APPLICATION OF BAT ALGORITHM FOR COMBINED ECONOMIC LOAD AND EMISSION DISPATCH

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Abstract: This paper presents an application of BAT algorithm for multi-objective optimization problem in power system. Considering the environmental impacts that grow from the emissions produced by fossil-fuelled power plant, the economic dispatch that minimizes only the total fuel cost can no longer be considered as single objective. Application of BAT algorithm in this paper is based on mathematical modelling to solve economic, emission and combined economic and emissions dispatch problems by a single equivalent objective function. BAT algorithm has been applied to two realistic systems at different load condition. Results obtained with proposed method are compared with other techniques presented in literature. BAT algorithm is easy to implement and much superior to other algorithms in terms of accuracy and efficiency.

Keywords: Economic dispatch; BAT algorithm; Artificial Bee Colony algorithm; Combined economic and emission dispatch; Mathematical modelling.

1 INTRODUCTION

This paper introduce the economic dispatch problem in a power system to determine the optimal combination of power output for all generating units which will minimize the total fuel cost while satisfying load and operational constraints. The economic dispatch problem is very complex to solve because of a non-linear objective function, and a large number of constraints.

Well known long-established techniques such as integer programming, dynamic programming, and lagerangian relaxation have been used to solve the economic dispatch problem. Recently other optimization methods such as Simulated Annealing, Genetic Algorithm, Particle Swarm optimization, and Tabu Search Algorithm are presented to solve the economic dispatch problem. This single objective economic dispatch can no longer considered due to the environmental concerns that arise from the emission produced by fossil-fuelled electric power plants. Economic and environmental dispatch is a multi-objective problem.

Recently, various modern heuristics multi-objective evolutionary algorithms such as Non-dominated Sorting Genetic Algorithm-II (NSGA-II), Evolutionary Programming algorithm (EP), Strength Pareto Evolutionary Algorithm (SPEA) and Multi-Objective Particle Swarm Optimization (MOPSO) may prove to be efficient in solving EED problem by tackling both two objectives of EED problem simultaneously as competing objectives. But all these methods seem to be lack of ability to find the Pareto-optimal front due to their drawbacks: NSGA-II and SPEA may obtain only near Pareto-optimal front with long simulation time when applied to solve EED problem because of the premature convergence of Genetic Algorithm (GA) which they are based on; EP suffers from the oscillation of the solution, and computational time may be too long when applying EP to solve EED problem; the premature convergence of PSO may lead optimization progresses of MOPSO methods to the local Pareto-optimum front, which would degrade their performance in solving EED problem. In [17-18] including emission constraints to the economic dispatch and unit commitment problems have been presented, under cost-minimization environment.

In this paper a multi-objective optimization problem i.e., BAT algorithm is proposed to solve combined economic and emissions dispatch problems is presented and the effectiveness of proposed algorithm is demonstrated using three and six generating unit test systems.

2 COMBINED ENVIRONMENTAL ECONOMIC DISPATCH

The traditional economic dispatch problem has been defined as minimizing of an objective function i.e., the generation cost function subject to equality constraints (total power generated should be equal to total system load plus losses for all solutions) and inequality constraints (generations should lie between their respective maximum and minimum specified values). The objective function (1) is minimised subject to equality constraint (2) and inequality constraints (3).

$$f(x) = \sum_{i=1}^{n} \varphi_i(P_i)$$

(1)

$$g(x) = \sum_{i=1}^{n} P_i - P_{D} = 0$$

(2)

$$H(x) \leq 0, \quad P_{min} \leq P_i \leq P_{max}$$

Where \(s\) is a state variable, \(P_i\) is the control variable, i.e., real power setting of \(i_{th}\) generator and \(n\) is the number of units or generators.

There are several ways to include emission into the problem of economic dispatch.
Reference [19] summarizes the various algorithms for solving environmental dispatch problem with different constraints. One approach is to include the reduction of emission as an objective. In this work, only NOx reduction is considered because it is a significant issue at the global level. A price penalty factor \( h \) is used in the objective function to combine the fuel cost, Rs/hr and emission functions, kg/hr of quadric form.

The combined economic and emission dispatch problem can be formulated as to minimize

\[
\begin{align*}
q_i &= \sum_{i=1}^{n} (d_i P_i^2 + b_i P_i + c_i) + h \sum_{i=1}^{n} (d_i P_i^2 + c_i) RS/hr \\
q_i &= \sum_{i=1}^{n} (d_i P_i^2 + b_i P_i + c_i) + h \sum_{i=1}^{n} (d_i P_i^2 + c_i) RS/hr
\end{align*}
\]

Subject to equality and inequality constraint defined by equations (2), (3). Once price penalty factor \( h \) is known, equation (5) can be rewritten as

\[
q_i = \sum_{i=1}^{n} (a_i + h d_i) P_i^2 + (b_i + h e_i) P_i + (c_i + f_i) RS/hr
\]

This has the resemblance of the familiar fuel cost equation, once \( h \) is determined. A practical way of determining \( h \) is discussed by Palanichamy and Srikrishnan [8]. Consider that the system is operating with a load of PD MW, it is necessary to evaluate the maximum cost of each generator at its maximum output, i.e.,

1. Evaluate the maximum cost of each generator at its maximum output, i.e.,

\[
F_i(P_{max}) = (a_i P_{max}^2 + b_i P_{max} + c_i) Rs/hr
\]

2. Evaluate the maximum NOx emission of each generator at its maximum output, i.e.,

\[
E_i(P_{max}) = (a_i P_{max}^2 + b_i P_{max} + c_i) Kg/hr
\]

3. Divide the maximum cost of each generator by its maximum NOx emission, i.e.,

\[
\frac{F_i(P_{max})}{E_i(P_{max})} = \frac{a_i P_{max}^2 + b_i P_{max} + c_i}{a_i P_{max}^2 + b_i P_{max} + c_i} Rs/kg
\]

Recalling that

\[
\frac{F_i(P_{max})}{E_i(P_{max})} = h_i Rs/kg
\]

(iv) Arrange \( h_i \) in ascending order.

(v) Add the maximum capacity of each unit, one at a time, starting from the smallest \( h_i \) unit until total demand is met as shown below.

\[
\sum_{i=1}^{n} P_i \geq P_D
\]

At this stage, \( h_i \) associated with the last unit in the process is the price penalty factor \( h \) Rs/Kg for the given load.

Arrange \( h \) in ascending order. Let ‘h’ be a vector having ‘\( h \)’ values in ascending order.

\[
h = [h_1, h_2, h_3, ..., h_n]
\]

For a load of PD starting from the lowest \( h_i \) value unit, maximum capacity of unit is added one by one and when this total equals or exceeds the load, \( h_i \) associated with the last unit in the process is the price penalty factor for the given PD. Then equation (6) can be solved to obtain environmental economic dispatch using lambda iteration method.

### 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 use 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 \( \lambda \)), varying wavelength \( \lambda \) (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 \( r \epsilon [0,1] \), 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 approximate or idealized rules:

Another obvious simplification is that no ray tracing is used in estimating the time delay and three dimensional topography. In addition to these approximations, 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 \([20 kHz, 300 kHz]\) 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

\[
f_i = f_{min} + (f_{max} - f_{min}) \beta \]

\[
v_i^t = v_i^{t-1} + (x_i^t - x_i) \beta \]

where \( \beta \epsilon [0, 1] \) is a random vector drawn from a uniform distribution. Here \( x_i \) 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 $\lambda_i$) to adjust the velocity change while fixing the other factor $\lambda_i$ (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

$$x_{new} = x_{old} + \epsilon A^t$$  \hspace{1cm} (15)

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 $f(x)$, $x = (x_1, \ldots, x_d)^T$

Initialize the bat population $x_i$ ($i = 1, 2, \ldots, n$) and $v_i$

Define pulse frequency $f_i$ at $x_i$

Initialize pulse rates $\tau_i$ and the loudness $A_i$ while ($t < \text{Max number of iterations}$)

Generate new solutions by adjusting frequency, and updating velocities and locations/solutions [equations (13) to (15)]

if (rand $> \tau_i$)

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 $< A_i$ $\&$ $f(x_i) < f(X_i)$)
Accept the new solutions
 Increase $\tau_i$ 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: $n=20; A=0.9; r=0.1; f_{min} = 0; f_{max} = 2$.

Test case 1: The system consists of three thermal units. The parameters of all thermal units are adapted from [1].

Table: 1 Comparison of test results for Three Generating units

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>400MW</td>
<td>44.788</td>
<td>Fuel cost, Rs/hr</td>
<td>20898.83</td>
<td>20831.54</td>
<td>20801.81</td>
<td>20838.729</td>
<td>208378.277</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Emission, kg/hr</td>
<td>201.5</td>
<td>201.35</td>
<td>201.21</td>
<td>200.198</td>
<td>200.211</td>
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<tr>
<td></td>
<td></td>
<td>Power loss, MW</td>
<td>7.41</td>
<td>7.69</td>
<td>7.39</td>
<td>7.403120</td>
<td>7.401407</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total cost, Rs/hr</td>
<td>29922</td>
<td>29820</td>
<td>29812</td>
<td>29805.615</td>
<td>29804.905</td>
</tr>
<tr>
<td>500MW</td>
<td>44.788</td>
<td>Fuel cost, Rs/hr</td>
<td>25486.64</td>
<td>25474.56</td>
<td>25491.64</td>
<td>25494.904</td>
<td>254939.128</td>
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<tr>
<td></td>
<td></td>
<td>Emission, kg/hr</td>
<td>312.0</td>
<td>311.89</td>
<td>311.33</td>
<td>311.125</td>
<td>311.133</td>
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<tr>
<td></td>
<td></td>
<td>Power loss, MW</td>
<td>11.88</td>
<td>11.80</td>
<td>11.70</td>
<td>11.679210</td>
<td>11.67600</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total cost, Rs/hr</td>
<td>39458</td>
<td>39441</td>
<td>39433</td>
<td>39429.646</td>
<td>39429.040</td>
</tr>
<tr>
<td>700MW</td>
<td>47.82</td>
<td>Fuel cost, Rs/hr</td>
<td>35485.05</td>
<td>35478.44</td>
<td>35471.4</td>
<td>35462.826</td>
<td>35462.501</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Emission, kg/hr</td>
<td>652.55</td>
<td>652.04</td>
<td>651.60</td>
<td>354.628</td>
<td>651.505</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Power loss, MW</td>
<td>23.37</td>
<td>23.29</td>
<td>23.28</td>
<td>23.334221</td>
<td>23.3300</td>
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<tr>
<td></td>
<td></td>
<td>Total cost, Rs/hr</td>
<td>66690</td>
<td>66659</td>
<td>66631</td>
<td>66617.903</td>
<td>66617.505</td>
</tr>
</tbody>
</table>
Table: 1 shows the summarized result of CEED problem for load demand of 400MW, 500MW and 700MW are obtained by the proposed BAT algorithm with stopping criteria based on maximum-generation=100.

Form Table: 1, it is clear that BAT algorithm gives optimum result in terms of minimum fuel cost, emission level and the total operating cost compared to other algorithms.

Table: 2 gives the best optimum power output of generators for CEED problem using BAT & ABC algorithm for load demand 400MW, 500MW and 700MW.

Table: 2 Optimum Power dispatch Results by ABC, Proposed BAT method for three units system

<table>
<thead>
<tr>
<th>Load demand, MW</th>
<th>Algorithm</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>400MW</td>
<td>ABC</td>
<td>102.5546</td>
<td>152.7996</td>
<td>152.0485</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>BAT</td>
<td>102.5589</td>
<td>153.7197</td>
<td>151.1228</td>
<td>8</td>
</tr>
<tr>
<td>500MW</td>
<td>ABC</td>
<td>128.8494</td>
<td>191.4610</td>
<td>191.3687</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>BAT</td>
<td>128.8501</td>
<td>192.5603</td>
<td>190.2657</td>
<td>18</td>
</tr>
<tr>
<td>700MW</td>
<td>ABC</td>
<td>182.6259</td>
<td>270.3542</td>
<td>270.3541</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>BAT</td>
<td>182.6477</td>
<td>271.2397</td>
<td>269.4426</td>
<td>7</td>
</tr>
</tbody>
</table>

The convergence tendency of proposed BAT algorithm based strategy for power demand of 400MW, 500MW and 700 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 three generating units system for load demand values 400MW, 500MW & 700MW.

Test case II: The system consists of six thermal units. The parameters of all thermal units are adapted from [1]. The summarized result of CEED problem for load demand of 500MW and 900MW are obtained by the proposed BAT algorithm with stopping criteria based on maximum-generation=100 is presented in Table: 3.

Table: 3 comparison of test Results for six generating unit system

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>500MW</td>
<td>Fuel cost, Rs/hr</td>
<td>27638.300</td>
<td>27692.1</td>
<td>27613.4</td>
<td>27612.749</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Emission, kg/hr</td>
<td>262.454</td>
<td>263.472</td>
<td>263.00</td>
<td>263.006</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power loss, MW</td>
<td>8.830</td>
<td>10.172</td>
<td>8.93</td>
<td>8.934145</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total cost, Rs/hr</td>
<td>39159.500</td>
<td>39258.1</td>
<td>39158.9</td>
<td>39158.199</td>
<td></td>
<td></td>
</tr>
<tr>
<td>900MW</td>
<td>Fuel cost, Rs/hr</td>
<td>48892.900</td>
<td>48567.7</td>
<td>48360.9</td>
<td>48350.163</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Emission, kg/hr</td>
<td>701.428</td>
<td>694.169</td>
<td>693.788</td>
<td>693.772</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power loss, MW</td>
<td>35.230</td>
<td>29.725</td>
<td>28.004</td>
<td>28.009673</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total cost, Rs/hr</td>
<td>82436.500</td>
<td>81764.5</td>
<td>81529.1</td>
<td>81527.739</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Form Table: 3, it is clear that BAT algorithm gives the optimum result in terms of minimum fuel cost, emission level and the total operating cost compared to other algorithms.

Table: 4 gives the best optimum power output of generators for CEED problem using BAT & ABC algorithms for load demand 500MW and 900MW.

<table>
<thead>
<tr>
<th>Load demand, MW</th>
<th>Algorithm</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
<th>Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>ABC</td>
<td>33.273</td>
<td>26.8554</td>
<td>89.9135</td>
<td>90.4852</td>
<td>135.6435</td>
<td>132.7631</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>BAT</td>
<td>33.2703</td>
<td>26.85361</td>
<td>89.91347</td>
<td>90.48638</td>
<td>135.6411</td>
<td>132.762</td>
<td>18</td>
</tr>
<tr>
<td>900</td>
<td>ABC</td>
<td>92.3297</td>
<td>98.3912</td>
<td>150.1948</td>
<td>148.5588</td>
<td>220.4043</td>
<td>218.1307</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td>BAT</td>
<td>92.3288</td>
<td>98.3910</td>
<td>150.1132</td>
<td>148.5586</td>
<td>220.4007</td>
<td>218.1267</td>
<td>25</td>
</tr>
</tbody>
</table>

The convergence tendency of proposed BAT algorithm based strategy for power demand of 500MW and 900 MW is plotted in figure:2. It shows that the technique converges in relatively fewer cycles there by possessing good convergence property.

Figure: 2 convergence of six generating unit system for load demand values of 500MW and 900MW.

5 CONCLUSION

In this paper, a new optimization of BAT algorithm has been proposed. In order to prove the effectiveness of algorithm it is applied to CEED problem with three and six generating unit. The results obtained by proposed method were compared to those obtained conventional method, RGA and SGA and Hybrid GA 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.

REFERENCES


*h values are considered based on literature.