COMBINED ECONOMIC AND EMISSION DISPATCH WITH VALVE POINT EFFECT USING MOTH FLAME OPTIMIZATION (MFO) ALGORITHM

Faseela C.K
Research Scholar, MES College of Engineering & Technology, Kunnukara, Kerala

Dr. H. Vennila
Professor, Noorul Islam College of Engineering, Nagercoil, TN

ABSTRACT
Optimum solution for Economic & Emission Dispatch problem along with the valve point effect is procured using Moth Flame Optimization (MFO) algorithm is proposed in this paper. The overall performance of this algorithm collate with early proven optimization methodology, Particle Swarm Optimization (PSO). The minimum cost for the generation of units is obtained for the standard bus system. Fuel cost and emission costs are considered separately and together to get better result. The analysis shows good convergence property for MFO and provides better results in comparison with PSO.

Key word: Particle Swan Optimization (PSO), Moth Flame Optimization (MFO), Economic and Emission Dispatch (EED), optimum, solution, Fuel cost, emission cost, optimization methodology.

Cite this Article: Faseela C.K and Dr. H. Vennila, Combined Economic and Emission Dispatch with Valve Point Effect Using Moth Flame Optimization (MFO) Algorithm, International Journal of Mechanical Engineering and Technology, 8(8), 2017, pp. 26–37.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=8

1. INTRODUCTION
The demand for electricity is increasing in a large factor in today’s life, therefore its highly crucial to run generators at optimum cost. This is the main factors of an Economic dispatch problem. With the unexceptional production of carbon emissions in thermal power plant, its needed to optimize the emission together with the optimization of cost which acts as two vital parts of Economic dispatch problem. The economic dispatch solution provide the best minimum cost of fuel and emission. This indirectly makes lower cost for electricity and makes electrical
utilities more competitive in the market. As the energy cannot be stored, it requires highly efficient estimation scenarios including transmission and distribution systems to make the same work effectively.

Economic dispatch problem is considered to be more complex in old power system. The dynamic dispatch problem and static dispatch problem are the two main types of dispatch problem. Various technologies have been introduced to solve the optimization of Economic Load Dispatch problems. The selection of the particular optimization algorithm is the important part of the problem involving economic dispatch. The EDP is developed based on real-valued codification. In modern methodology only the cost function is evaluated and a global minimum solution is computed, independently of the cost function. The use of digital computers for obtaining loading schedules were investigated and used today.

A lot of optimization algorithms have been used to analyze the economic and environmental dispatch problem. The already available mathematical methods such as dynamic programming [1], linear programming [2], non-linear programming [7], and quadratic programming [15] are used to find the global optimal solution for economic and environmental dispatch problem. The introduction of evolutionary algorithms such as Honey Bee algorithm [8], Genetic Algorithm [9] and Particle Swarm Optimization (PSO) algorithm [11] provides even better global optimal solutions when compared to conventional mathematical methods. The EED problem to be a nonlinear constrained multi objective problem with objectives such as fuel cost, environmental loss and system loss.

A newly nature based optimization technique Moth Flame Optimization (MFO) is developed based on the behavior of moths with respect to the light. The modelling is done based on the paths of the moths with respect to the flame and algorithm is developed based on the same. Yet many researches have been carried out to find the closest optimum result in determining the power generation of each generator using optimization techniques. In this paper, we had studied multiple algorithms to come up with Moth Flame Optimization algorithm for solving Economic dispatch problems.

The paper is designed as follows: section II contains problem formulation included objective function and corresponding system constraints (equality and inequality). The proposed optimization method is explained in section III. This section details the basic Moth Flame Optimization (MFO), and MFO procedure in order to find optimum solution for the dispatch problem.

2. PROBLEM FORMULATION

The minimum cost for operation is obtained by economic allocation of loads between different generating units. Objective function that need to be minimized for the economic dispatch considering the valve point effect is given by

\[
FC_i = a_i + b_i P_i + c_i P_i^2
\]

(1)

Where \( a_i, b_i, c_i \) are the fuel cost coefficients of generator \( i \)

\( P_i \) is the power generated by unit \( i \), MW

\( FC_i \) is the fuel cost function of unit \( i \)

The total fuel cost for the entire system of \( N \) generators can then be calculated as,

\[
FC_T = \sum_{i=1}^{N} FC_i(P_i) = \sum_{i=1}^{N} a_i + b_i P_i + c_i P_i^2
\]

(2)
Combined Economic and Emission Dispatch with Valve Point Effect Using Moth Flame Optimization (MFO) Algorithm

The fuel cost function is modified by adding a sine term to the equation to simulate the ripple effect of valve point loading. Thus the new Fuel Cost function becomes,

\[
FC_T = \sum_{i=1}^{N} a_i + b_i P_i + c_i P_i^2 + d_i \sin\left( e_i \left( P_{i_{\text{min}}} - P_i \right) \right)
\]  

(3)

Where \( a_i, b_i, c_i, d_i \) and \( e_i \) are the fuel cost coefficients of generator \( i \)

\( P_i \) is the power generated by unit \( i \), MW

\( N_i \) is the number of generating units

\( P_{i_{\text{min}}} \) is the minimum generation limit of unit \( i \), MW

\( FC_i \) is the fuel cost function of unit \( i \)

\( FC_T \) is the total fuel cost, $/hr.

In order to minimize the pollutants, economic dispatch is considered. The generator can be modelled as having a quadratic relation between the amount of pollutants released and the power generated. The mathematical formulation for generator \( i \) is given by,

\[
E_i = \alpha_i + \beta_i P_i + \gamma_i P_i^2
\]  

(4)

Where \( \alpha_i, \beta_i, \gamma_i \) are the emission coefficients of generator \( i \)

\( P_i \) is the power generated by unit \( i \), MW

\( E_i \) is the fuel cost function of unit \( i \)

The total emission for the entire system of \( N \) generators can then be calculated as,

\[
E_T = \sum_{i=1}^{N} E_i(P_i) = \sum_{i=1}^{N} \alpha_i + \beta_i P_i + \gamma_i P_i^2
\]  

(5)

The emission function is modified by adding an exponential term to the equation to simulate the ripple effect of valve point loading. Thus the new Emission function becomes,

\[
E_T = \sum_{i=1}^{N} \alpha_i + \beta_i P_i + \gamma_i P_i^2 + \epsilon_i \exp(\zeta_i P_i)
\]  

(6)

Where \( \alpha_i, \beta_i, \gamma_i, \epsilon_i \) and \( \zeta_i \) are the emission coefficients of generator \( i \)

\( P_i \) is the power generated by unit \( i \), MW

\( N_i \) is the number of generating units

\( E_i \) is the emission function of unit \( i \),

\( E_T \) is the total emission, ton/hr.

**POWER BALANCE CONSTRAINT**

The power balance equation[2] is given by

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

(7)

Adding loss factor to the equation.

\[
\sum_{i=1}^{N} P_i = P_D - P_L
\]  

(8)

Power loss \( PL \) is calculated as

\[
P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{ii} P_i + B_{00}
\]  

(9)

The actual power generation for the generator will be between its maximum and minimum limits which is represented as
3. MOTH FLAME OPTIMIZATION ALGORITHM

Now Bio inspired algorithms are commonly used considering its effectiveness in solving the problems when all the constraints are met. Moth Flame optimization algorithm makes use of behavior of moths with respect to light.

INSPIRATION

Figure 1 Moths and Moth flying towards artificial light

Moth flame optimization is a new, meta-heuristic, nature inspired algorithm introduced in 2015. Moth flame optimization is based on the peculiar navigational habit of a moth called Transverse Orientation. In transverse orientation, navigation in a straight line is accomplished by using a faraway light source, such as the moon in the night sky, as a reference. The moth corrects its angle of approach so that it remains constant to fly in a straight line.

Figure 2 Moth follows perfect transverse path for far away light (Moon) and being fooled by artificial light (Candle) which is near

However, when the faraway light source is replaced with a nearby light source, such as an open fire or a light bulb, the constant approach angle change leads to a spiral path. This spiral is in the form a logarithmic spiral, a shape very commonly found in nature. Essentially the moth ends up spiraling into the light source following the path traced by the logarithmic spiral.
OPERATORS OF MFO ALGORITHM

In MFO algorithm, it is assumed that the candidate solutions are moths and variables are the position of moths in the space. This makes the possibility of to fly in 1-D, 2-D, 3-D, or hyper dimensional space with changing their position vectors. This makes the MFO algorithm is a population-based algorithm. Here the moths and flames are both treated as solutions. The difference between them is the way we treat and update them in each iteration. The moths are actual search agents that move around the search space, whereas flames are the best position of moths that obtains so far. In other words, flames can be considered as flags or pins that are dropped by moths when searching the search space. Therefore, each moth searches around a flag (flame) and updates it in case of finding a better solution. With this mechanism, a moth never lose its best solution.

A logarithmic spiral is chosen as the main update mechanism of moths in this algorithm. However, any types of spiral can be utilized here subject to the following conditions:

- Spiral’s initial point should start from the moth
- Spiral’s final point should be the position of the flame
- Fluctuation of the range of spiral should not exceed from the search space

Figure 4 conceptual model of position updating of a moth around a flame
Moth flame optimization aims to mimic this behavior using a program. The moth here is the solution to the program currently available whereas the flame is the final optimal solution. So the current solution evolves through many iterations along a spiral to reach the final destination. As logarithmic spirals are a whole family of curves, it is possible to alter the equation used in the algorithm by changing the proportions of the spiral. This can yield better results in some cases and is an area where further studies could be conducted in the future.

Moth Flame Optimization algorithm is population based, so the first step in implementing it is to consider the various arrays in which values are stored,

1. Consider a population of moths represented in Matrix form as:

\[ M = \begin{bmatrix} M_{11} & \cdots & M_{1d} \\ \vdots & \ddots & \vdots \\ M_{n1} & \cdots & M_{nd} \end{bmatrix} \]

Where \( n \) is the number of moths
\( d \) is the number of variables or dimensions comprising each moth

2. The fitness values of each moth are stored in a column matrix as:

\[ FM = \begin{bmatrix} FM_1 \\ FM_2 \\ \vdots \\ FM_n \end{bmatrix} \]

Where \( FM_i \) is the fitness of moth \( M_i \)

3. The flames can be represented by the Flame Matrix:

\[ Fl = \begin{bmatrix} Fl_{11} & \cdots & Fl_{1d} \\ \vdots & \ddots & \vdots \\ Fl_{n1} & \cdots & Fl_{nd} \end{bmatrix} \]

4. The fitness values of flames are stored in the Flame fitness matrix:

\[ FF = \begin{bmatrix} FF_1 \\ FF_2 \\ \vdots \\ FF_n \end{bmatrix} \]

Where \( FF_j \) is the fitness of flame \( Fl_j \)

5. Both Flames and Moths are solutions of the given problem, but the manner in which they are updated each iterations is different.

6. Flames are basically the best positions of moths found so far.

**MFO ALGORITHM OVERVIEW**

The general algorithm of Moth Flame Optimization is,

1. Input the system parameters, and specify the lower and upper boundaries of each variable.
2. Initialize a population of \( n \) moths randomly in the search space.
3. Update the number of flames \( N \) as

\[ \text{no. of Flames} = \text{round} \left( N - \left( l \times \frac{(N-1)}{T} \right) \right) \]
Combined Economic and Emission Dispatch with Valve Point Effect Using Moth Flame Optimization (MFO) Algorithm

Where $l$ is the present iteration count
$N$ is the maximum no. of flames
$T$ is the maximum no. of iterations considered.

4. Compute the fitness value for each moth.
5. Sort the moths from best to worst as per their fitness and place the result in the flame list.
6. Calculate the convergence constant $r$, a number linearly decreased from $-1$ to $-2$ as

$$r = -1 - \left(\frac{1}{T}\right)$$

7. Compute $t$ as a random number between $r$ and 1
8. Update Moth $i$ position as indicated by Flame $j$ as

$$S(M_i, F_i) = |F_i - M_i| \cdot e^{bt} \cdot \cos(2\pi t) + F_i$$

Where $b$ is a constant which determines the convergence rate and shape of the spiral followed by the moth.

9. Compute fitness of each moth.
10. If any moth is fitter than any flame, the fitter moth is considered as a new flame.
11. If stopping criterion is met or $T$ iterations are complete, the first moth is the required optimum solution.

**MFO ALGORITHM – PSEUDO CODE**

Update flame no using the Equation discussed above

OM=FitnessFunction(M)
if iteration==1
  F=sort(M);
  OF=sort(OM);
else
  F=sort(Mt-1, Mt);
  OF=sort(Mt-1, Mt);
end
for i = 1 : n
  for j= 1 : d
    Update r and t
    Calculate D with respect to the corresponding flame
    Update M(i,j) with respect to the corresponding flame
  end
end
4. MFO FOR EED CASE

Merit order dispatch case is implemented using MFO algorithm. The Economic dispatch case implementation is done on standard IEEE 30 bus system. As it’s a standard test system, various parameters had already been recorded. This system was used in many comparable studies in the merit order dispatch. The implementation is done separately for Economic dispatch, Emission dispatch and combined dispatch.

IEEE-30 BUS SYSTEM – SAMPLE VALUES

This system has 6 generator buses at bus 1, 2, 5, 8, 11 and 13. Each of these generators has their own fuel and emission coefficients. These are represented in per unit values to simplify calculations. The base considered is 100 MVA. The total demand considered is 2.38 p.u. The various generation parameters are tabulated as follows,

Generator cost coefficients for IEEE 30 bus system is provided in Table 1 given below.

<table>
<thead>
<tr>
<th>Unit</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>e</th>
<th>f</th>
<th>$P_{l\min}$</th>
<th>$P_{l\max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>200</td>
<td>100</td>
<td>15</td>
<td>6.283</td>
<td>0.05</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>150</td>
<td>120</td>
<td>10</td>
<td>8.976</td>
<td>0.05</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>180</td>
<td>40</td>
<td>10</td>
<td>14.784</td>
<td>0.05</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>100</td>
<td>60</td>
<td>5</td>
<td>20.944</td>
<td>0.05</td>
<td>1.2</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>180</td>
<td>40</td>
<td>5</td>
<td>25.133</td>
<td>0.05</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>150</td>
<td>100</td>
<td>5</td>
<td>18.48</td>
<td>0.05</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Generator emission coefficients for IEEE-30-bus system is provided in Table-2 given below.

<table>
<thead>
<tr>
<th>Unit</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\gamma$</th>
<th>$\varepsilon$</th>
<th>$\zeta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.091</td>
<td>-5.554</td>
<td>6.49</td>
<td>2.00E-03</td>
<td>2.857</td>
</tr>
<tr>
<td>2</td>
<td>2.543</td>
<td>-6.047</td>
<td>5.638</td>
<td>5.00E-04</td>
<td>3.333</td>
</tr>
<tr>
<td>3</td>
<td>4.258</td>
<td>-5.094</td>
<td>4.586</td>
<td>1.00E-06</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>5.326</td>
<td>-3.35</td>
<td>3.38</td>
<td>2.00E-03</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>4.258</td>
<td>-5.094</td>
<td>4.586</td>
<td>1.00E-06</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>6.131</td>
<td>-5.555</td>
<td>5.151</td>
<td>1.00E-05</td>
<td>6.667</td>
</tr>
</tbody>
</table>

IEEE-30 BUS SYSTEM - RESULTS

IEEE-30 bus system simulation and implementation of Economic dispatch using MFO is done. MFO algorithm is implemented to find the optimal power generation schemes for standard IEEE 30-Bus test system. Different objective functions are considered for the same system. The program is implemented using C++ and applied on a 2.50 GHz i5 PC having 4 GB RAM. The moth population size is selected to be 10. The maximum number of iterations is set to be 200.

The convergence rate factor ($b$) is chosen as 1. These values are chosen by trial and error for minimum computation time, maximum search capability and to provide a smooth yet quick approach to the optimal solution. The values may be changed in future modifications to the project in case better results can be obtained. The process of determining the best set of values of these variables is an optimization problem and may be considered in future studies.
The program is implemented under 3 different cases. Each case representing a different form of power dispatch. Depending on the nature of power dispatch, the problem may be a single objective problem or a multi objective problem. All programs were made to run on the same machine and under similar circumstances.

**ECONOMIC DISPATCH**

In this case the objective is to minimize the fuel cost alone. Here the emission is not taken into consideration. This is a single objective case. The fuel cost at the minimum Fuel cost is considered in the calculations of total cost but the emission costs are not optimized. The expected result is minimum Fuel Cost of all the 3 cases. The obtained results are also compared with comparable studies. The results are tabulated below as,

<table>
<thead>
<tr>
<th></th>
<th>PSO[20]</th>
<th>MFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>0.099441</td>
<td>0.0595447</td>
</tr>
<tr>
<td>$P_2$</td>
<td>0.36248</td>
<td>0.382615</td>
</tr>
<tr>
<td>$P_3$</td>
<td>0.48349</td>
<td>0.69033</td>
</tr>
<tr>
<td>$P_4$</td>
<td>0.87359</td>
<td>1.00743</td>
</tr>
<tr>
<td>$P_5$</td>
<td>0.66428</td>
<td>0.316906</td>
</tr>
<tr>
<td>$P_6$</td>
<td>0.39004</td>
<td>0.37721</td>
</tr>
<tr>
<td>Total Fuel Cost (optimized) ($FC_T$) INR/hr</td>
<td>40752.1855</td>
<td><strong>39963.443</strong></td>
</tr>
<tr>
<td>Total Emission (Non-Optimized) ($E_T$) ton/hr</td>
<td>0.213921</td>
<td>0.225590</td>
</tr>
<tr>
<td>Total Emission Cost (Non Optimized) ($EC_T$) INR/hr</td>
<td>661.0175</td>
<td>697.073</td>
</tr>
<tr>
<td>Total Cost (Non Optimized) ($TC$) $/hr</td>
<td>41413.203</td>
<td>40660.516</td>
</tr>
</tbody>
</table>

**ENVIRONMENTAL DISPATCH**

In this case the objective is to minimize the emission alone. Here the fuel cost is not taken into consideration. This is a single objective case. The fuel cost at the minimum Emission cost is considered in the calculations of total cost but the fuel costs are not optimized. The expected result is minimum Emission of all the 3 cases. The obtained results are also compared with comparable studies.
Table 4  Environmental Dispatch - Only Emission costs are optimized

<table>
<thead>
<tr>
<th></th>
<th>PSO[20]</th>
<th>MFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>0.37883</td>
<td>0.404918</td>
</tr>
<tr>
<td>$P_2$</td>
<td>0.39323</td>
<td>0.456312</td>
</tr>
<tr>
<td>$P_3$</td>
<td>0.49948</td>
<td>0.554525</td>
</tr>
<tr>
<td>$P_4$</td>
<td>0.53439</td>
<td>0.411288</td>
</tr>
<tr>
<td>$P_5$</td>
<td>0.57341</td>
<td>0.55098</td>
</tr>
<tr>
<td>$P_6$</td>
<td>0.48651</td>
<td>0.505074</td>
</tr>
<tr>
<td>Total Fuel Cost (Non optimized) ($FC_T$) INR/hr</td>
<td>42863.236</td>
<td>44322.98</td>
</tr>
<tr>
<td>Total Emission (Optimized) ($E_T$) ton/hr</td>
<td>0.195675</td>
<td>0.194211</td>
</tr>
<tr>
<td>Total Emission Cost (Optimized) ($EC_T$) $/hr</td>
<td>604.6365</td>
<td>600.1125</td>
</tr>
<tr>
<td>Total Cost (Non Optimized) ($TC$) $/hr</td>
<td>43467.8725</td>
<td>44923.0925</td>
</tr>
</tbody>
</table>

COMBINED DISPATCH

In this case the objective is to minimize the total cost by minimizing both Fuel cost as well as Emission cost. This is a multi-objective case. The expected result is moderate Fuel cost and Emission Cost but minimum Total Cost of all the 3 cases. The obtained results are also compared with comparable studies. The results are tabulated below as:

<table>
<thead>
<tr>
<th></th>
<th>PSO[20]</th>
<th>MFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>0.14089</td>
<td>0.0777825</td>
</tr>
<tr>
<td>$P_2$</td>
<td>0.34415</td>
<td>0.383773</td>
</tr>
<tr>
<td>$P_3$</td>
<td>0.67558</td>
<td>0.480221</td>
</tr>
<tr>
<td>$P_4$</td>
<td>0.83971</td>
<td>0.822399</td>
</tr>
<tr>
<td>$P_5$</td>
<td>0.49043</td>
<td>0.660642</td>
</tr>
<tr>
<td>$P_6$</td>
<td>0.39797</td>
<td>0.409287</td>
</tr>
<tr>
<td>Total Fuel Cost (Non optimized) ($FC_T$) INR/hr</td>
<td>41577.2955</td>
<td>39975.104</td>
</tr>
<tr>
<td>Total Emission (Optimized) ($E_T$) ton/hr</td>
<td>0.211052</td>
<td>0.212077</td>
</tr>
<tr>
<td>Total Emission Cost (Optimized) ($EC_T$) $/hr</td>
<td>652.1515</td>
<td>655.317</td>
</tr>
<tr>
<td>Total Cost (Non Optimized) ($TC$) INR/hr</td>
<td>42229.447</td>
<td>40630.4275</td>
</tr>
</tbody>
</table>
REFERENCES


