Economic Load Dispatch Problem with Valve – Point Effect Using a Binary Bat Algorithm

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Abstract—This paper proposes application of BAT algorithm for solving economic load dispatch problem. BAT algorithmic rule is predicated on the localization 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 projected BAT formula are compared with that of other techniques such as lambda iteration, GA, PSO, APSO, EP, ABC and basic principle. For each case, the projected algorithmic program outperforms the answer reported for the existing algorithms. Additionally, the promising results show the hardness, quick convergence and potency of the projected technique.

Index Terms—Binary BAT algorithm, Economic load dispatch, valve-point effect, mathematical modeling.

I. INTRODUCTION

The economic load dispatch is an important real time drawback, in properly allocating the important power demand among the online generating units. Traditional optimization techniques [1] such as the lambda iteration method, gradient method, the linear programming method and Newton’s method are used to solve the ELD problem with monotonically increasing cost function. But they are highly sensitive to starting points and often converge to local optimum or diverge altogether. In reality, the input-output characteristic of generating units are nonlinear due to valve-point loading and more advanced algorithms are worth developing to obtain accurate dispatch results.

Many works are in literature to solve the ELD problem with valve-point loading. Dynamic programming (DP) is one of the approaches to solve the non-convex ELD problem. However, the DP method requires too many computational resources in order to provide accurate results for large scale power systems [1], [2]. Over the past few years, in order to solve this problem, many stochastic methods have been developed such as GA [3], Evolutionary Programming (EP) [4], [5], Simulated Annealing (SA) [6], and Particle Swarm Optimization (PSO) [7]. They may prove to be very effective in solving non-linear ED problems without any restriction on the shape of the cost curves. SA is applied in many power system problems. Nevertheless, the setting of control parameters of the SA algorithm is a difficult task and convergence speed is slow when applied to a real system [8]. Tabu Search (TS), a heuristic search approach has also been applied to solve the ED problem [9]. Though GA methods have been employed successfully to solve complex optimization problems, traditional GA has some drawbacks when applied to multidimensional, high-precision numerical problems. The basic disadvantage of GA is the fact that they may miss the optimum and provide a near-optimum solution in a limited runtime period [10]. Moreover, the premature convergence of GA degrades its performance and reduces its search capability that leads to a higher probability towards obtaining a local optimum [11]. EP seems to be a good method to solve optimization issues. Once applied to issues consisting of additional number of local optima the solutions obtained from EP method is just near global optimum. In addition, GA and EP take long simulation time in order to obtain answer for such issues. Therefore, hybrid strategies combining two or more improvement strategies were introduced [12]-[15]. These techniques are more efficient than the conventional procedures because of their heuristic search procedure. Recent research endeavours, therefore, have been directed towards the application of these techniques.

In this paper, bat algorithm (BA) was based on the echolocation is proposed to solve the ELD problem with non-convex functions to consider non-linear generator characteristics such as valve-point effect. The echolocation based algorithm described in this paper is a search algorithm capable of locating optimal solutions efficiently. The effectiveness of the proposed algorithm is demonstrated using three and five generating unit test systems. Results show that the algorithm can handle complex multi-model optimization problems.

II. 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 outlined on minimize equation (1) subjected to the energy balance equation given by (2) and the inequality constraints given by equation (3).
Although the loudness can vary in many ways, we all the bats use an echolocation to sense the prey. When searching for their prey, the bats randomly emit short, loud sound impulses. The pulse rate is usually defined as 10 to 20 times per second. After hitting and reflecting, the bats transform their own pulse into useful information to gauge how far away the prey is. The bats are using wavelengths that vary in the range from 0.7 to 17 mm and inaudible frequencies of 20-500 kHz. To implement the algorithm, the pulse frequency and the rate have to be defined. The pulse rate can be simply determined in the range from 0 to 1, where 0 means that there is no emission and 1 means that the bats’ emitting is their maximum [17, 18, 19]. The bat behavior can be used to formulate a new BA. Yang [18] used three generalized rules when implementing the bat algorithms:

1. All the bats use an echolocation to sense the distance and they also guess the difference between the food/prey and background barriers in a somewhat magical way.
2. When searching for their prey, the bats randomly emit short, loud sound impulses. They typically emit short, loud sound impulses. The pulse rate is usually defined as 10 to 20 times per second. After hitting and reflecting, the bats transform their own pulse into useful information to gauge how far away the prey is. The bats are using wavelengths that vary in the range from 0.7 to 17 mm and inaudible frequencies of 20-500 kHz. To implement the algorithm, the pulse frequency and the rate have to be defined. The pulse rate can be simply determined in the range from 0 to 1, where 0 means that there is no emission and 1 means that the bats’ emitting is their maximum [17, 18, 19]. The bat behavior can be used to formulate a new BA. Yang [18] used three generalized rules when implementing the bat algorithms:

3. Although the loudness can vary in many ways, we assume that it varies from a large (positive) $A_{\text{max}}$, to a minimum constant value $A_{\text{min}}$.

For simplicity, we do not use ray tracing in this algorithm, though it can form an interesting feature for further extension. In general, ray tracing can be computational extensive, but it can be a very useful feature for computational geometry and other applications. Furthermore, a given frequency is intrinsically linked to a wavelength. For example, a frequency range of [20 kHz, 500 kHz] corresponds to a range of wavelengths from 0.7 mm to 17 mm in the air. Therefore, we can describe the change in terms of frequency $f$ or wavelength $\lambda$ to suit different applications, depending on the ease of implementation and other factors.

B. BAT Motion

Each bat is associated with a velocity $v_i^t$ and a location $x_i^t$ at iteration $t$. In a $d$-dimensional search or solution space, the bat motion is defined as:

$$f_i^t = f_{\text{min}} + (f_{\text{max}} - f_{\text{min}}) \beta$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_{\text{g}}) f_i$$

$$x_i^t = x_i^{t-1} + v_i^t$$

A. BAT Algorithm

The Bat algorithm was developed by Xin-She Yang in 2010 [16]. The algorithm exploits the so-called echolocation of the bats. The bats use sonar echoes to detect and avoid obstacles. It is generally known that sound pulses are transformed into a frequency which reflects from obstacles. The bats navigate by using the time delay from emission to reflection. They typically emit short, loud sound impulses. The pulse rate is usually defined as 10 to 20 times per second. After hitting and reflecting, the bats transform their own pulse into useful information to gauge how far away the prey is. The bats are using wavelengths that vary in the range from 0.7 to 17 mm and inaudible frequencies of 20-500 kHz. To implement the algorithm, the pulse frequency and the rate have to be defined. The pulse rate can be simply determined in the range from 0 to 1, where 0 means that there is no emission and 1 means that the bats’ emitting is their maximum [17, 18, 19]. The bat behavior can be used to formulate a new BA. Yang [18] used three generalized rules when implementing the bat algorithms:

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3. Although the loudness can vary in many ways, we assume that it varies from a large (positive) $A_{\text{max}}$, to a minimum constant value $A_{\text{min}}$.
where $\beta \in [0, 1]$ is a random vector drawn from a uniform distribution. As mentioned earlier, we can either use wavelengths or frequencies for implementation, we will use $f_{\text{min}} = 0$ and $f_{\text{max}} = O(1)$, depending on the domain size of the problem of interest. Initially, each bat is randomly assigned a frequency which is drawn uniformly from $[f_{\text{min}}, f_{\text{max}}]$. For this reason, bat algorithm can be considered as a frequency-tuning algorithm to provide a balanced combination of exploration and exploitation. The loudness and pulse emission rates essentially provide a mechanism for automatic control and auto zooming into the region with promising solutions.

C. Variations of Loudness and Pulse Rates

In order to provide an effective mechanism to control the exploration and exploitation and switch to exploitation stage when necessary, we have to vary the loudness $A_i$ and the rate $r_i$ of pulse emission during the iterations. Since the loudness usually decreases once a bat has found its prey, while the rate of pulse emission increases, the loudness can be chosen as any value of convenience, between $A_{\text{min}}$ and $A_{\text{max}}$, assuming $A_{\text{min}} = 0$ means that a bat has just found the prey and temporarily stop emitting any sound. With these assumptions, we have

$$A_{i+1}^t = \alpha A_i^t, \quad r_{i+1}^t = r_i^t [1 - \exp(-\gamma t)], \quad (9)$$

where $\alpha$ and $\gamma$ are constants.

In essence, here $\alpha$ is similar to the cooling factor of a cooling schedule in simulated annealing. For any $0 < \alpha < 1$ and $\gamma > 0$, we have

$$A_i^t \rightarrow 0, r_i^t \rightarrow r_i^0, \text{ as } t \rightarrow \infty \quad (10)$$

In the simplest case, we can use $\alpha = \gamma$, and we have used $\alpha = \gamma = 0.9$ to 0.98 in our simulations.

D. Variants of BAT Algorithm

The Binary bat algorithm has many advantages, and one of the key advantages is that it can provide very quick convergence at a very initial stage by switching from exploration to exploitation. This makes it an efficient algorithm for applications such as classifications and others when a quick solution is needed. However, if we allow the algorithm to switch to exploitation stage too quickly by varying $A_i$ and $r_i$ too quickly, it may lead to stagnation after some initial stage.

E. Pseudo Code of BAT Algorithm

Objective function $f(x), x = (x_1, \ldots, x_d)$

Initialize the bat population $x_i$ and $v_i$ for $i = 1, \ldots, n$

Define pulse frequency $Q \in [Q_{\text{min}}, Q_{\text{max}}]$

Initialize pulse rates $r_i$ and the loudness $A_i$

while ($t < T_{\text{max}}$) // number of iterations

Generate new solutions by adjusting frequency and update velocities and locations/solutions [Eq.(7) to (9)]

if (rand (0; 1) < $A_i$ and $f(x_i) < f(x)$)

Accept the new solutions

Increase $r_i$ and reduce $A_i$

end if

Rank the bats and find the current best

Post process results and visualization

IV. SIMULATION RESULTS AND DISCUSSION

The applicability and validity of the BAT algorithm for practical applications has been tested on various test cases. The obtained best solution in fifty runs are compared with the results obtained using GA. All the programs are developed using MATLAB 7.8.0 (2009a) and the system configuration is core i3 processor with 2.30 GHz speed and 6 GB RAM.

A. Settings of BAT Algorithm Parameters

The Parameters for BAT algorithm considered here are:

$n=20, A=0.9; r=0.1; f_{\text{min}}=0; f_{\text{max}}=2$. The proposed BAT algorithm stopping criteria is based on maximum-generation=100.

B. Numerical Solutions

i. Test Case I: The system consists of three thermal units. 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. Fig. 1: shows the convergence tendency of proposed BAT algorithm based strategy for power demand of 850 MW and 1050 MW. It was reported in that the global optimum solution found for the 3-generator system is 8121.8568 Rs/hr and 10123.6953 Rs/hr.

From the results in Table 2 it is explicit that BAT algorithm has succeeded in finding the global optimum solution that has been reported in the literature. Fig. 1: shows the convergence tendency of proposed BAT algorithm based strategy for power demand of 850 MW and 1050 MW. It shows that the technique converges in relatively fewer cycles thereby possessing good convergence property.

ii. Test Case II: 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 economic load dispatch problem is solved to meet a load demand of 730 MW. This test system comprises of five generating units. In this case, valve-point effect is included and transmission losses are neglected. The total load demand for the system is 850 MW and 1050MW. Results obtained for the proposed method is shown in Table 2 and the results are compared with Lambda, GA, PSO and ABC. It was reported in that the global optimum solution found for the 3-generator system is 8121.8568 Rs/hr and 10123.6953 Rs/hr.

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<table>
<thead>
<tr>
<th>Unit</th>
<th>Fuel cost coefficients</th>
<th>(MW)</th>
<th>(MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>0.0016 7.92 561.0 300 0.032</td>
<td>100</td>
<td>600</td>
</tr>
<tr>
<td>G2</td>
<td>0.0048 7.92 78.0 150 0.063</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>G3</td>
<td>0.0019 7.85 310.0 200 0.042</td>
<td>100</td>
<td>400</td>
</tr>
</tbody>
</table>

**Table: II Comparison of results for test case 1**

<table>
<thead>
<tr>
<th>Load demand</th>
<th>Parameter</th>
<th>Lambda</th>
<th>GA</th>
<th>PSO</th>
<th>ABC</th>
<th>BAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>850 MW</td>
<td>P1, MW</td>
<td>382.258</td>
<td>382.2552</td>
<td>394.5243</td>
<td>300.266</td>
<td>296.3495</td>
</tr>
<tr>
<td></td>
<td>P2, MW</td>
<td>127.419</td>
<td>127.4184</td>
<td>200.000</td>
<td>149.733</td>
<td>199.6002</td>
</tr>
<tr>
<td></td>
<td>P3, MW</td>
<td>340.323</td>
<td>340.3202</td>
<td>255.4756</td>
<td>400.000</td>
<td>334.0503</td>
</tr>
<tr>
<td></td>
<td>Total cost, Rs/h</td>
<td>8575.68</td>
<td>8575.64</td>
<td>8280.81</td>
<td>8253.10</td>
<td>8121.8568</td>
</tr>
<tr>
<td>1050 MW</td>
<td>P1, MW</td>
<td>487.500</td>
<td>487.498</td>
<td>492.699</td>
<td>492.699</td>
<td>492.6991</td>
</tr>
<tr>
<td></td>
<td>P2, MW</td>
<td>162.500</td>
<td>162.499</td>
<td>157.30</td>
<td>157.3001</td>
<td>158.0995</td>
</tr>
<tr>
<td></td>
<td>P3, MW</td>
<td>400.000</td>
<td>400.000</td>
<td>400.00</td>
<td>400.00</td>
<td>399.2014</td>
</tr>
<tr>
<td></td>
<td>Total cost, Rs/h</td>
<td>10212.459</td>
<td>10212.44</td>
<td>10123.73</td>
<td>10123.73</td>
<td>10123.6953</td>
</tr>
</tbody>
</table>

Fig. 1 Convergence characteristics of three generating units.
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.

VI. REFERENCES


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TABLE III. COST COEFFICIENTS FOR THREE GENERATING UNITS

<table>
<thead>
<tr>
<th>Unit</th>
<th>(a_1)</th>
<th>(b_1)</th>
<th>(c_1)</th>
<th>(d_1)</th>
<th>(e_1)</th>
<th>(P) (MW)</th>
<th>(Q) (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>0.0015</td>
<td>1.8</td>
<td>40.0</td>
<td>200.0</td>
<td>0.035</td>
<td>50</td>
<td>300</td>
</tr>
<tr>
<td>G2</td>
<td>0.0030</td>
<td>1.8</td>
<td>60.0</td>
<td>140.0</td>
<td>0.040</td>
<td>20</td>
<td>125</td>
</tr>
<tr>
<td>G3</td>
<td>0.0012</td>
<td>2.1</td>
<td>100.0</td>
<td>160.0</td>
<td>0.038</td>
<td>30</td>
<td>175</td>
</tr>
<tr>
<td>G4</td>
<td>0.0080</td>
<td>2.0</td>
<td>25.0</td>
<td>100.0</td>
<td>0.042</td>
<td>10</td>
<td>75</td>
</tr>
<tr>
<td>G5</td>
<td>0.0010</td>
<td>2.0</td>
<td>120.0</td>
<td>180.0</td>
<td>0.037</td>
<td>40</td>
<td>250</td>
</tr>
</tbody>
</table>

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TABLE IV. COMPARISON OF RESULTS FOR TEST CASE 2

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>730 MW</td>
<td>P1, MW</td>
<td>218.028</td>
<td>218.0184</td>
<td>229.5195</td>
<td>225.3845</td>
<td>229.8030</td>
<td>229.5247</td>
<td>229.5209</td>
</tr>
<tr>
<td></td>
<td>P2, MW</td>
<td>109.014</td>
<td>109.0092</td>
<td>125.0000</td>
<td>113.0208</td>
<td>113.7999</td>
<td>113.4005</td>
<td>112.6753</td>
</tr>
<tr>
<td></td>
<td>P3, MW</td>
<td>147.535</td>
<td>147.5229</td>
<td>175.0000</td>
<td>109.4146</td>
<td>113.7999</td>
<td>113.4005</td>
<td>112.6753</td>
</tr>
<tr>
<td></td>
<td>P4, MW</td>
<td>28.380</td>
<td>28.37844</td>
<td>75.0000</td>
<td>73.11176</td>
<td>75.0000</td>
<td>75.0000</td>
<td>75.0000</td>
</tr>
<tr>
<td></td>
<td>P5, MW</td>
<td>272.042</td>
<td>227.0275</td>
<td>125.4804</td>
<td>209.0692</td>
<td>209.8235</td>
<td>210.0079</td>
<td>209.8164</td>
</tr>
<tr>
<td></td>
<td>Total cost, Rs/h</td>
<td>2412.709</td>
<td>2412.538</td>
<td>2252.572</td>
<td>2140.970</td>
<td>2030.673</td>
<td>2030.259</td>
<td>2029.668</td>
</tr>
</tbody>
</table>

---

Fig. 2 shows the convergence tendency of proposed BAT algorithm based strategy for power demand of 750 MW is plotted in Fig. 3. It shows that the technique converges in relatively fewer cycles thereby possessing good convergence property.


