A Hybrid (FF-DE) Approach to Solve Economic Load Dispatch

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In this paper an attempt has been made to determine Economic Load Dispatch (ELD) using Hybrid (FF-DE) and FF techniques. The methods for ELD evaluation are developed considering fuel cost of the system. Economic Load Dispatches are calculated using FF-DE technique without violating the reactive power constraints of the system. Most of the studies related to ELD use traditional methods based on quadratic programming. In this paper, a new approach is proposed that first determine the power losses in the system for IEEE 30 & IEEE 9 bus systems and then calculate the minimized fuel cost of the system. The effectiveness of the proposed method is successfully demonstrated on IEEE 30 bus system & IEEE 9 bus systems.

Keywords: Economic Load Dispatch (ELD), Firefly Algorithm (FF), Differential Evolution (DE), Hybrid Method.

Index Terms— Economic Load Dispatch (ELD), Firefly Algorithm (FF), Differential Evolution (DE), Hybrid Method.

1. INTRODUCTION

Economic dispatch is a method of determining the most efficient, low cost and reliable operation of power system by dispatching the generation resources to supply the load on the system. The primary objective of the economic dispatch is to minimize the fuel cost of the generating unit to meet the system load [1]. The optimization method used, tools and software contribute to both security and economic issue in support of power system operation and control. There are various techniques available for economic load dispatch problem like Lambda iterations, Gradient based method, Newton’s method and these methods use quadratic equations to solve ELD. In the traditional ED (Economic Dispatch) problem the cost function is represented by the single quadratic equation and solved by using Lambda iteration & Gradient based methods. These methods require incremental cost curves to be monotonically increasing linear in nature. But in the modern generating units the input-output characteristics are non-linear in nature. For generators with non-monotonically incremental cost curves, a conventional method ignores or flattens out portions of incremental cost curve that are not continuously increasing. Newton-based methods are not capable of obtaining quality solutions for ELD problems due to highly non-linear characteristics and large number of constraints. This makes the optimization problem challenging. Therefore more interest has been focused on the Artificial Intelligence (AI) technique for solution of economic dispatch problems. Various methods such as Genetic Algorithm (GA), Artificial Neural Networks (ANN), Evolutionary Programming, Particle Swarm Optimization (PSO), Ant Colony Optimization, Differential Evolution, and Dynamic Programming have been developed. These methods are applied successfully to the small and large systems to solve (Economic Load Dispatch) ELD problems to find better results [3-7].

In this paper to solve the Economic Load Dispatch (ELD) problem and to improve results a practical combination strategy of FF-DE is used. In this paper it is explained how Firefly and differential algorithm works in a combined manner to solve the optimization problem. For the validation and efficiency of this algorithm, an IEEE 30 bus test...
system is used with six generators as an example. The results obtained are compared with the results of Firefly algorithm only. A brief description and mathematical formulation of ELD problem has been discussed in the following section. The algorithm applied in this paper is Capable of obtaining optimal solutions efficiently. A brief description and formulation of Firefly-DE method has been discussed in the following section.

2. Problem Formulation
2.1. Economic Dispatch
The objective of economic load dispatch (ELD) problem is to reduce the fuel cost by minimizing the total cost of the generation to meet the load demand of power system while satisfying all units and operational constraints of the power system.

The economic load dispatch problem is a constrained optimized problem and can be expressed mathematically as follow:

Minimize $F_T = \sum_{n=1}^{N} F_n (P_n)$

Where $F_T = a_n P_n^2 + b_n P_n + c_n$ (2)

Where,
- $F_T$, is the total cost of production in Rs./hr.
- $F_n$, is the fuel cost of each unit in Rs./hr.
- $a_n, b_n, c_n$, are the cost coefficients.
- $P_n$, is the real power output of the unit in MW.

N represents the number of generating units.

2.2. Active Power Balance of the System
For the power balance of the system the equality constraints must be satisfied. The total power generated in the system should be the same as the total load demand plus total line losses as described by the Eqn. 3 given below as;

$P_D + P_L - \sum_{i=1}^{N} P_i = 0$ (3)

Where $P_D$: Total system demand (MW)
Where $P_L$: Transmission loss of the system (MW)

2.3. Generation Limits of the System
Generation limit of each generator should be laid between maximum and minimum limits.
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The inequality constraints for each generator are defined as below:

\[ P_{n\text{min}} \leq P_n \leq P_{n\text{max}} \]

Where \( P_{n\text{min}} \): Minimum power output limit of the \( n^{th} \) generator (MW).
Where \( P_{n\text{max}} \): Maximum power output limit of the \( n^{th} \) generator (MW).

The generator cost function \( F_n(P_n) \) is usually expressed as a quadratic polynomial as;

\[ F_n(P_n) = a_n P_n^2 + b_n P_n + c_n \] (4)

Where, \( a_n \), \( b_n \) and \( c_n \) are the fuel cost Coefficients.

2.4. Network Losses of the System

Since the power stations are usually spread all over the world, the transmission network losses should be taken into account to calculate true economic load dispatch. Network losses are calculated by unit generation. For calculation of network losses, there are two methods which are mainly used. One is the Penalty factors method and other is the Loss coefficients methods. The other methods are mainly used by the power utility industry. In the second method which is Loss coefficients method, network losses are calculated as a quadratic function which is given below as;

\[ P_L = \sum_m \sum_n P_m B_{mn} P_n \] (5)

Where \( B_{mn} \): Known as loss coefficients.

3. The Firefly Algorithm

Firefly algorithm is a nature inspired optimization algorithm based on the behavior of the fireflies. Firefly algorithm has many similarities with other algorithms which are based on the Particle Swarm Optimization (PSO) technique. These methods are similar in concept but the main difference is that the firefly algorithm picks the real random numbers and is based on the social swarm behavior of the fireflies.

Mainly three rules based on the real fireflies’ behavior used in firefly algorithm are as follows;
ii) The degree of attractiveness is directly proportional to the brightness of a firefly which decreases with the increase in the distance from other fireflies.

iii) The brightness or light intensity of a firefly is calculated by the objective function of the given problem. For maximization problems, the light intensity is proportional to the value of the objective function.

4. Differential Evolution

The differential evolution algorithm, proposed by Storn and Price, is a simple yet powerful population-based stochastic search technique, which is an efficient and effective global optimizer in the continuous search domain. DE has been successfully applied in diverse fields such as mechanical engineering, communication, and pattern recognition. In DE, there exist many trials vector generation strategies out of which a few may be suitable for solving a particular problem.

Moreover, three crucial control parameters involved in DE, i.e., population size, scaling factor, and crossover rate, may significantly influence the optimization performance of the DE. Therefore, to successfully solve a specific optimization problem at hand, it is generally required to perform a time-consuming trial-and-error search for the most appropriate strategy and to tune its associated parameter values. However, such a trial-and-error searching process requires high computational costs.

Moreover, as evolution proceeds, the population of DE may move through different regions in the search space, within which certain strategies associated with specific parameter settings may be more effective than others. Therefore, it is desirable to adaptively determine an appropriate strategy and associated parameter values at different stages of evolution/search process.

- Initialize all agents x with random positions in the search-space.
- Until a termination criterion is met (e.g. number of iterations performed, or adequate fitness reached), repeat the following:
  - For each agent x in the population P
  - Pick three agents a, b and c from the population at random, they must be distinct from each other as well as from agent x.
  - Pick a random index $R \in \{1, \ldots, n\}$ (n being the dimensionality of the problem to be optimized).
  - Compute the agent's potentially new position $Y = [y_1, \ldots, y_n]$ as follows:
    - For each i, pick a uniformly distributed number $I_i = U(0,1)$
    - If $r_i < CR$ or $I = R$ then set $y_i = a_i + F \ast (b_i - c_i)$ otherwise set $y_i = x_i$
  - If $f(y) < f(x)$ then replace the agent in the population with the improved candidate solution, that is, replace $x$ with $y$ in the population.
  - Pick the agent from the population that has the highest fitness or lowest cost and return it as the best found candidate solution.

5. The Proposed Method

To minimize the total complex fuel cost, Firefly-DE method is used. In this paper the fuel cost is minimized for IEEE 30 bus system. The IEEE 30 bus system is used which has 6 generating units. Because of their complexity firefly optimization and firefly DE optimization methods are used. Both are meta-heuristic optimization techniques. A comparison has been done in between both techniques and results are found out for better optimization method. Initially the firefly optimization technique is used to minimize the fuel cost and the power settled for each generating unit for minimized fuel cost is transferred to differential evolution (DE) algorithm for further minimization. Fig. 2 shows the flow chart for the proposed method. Different steps for algorithm are described in section 5.1 given below.
5.1 Algorithm

Step 1: Read the system data such as cost coefficients, minimum and maximum power limits of all generator units, power demand and B-coefficients.

Step 2: Initialize the parameters and constants of Firefly Algorithm. They are \( n_{\text{off}} \), \( \alpha_{\text{max}} \), \( \alpha_{\text{min}} \), \( \beta_{0} \), \( \gamma_{\text{min}} \), \( \gamma_{\text{max}} \) and \( \text{iter}_{\text{max}} \) (maximum number of iterations).

Step 3: Generate \( n_{\text{off}} \) number of fireflies \( (x_{i}) \) randomly between \( \lambda_{\text{min}} \) and \( \lambda_{\text{max}} \).

Step 4: Set iteration count to 1.

Step 5: Calculate the fitness values corresponding to \( n_{\text{off}} \) number of fireflies.

Step 6: Obtain the best fitness value \( (E_{\text{best FV}}) \) by comparing all the fitness values and also obtain the best firefly values \( E_{\text{best FF}} \) corresponding to the best fitness value \( E_{\text{best FV}} \) (current iteration number)/itermax)

Step 7: Determine alpha \( (\alpha) \) value of current iteration using the following equation:

\[
\alpha = \alpha_{\text{max}} - (\alpha_{\text{max}} - \alpha_{\text{min}}) \times \frac{(\text{current iteration number})}{\text{iter}_{\text{max}}}
\]

Step 8: Determine the distance of each firefly by the following equation:

\[
R_{ij} = E_{\text{best FV}} - FV
\]

\( R_{ij} \) is obtained by finding the difference between the best fitness value \( E_{\text{best FV}} \) (\( j \)th firefly) and fitness value \( FV \) of the \( i \)th firefly.

Step 9: New \( x_{i} \) values are calculated for all the fireflies using the following equation:

\[
X_{ij}(\text{new}) = X_{ij}(\text{old}) + \beta_{0} \times \exp(-\gamma R_{ij}^{2}) \times (X_{i} - X_{j}) + \alpha(\text{iter}) \times (\text{rand} - \frac{1}{2})
\]

Step 10: Read data, Cost Coefficients, \( a_{i}, b_{i}, c_{i} \) (i=1, 2... N\text{G}), convergence tolerance error, scaling factor, maximum allowed iterations, \( \text{IT}_{\text{MAX}} \), population size, L, and \( P_{\text{Gmin}} \) and \( P_{\text{Gmin}} \) (i=1, 2... N\text{G}),

Generate an array of uniform random numbers

Set population counter, \( i=0 \), generation counter \( j=0 \)

IF \( (j \neq d) \)

THEN generate the position of particle \( P_{ij} \).

Step 11: Compute \( P_{id} \) using check limits and adjust. Then compute penalty factor, \( \varphi_{j} \) and \( f_{i} \).

Set population counter, \( i=1 \),

\[
f_{i}^{\text{best}} = f_{i} \quad \text{IF} \quad (f_{i}^{\text{best}} < f_{i}^{j})
\]

THEN \( f_{i}^{\text{best}} = f_{i}^{j} \)

WHILE ( \( i < \text{L} \)).

Set iteration counter \( \text{IT}=0 \), population counter \( i=0 \), generation counter \( j=0 \).

Step 12: Generate an array of uniform random numbers and generate three different integer random numbers and generate three different integer random numbers within the range 1 to L.

IF (\( j \neq d \)) THEN compute \( Z_{ij} \).

Step 13: Compute \( P_{id} \) using check limits and adjust. Then compute penalty factor, \( \varphi_{j} \) and \( f_{i} \).

Step 14: Set Population counter, \( i=0 \) and a counter \( k=0 \), generation counter, \( j=0 \)

Generate an array \( R_{ij} \) of random numbers, R and of size L Increment population counter,

\( i = i+1 \) & increment the generation counter \( j+1 \)

IF (\( j \neq d \))

Then increment Counter, \( k=k+1 \), Generate a random integer \( R_{5} \) (i) within the range from 1 to L.

Step 15: IF ((\( R_{4} (k) \leq \text{CR} \)) or ( \( j = R_{5} (i) \))) then \( U_{ij}(t+1) = Z_{ij}(t+1) \)

IF ((\( R_{4} (k) > \text{CR} \)) or ( \( j \neq R_{5} (i) \))) then \( U_{ij}(t+1) = P_{ij}(t+1) \).

Step 16: Compute \( U_{id}(t+1) \) check limits and adjust.
Then compute penalty factor, \( p_1 \) and \( f_t \)
While (j < N_G)
While (I < L).

**Step 17:** Set population counter, \( i = 0 \), then increment population counter, \( i = i + 1 \).
IF \( f_i(U_{ij}(t+1)) < f_i(P_{ij}(t)) \)
THEN \( P_{ij}(t+1) = U_{ij}(t+1), (j = 1, 2, 3 \ldots N_G) \)
ELSE \( P_{ij}(t+1) = P_{ij}(t), (j = 1, 2, 3 \ldots N_G) \)
While (I < L) Set population counter, \( i = 1 \), increment population counter, \( i = i + 1 \)
IF \( f_i^{\text{best}} < f_i \)
Then set \( f_i^{\text{best}} = f_i \)
While (I < L)
IF abs \( f_i^{\text{best}} - f_i \) \( \leq \) err
IF \( f_i^{\text{min}} \leq f_i^{\text{best}} \) THEN \( f_i^{\text{best}} = f_i^{\text{min}} \)
While (t < t_{max})
STOP.

5.2 Flow Chart of the Proposed Method

The flow chart of the proposed method shown in Fig. 2 shows the process of the proposed method. In the flow chart of the proposed method in each step it is described that how the process of FF-DE proceeds.

![Flow Chart of the Proposed Method](image-url)
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6. Result & Discussion

The results are shown for Firefly-DE optimization for IEEE 30 bus system and these results are compared with the Firefly optimization technique. Fig. 3 shows the Fuel cost with respect to number of iterations in case of Firefly-DE optimization. It shows that the fuel cost is decreasing as the numbers of iterations are increasing. Fig. 4 shows the fuel cost in case of Firefly optimization. Fig. 5 shows the comparison of generated power for Firefly and Firefly-DE. The Fig. 6 shows the comparison of the fuel cost for Firefly and Firefly De optimization. It is clear that the fuel cost is reduced in case of Firefly-De optimization as compared to Firefly optimization. It is because power losses in case of FF-DE are less as compared to only FF. The result shown in tables 1 to 3 shows the generated power and the fuel cost and power losses for both the optimization techniques. The results discussed so far shows that the Hybrid method (i.e. FF-DE) is better than the Firefly optimization technique.

![Fig. 3: Fitness function for Firefly-De Optimization](image)

Table 1: Power set for each generating unit for 700MW demand in case of Firefly-DE Technique

<table>
<thead>
<tr>
<th>No. of generators</th>
<th>Power Set (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gen1</td>
<td>58.261410</td>
</tr>
<tr>
<td>Gen 2</td>
<td>55.129587</td>
</tr>
<tr>
<td>Gen 3</td>
<td>156.793180</td>
</tr>
<tr>
<td>Gen 4</td>
<td>114.744304</td>
</tr>
<tr>
<td>Gen 5</td>
<td>131.000000</td>
</tr>
<tr>
<td>Gen 6</td>
<td>188.920547</td>
</tr>
<tr>
<td>Total Power Loss</td>
<td>16.280</td>
</tr>
</tbody>
</table>
Table 2: Power set for each generating unit of 700 MW demand in case of Firefly Technique

<table>
<thead>
<tr>
<th>No. of Generators</th>
<th>Power Set (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gen1</td>
<td>125.000000</td>
</tr>
<tr>
<td>Gen 2</td>
<td>58.000000</td>
</tr>
<tr>
<td>Gen 3</td>
<td>87.427681</td>
</tr>
<tr>
<td>Gen 4</td>
<td>83.000000</td>
</tr>
<tr>
<td>Gen 5</td>
<td>178.000000</td>
</tr>
<tr>
<td>Gen 6</td>
<td>173.000000</td>
</tr>
<tr>
<td><strong>Total Power Loss</strong></td>
<td><strong>16.3232</strong></td>
</tr>
<tr>
<td><strong>Total Power generated</strong></td>
<td><strong>704.42</strong></td>
</tr>
</tbody>
</table>

Table 2 shows the power of each generator in case of Firefly-DE optimization along with fuel cost.
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![Comparison Graph between Firefly and Firefly-DE.](image)

**Fig. 5: Comparison Graph between Firefly and Firefly-DE.**

<table>
<thead>
<tr>
<th>Table 3: Comparison table of both optimizations for fuel cost and total power generated for power demand of 700MW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optimization</strong></td>
</tr>
<tr>
<td>Fuel Cost ($/MWh)</td>
</tr>
<tr>
<td>Total power generated (MW)</td>
</tr>
</tbody>
</table>

Figs. 6 & 7 show the comparison between fuel cost and total generated power with respect to power demanded for both the optimization techniques. It shows that the fuel cost is minimized in case of Firefly-DE optimization as comparison to Firefly optimization as there are less losses in the Firefly-DE optimization. Hence the hybrid method (FF-DE) is proved to be better than Firefly optimization alone.

![Fuel Cost Comparison for Different Powers](image)

**Fig. 6: Fuel Cost Comparison for Different Powers**
6. Conclusions

A method of calculating ELD by incorporating reactive power constraints is proposed in this paper. From the inspection of table 1 of this paper it is evident that the power losses in the system in case of FF-DE are less. Therefore, it is concluded that FF-DE technique can offer an effective and promising solution to reduce the fuel cost of the system. Furthermore, the results are also obtained for IEEE 30 bus system and IEEE 9 bus system. This work shows that fuel cost is reduced comparatively more in case of Firefly-DE as compared to Firefly alone.

References

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7. Author’s Profile

Shivani Jindal obtained B. Tech. in Electrical and Electronics Engineering from J.C.D Engineering College, Sirsa-Haryana, India in 2011. Presently she is pursuing her M. Tech. at Deenbandhu Chhotu Ram University of Science & Technology, Murthal (Haryana), India. Her research interests include Electrical Power System Deregulation, etc.

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Control etc. Mr. Yadav is a life time member of Indian Society for Technical Education. He has participated in and presented papers at many National and International Conferences. He has published almost twenty research papers in International Journals.