solution methodology. Now days heuristic search methods such as simulated annealing (SA)[3]-[4], genetic algorithm (GA) [7], evolutionary programming (EP) [8], particle swarm optimization (PSO) [9]-[12], Bacteria foraging optimization (BFO) [13], differential evolution (DE) [14] and chaotic ant swarm optimization [17] are employed to solve the ED problems All the approaches have achieved success to a certain extent.

This paper presents the application of proposed BAT algorithm to economic load dispatch problem with valve point loading. The paper is organized as follows. Section 2 describes mathematical modelling of economic load dispatch problem with valve point loading without considering prohibited operating zones and ramp rate limits. The proposed BAT algorithm is described in section 3 and the description of test systems, results and comparisons of proposed algorithm with other methods are presented in section 4. Finally conclusion is given in section 5.

2 ECONOMIC LOAD DISPATCH PROBLEM

The economic load dispatch problem is defined as to minimize the total operating cost of a power system while meeting the total load plus transmission losses with in the generator limits. Mathematically, the problem is defined as to minimize equation (1) subjected to the energy balance equation given by (2) and the inequality constraints given by equation (3).

$$F_i(P_i) = \sum_{i=1}^{NG} \left(a_i P_i^2 + b_i P_i + c_i\right) \quad (1)$$

$$\sum_{i=1}^{NG} P_i = P_D + P_L \quad (2)$$

$$P_{imin} \le P_i \le P_{imax} \quad \text{(i=1, 2, 3... NG)} \quad (3)$$

Where a_i, b_i and c_i are cost coefficients

P_D is load demand

P_i is real power generation

P_L is power transmission loss

NG is number of generators

One of the important, simple but approximate methods of expressing transmission loss as a function of generator powers is through B-coefficients. The general form of the loss formula using B- coefficients is

$$P_i = \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_i B_{ij} P_j \quad \text{MW} \tag{4}$$

Where P_i, P_j are real power injections at the *i*th, *j*th buses

B_{ij} are loss coefficients

The above loss formula (4) is known as George's formula.

In normal economic load dispatch problem the input – output characteristics of a generator are approximated using quadratic functions, under the assumption that the incremental cost curves of the units are monotonically increasing piecewise-linear functions. However, real input- output characteristics display higher – order nonlinearities and discontinuities due to valve – point loading in fossil fuel burning plants.

The generating units with multi – valve steam turbines exhibit a greater variation in the fuel cost functions. The valve – point effects introduces ripples in the heat – rate curves. Mathematically operating cost is defined as:

$$F_i(P_i) = \sum_{i=1}^{NG} (a_i P_i^2 + b_i P_i + c_i + |d_i * \sin\{e_i * (P_i^{min} - P_i)\}|) \tag{5}$$

Where a_i, b_i, c_i, d_i and e_i are cost coefficients of i^{th} unit.

Mathematically, economic dispatch problem considering valve point loading is defined as minimizing operating cost given by equation (5) subjected to energy balance equation and inequality constraints given by equations (2) and (3) respectively.

3 BAT ALGORITHM

Bats are fascinating animals. They are the only mammals with wings and they also have advanced capability of echolocation. Most of bats uses echolocation to a certain degree; among all the species, microbats are famous example as microbats use echolocation extensively, while megabats do not. Microbats use a type of sonar, called echolocation, to detect prey, avoid obstacles, and locate their roosting crevices in the dark.

If we idealize some of the echolocation characteristics of microbats, we can develop various bat-inspired algorithms or bat algorithms. For simplicity, we now use the following approximate or idealized rules: 1. All bats use echolocation to sense distance, and they also know the difference between food/prey and background barriers.
2. Bats fly randomly with velocity v_i at position x_i with a fixed frequency f_{min}(or wavelength λ), varying wavelength λ (or frequency *f*) and loudness A_o to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission $r \in [0,1]$depending on the proximity of their targets;
3. Although the loudness can vary in many ways, we assume that the loudness varies from a large (positive) A_o to a minimum valueA_{min}.

Another obvious simplification is that no ray tracing is used in estimating the time delay and three dimensional topography. In addition to these simplified assumptions, we also use the following approximations, for simplicity. In general the frequency *f* in a range $[f_{min}, f_{max}]$ corresponds to a range of wavelengths $[\lambda_{min},, \lambda_{max}]$. For example , a frequency range of [20 kHz, 500 kHz] corresponds to a range of wavelengths from 0.7mm to 17mm.

In simulations, we use virtual bats naturally. We have to define the rules how their positions x_i and velocities v_i in a d-dimensional search space are updated. The new solutions x_i^t and velocities v_i^t at time step t are given by

$$f_i = f_{min} + (f_{max} - f_{min})\beta \tag{6}$$
$$v_i^t = v_i^{t-1} + (x_i^t - x_*) f_i \tag{7}$$

where $\beta \in [0,1]$ is a random vector drawn from a uniform distribution. Here x_* is the current global best location (solution) which is located after comparing all the solutions among all the n bats. As the product $\lambda_i f_i$ is the velocity increment, we can use either f_i (or λ_i) to adjust the velocity change while fixing the other factor λ_i (or f_i), depending on the type of the problem of interest. For the local search part, once a solution is selected among the current best solutions, a new solution for each bat is generated locally using random walk

$$x_{new} = x_{old} + \epsilon A^t \tag{8}$$

Where $\epsilon \in [-1,1]$ is a random number, while $A^t = \langle A_i^t \rangle$ is the average loudness of all the bats at this time step.

Based on the above approximations and idealization, the pseudo-code of the Bat Algorithm (BA) can be summarized below.

3.1 PSEUDO-CODE OF THE BAT ALGORITHM

Objective function f(x), x = (x1, … , xd)^T
Initialize the bat population x_i (i = 1, 2, .., n) *and* v_i
Define pulse frequency f_i *at* x_i
Initialize pulse rates r_i *and the loudness* A_i
while (t <*Max number of iterations)*
Generate new solutions by adjusting frequency, and updating velocities and locations/solutions [equations (13) to (15)]
if *(rand >* r_i*)*
Select a solution among the best solutions
Generate a local solution around the selected best solution
end if
Generate a new solution by flying randomly
if *(rand <* A_i& f(x_i) < f(X_*))
Accept the new solutions
Increase r_i *and reduce* A_i
end if
Rank the bats and find the current best X_*
end while
Post process results and visualization

4 SIMULATION RESULT AND DISCUSSIONS

The applicability and efficiency of BAT algorithm for practical applications has been tested on two test cases. The programs are developed using MATLAB 7.9.

The Parameters for BAT algorithm considered here are: n=20; A=0.9; r=0.1; $f_{min} = 0$; $f_{max} = 2$. The proposed BAT algorithm stopping criteria is based on maximum-generation=100.

Test case 1: The system consists of three thermal units[1]. The cost coefficients of all thermal generating units with valve point effect are listed in table (1). The transmission losses are neglected. Prohibited zones and ramp rate limits of generating units are not considered. The economic load dispatch problem is solved to meet a load demand of 850 MW and 1050 MW.

Table: 1 Cost coefficients for Three Generating units

Unit	Fuel cost coefficients					$P_{G\,min}$ (MW)	$P_{G\,max}$ (MW)
	a_i	b_i	c_i	d_i	e_i		
G1	0.0016	7.92	561.0	300	0.032	100	600
G2	0.0048	7.92	78.0	150	0.063	50	200
G3	0.0019	7.85	310.0	200	0.042	100	400

Table: 2 Comparison of results for test case 1.

Load demand	Parameter	Lambda	GA	PSO	ABC	BAT
850 MW	P1,MW	382.258	382.2552	394.5243	300.266	384.4228
	P2,MW	127.419	127.4184	200.000	149.733	151.6428
	P3,MW	340.323	340.3202	255.4756	400.000	313.9343
	Total cost, Rs/h	8575.68	8575.64	8280.81	8253.10	8253.10
1050 MW	P1, MW	487.500	487.498	492.699	492.6991	492.6993
	P2, MW	162.500	162.499	157.30	157.301	158.1006
	P3, MW	400.000	400.000	400.00	400.00	399.2001
	Total cost, Rs/h	10212.459	10212.44	10123.73	10123.73	10123.6954

Table: 2 show the summarized result of all the existing algorithms along with BAT algorithm for test case 1. Form Table: 2, it is clear that BAT algorithm gives optimum result in terms of minimum fuel cost compared to other existing algorithms shown.

The convergence tendency of proposed BAT algorithm based strategy for power demand of 850 MW and 1050 MW is plotted in figure: 1. It shows that the technique converges in relatively fewer cycles thereby possessing good convergence property.

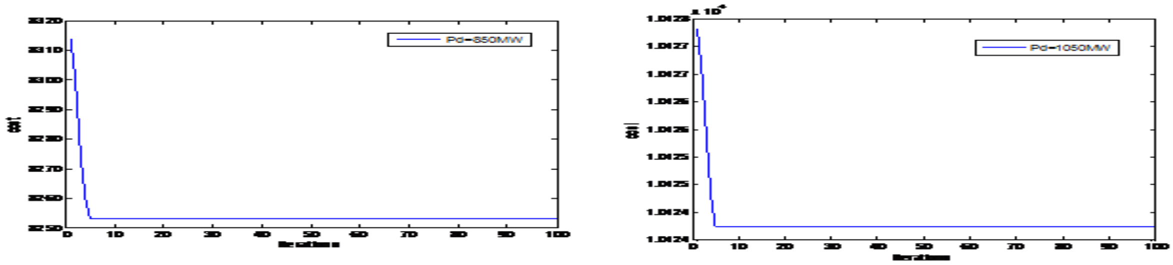

Figure: 1 Convergence of BAT algorithm for load demand values 850 MW and 1050 MW.

Test case 2: The system consists of five thermal units[1]. The cost coefficients of all thermal generating units with valve point effect are listed in table (3). The transmission losses are neglected. Prohibited zones and ramp rate limits of generating units are not considered. The economic load dispatch problem is solved to meet a load demand of 730 MW.

Table: 3 Cost coefficients for Three Generating units

Unit	Fuel cost coefficients					$P_{G\ min}$ (MW)	$P_{G\ max}$ (MW)
	a_i	b_i	c_i	d_i	e_i		
G1	0.0015	1.8	40.0	200.0	0.035	50	300
G2	0.0030	1.8	60.0	140.0	0.040	20	125
G3	0.0012	2.1	100.0	160.0	0.038	30	175
G4	0.0080	2.0	25.0	100.0	0.042	10	75
G5	0.0010	2.0	120.0	180.0	0.037	40	250

Table: 4 Comparison of results for test case 2.

Load demand	Parameter	Lambda	GA	PSO	APSO[1]	EP[1]	ABC	BAT
730 MW	P1, MW	218.028	218.0184	229.5195	225.3845	229.8030	229.5247	229.5209
	P2, MW	109.014	109.0092	125.00	113.020	101.5736	102.0669	102.9878
	P3, MW	147.535	147.5229	175.00	109.4146	113.7999	113.4005	112.6753
	P4,MW	28.380	28.37844	75.00	73.11176	75.000	75.000	75.000
	P5,MW	272.042	227.0275	125.4804	209.0692	209.8235	210.0079	209.816
	Total cost, Rs/h	2412.709	2412.538	2252.572	2140.97	2030.673	2030.259	2029.668

Table: 4 show the summarized result of all the existing algorithms along with BAT algorithm for test case 2. Form Table: 4, it is clear that BAT algorithm gives optimum result in terms of minimum fuel cost compared to other existing algorithms shown.

The convergence tendency of proposed BAT algorithm based strategy for power demand of 730 MW is plotted in figure: 1. It shows that the technique converges in relatively fewer cycles thereby possessing good convergence property.

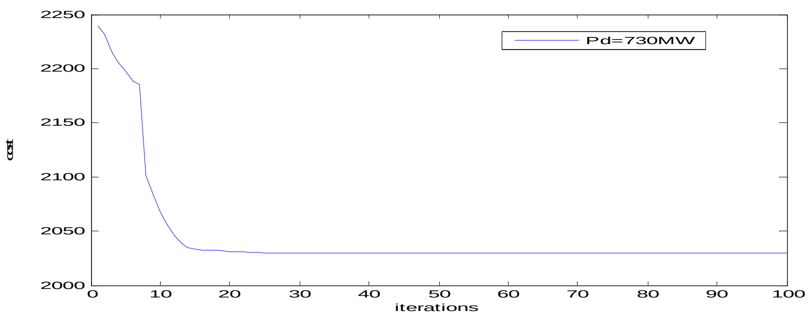

Figure: 2 Convergence of BAT algorithm for test case 2 to a load demand of 730 MW.

5 CONCLUSION

In this paper, a new BAT algorithm has been proposed. In order to prove the effectiveness of algorithm it is applied to economic load dispatch problem with three and five generating units. The results obtained by proposed method were compared to those obtained by lambda iteration method, GA, PSO, APSO and ABC. The comparison shows that BAT algorithm performs better than above mentioned methods. The BAT algorithm has superior features, including quality of solution, stable convergence characteristics and good computational efficiency. Therefore, this results shows that BAT optimization is a promising technique for solving complicated problems in power system.

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