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ORIGINAL CONTRIBUTION

# Economic Load Dispatch Using PSO and Firefly Algorithm

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**ABSTRACT**

Economic dispatch is the process to find the generation of different units in a power plant so that the cost of fuel is minimum and the equality and inequality constraints are satisfied. In this paper the effectiveness of the Firefly algorithm in finding out the economic generation of different units has been tested and compared to another evolutionary algorithm i.e. PSO and the conventional lambda iteration method to find out the optimal load dispatch. The MATLAB programs were developed for each of the abovementioned methods and the results obtained were compared to find out the superiority of the Firefly Algorithm.

**KEYWORDS**— Firefly Algorithm, Particle Swarm Optimization, Economic Load Dispatch, Unit Commitment, Optimal Power Flow

## 1. INTRODUCTION

Power plants in a practical power system are located at different distances from the load centers. Depending upon the location of power plants the generation costs are different for different plants. Under normal operating conditions the load can be shared in the available power plants in many different combinations. Thus there are many options by which the load scheduling can be done. With the ever increasing vastness of the power system, numerous interconnections and increasing prices it is very necessary to develop methods which can give a fast and affordable solution to load scheduling while at the same time maintaining the system security and stability. The primary objective in such a process is the reduction of the generation cost. To meet the demand of economic load dispatch the real and reactive power generations of the units involved in supplying a particular load demand, are allowed to vary within certain limits to supply a particular load at minimum cost. This is broadly classified as optimal power flow (OPF). Economic Load Dispatch (ELD) is a part of OPF. This is achieved by the minimization of a few objective functions. The objective functions can be fuel cost, transmission loss, emission levels, system security or a combination of the above. For e.g. effective reactive power planning can help in the enhancement of system security.

Apart from the conventional lambda iteration method the solution to the problem of economic load dispatch has been obtained by several metaheuristic methods such as genetic algorithm [1-3] and PSO [5-11]. In this work we have presented the solution of the ELD problem by another new evolutionary algorithm called the Firefly Algorithm [12-16] and compared its efficiency to that of PSO and lambda iteration method.

## 2. ECONOMIC LOAD DISPATCH PROBLEM FORMULATION

The primary objective of the economic load dispatch problem is to find out the optimum generation schedule for multiple units so that the load demand can be supplied while satisfying all units and operational constraints of the power network is satisfied. The objective function of the ELD problem can be expressed mathematically as follows:

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$$F_T = \sum_{n=1}^{N} a_n P_n^{\ 2} + b_n P_n + c_n \qquad (4.1)$$

where:
$P_n$ is the real power generation of the nth unit in MW
$a_n$, $b_n$, $c_n$ are fuel cost coefficients.
The primary target of the solution is to minimize this objective function based on the following constraints:
For power balance, the following equality constraint must hold true. The summation of the total power demand and losses should be equal to the power generated.

$$P_D + P_L - \sum_{n=1}^{N} P_n = 0 \qquad (4.2)$$

where $P_D$= Total system demand (MW)
$P_L$=Transmission loss of the system (MW)

The output of each generator should be within the specified limits:

$$P_{n\min} \le P_n \le P_{n\max} \qquad (4.3)$$

As the power plants are spread out over a large distance, the transmission line losses should also be taken into account while calculating optimal generation. Here we have used the B coefficients method to calculate the losses. The network losses are essentially the function of the units generated.

$$P_L = \sum_m \sum_n P_m B_{mn} P_n \qquad (4.4)$$

## 3. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization was first introduced by Kennedy and Eberhart in the year 1995. It is an exciting new methodology in evolutionary computation and a population-based optimization tool like GA. PSO is motivated from the simulation of the behavior of social systems such as fish schooling and birds flocking.
The PSO algorithm requires less memory because of its inherent simplicity. PSO is similar to the other evolutionary algorithms in that the system is initialized with a population of random solutions, call particle (swarm), flies in the d-dimension problem space with a velocity, which is dynamically adjusted according to the flying experiences of its own and colleagues. Swarms collect information from each other through an array constructed by their positions using the velocity of particles. Position and velocity are both updated by using guidance from particles' own experience and experience of neighbors.
The position and velocity vectors of the ith particle of a d-dimensional search space can be represented as $X_i = (xi_1, xi_2, \ldots, xi_d)$ and $Vi = (vi_1, vi_2, \ldots vi_d)$, respectively. On the basis of the value of the evaluation function, the best previous position of a particle is recorded and represented as $pbest_i = (pi_1, pi_2, \ldots pi_d)$.If the $g^{th}$ particle is the best among all particles in the group so far, it is represented as $Pbest_g$ = G-best= $(pg_1, pg_2, \ldots pg_d)$.The particle tries to modify its position using the current velocity and the distance from pbest and gbest. The modified velocity and position of each particle for fitness evaluation in the next, that is, $(k+1)^{th}$ iteration, are calculated using following equations:

$$v_{id}^{\ (k+1)} = [W * v_{id}^{\ k} + c_1 * Rand_1() * (P_{bestid} - x_{id}^{\ k}) + c_2 * Rand_2() * (G_{bestgd} - x_{id}^{\ k})] \qquad (4.5)$$

$$x_{id}^{\ (k+1)} = x_{id}^{\ k} + v_{id}^{k+1} \qquad (4.6)$$

$$W = W_{\max} - \frac{W_{\max} - W_{\min}}{\max\_iter} * iter \qquad (4.7)$$

Here W is the inertia weight parameter which controls the global and local exploration capabilities of the particle. $c_1$ and $c_2$ are cognitive and social coefficients, respectively, and $Rand_1()$,$Rand_2()$ are random numbers between 0 and 1. $c_1$ pulls the particles towards local best position and $c_2$ pulls towards the global best position.
For faster convergence of the problem presented in this paper we have taken the parameters as follows:
$c_1=c_2=2$, $W_{min}$=0.4, $W_{max}$=0.9, population=100, maximum iteration= 1000.

### 4.1 Pseudo code for PSO

*For each particle*
*Initialize particle*
*End*
*Do*
*For each particle*
*Calculate fitness value*
*If the fitness value is better than the best fitness value (pBest) in history*
*Set current value as the new pBest*
*End*
*Choose the particle with the best fitness value of all the particles as the gBest*
*For each particle*
*Calculate particle velocity according to equation 4.5*
*Update particle position according to equation 4.6*
*End*
*While maximum iterations or minimum error criteria is not attained*

This algorithm has been implemented in MATLAB for obtaining the results of this problem.

## 5. THE FIREFLY ALGORITHM DESCRIPTION

The Firefly Algorithm is based on the social behavior of fireflies. It is a nature inspired, metaheuristic optimization algorithm developed by Dr. Xin- She Yang [16-18] . It shares many common traits with the other metaheuristic algorithms which were developed based on the swarm behavior of fish, insects or birds as seen in nature e.g. Particle Swarm Optimization (PSO), Artificial Bee Colony Optimization (ABC), Bacterial Foraging (BF) etc. This algorithm has been found to be very efficient and capable of outperforming other conventional optimization algorithms. The fact that it uses random real numbers and is dependent upon the global communication of the swarm particles is its main advantage.

The major characteristics of the firefly algorithm are as follows:

1. All the fireflies being unisex, they will move towards the brighter ones in the swarm regardless of their sex.

2. The brightness of a firefly determines its level of attractiveness which is also proportional to its distance from the other fireflies as air absorbs light. If there is no other brighter particle in the vicinity then the firefly will start moving randomly.

3. The value of the objective function for a particular set of generated solution set determines the brightness of that firefly containing the solution set in the search space.

### 5.1 Attractiveness

The attractiveness function of a firefly in the firefly algorithm is as follows:

$$\beta(r) = \beta_0 * \exp(-\gamma r^m) \text{, with } m \geq 1, \qquad (4.5)$$

where, r= distance between any two fireflies, $\beta_0$=initial attractiveness at r=0, and $\gamma$= absorption coefficient controlling the decrease of intensity of light.

### 5.2 Distance

The distance between two fireflies i and j, at positions $x_i$ and $x_j$ can be defined by the following formula:

$$r_{ij} = \prod x_i - x_j \prod = \sum_{k=1}^{d} \sqrt{(x_{i,k} - x_{j,k})^2} \quad (4.6)$$

Where $x_{i,k}$ is the $k^{th}$ component of the coordinate $x_i$ of the $i^{th}$ firefly in space and d is the number of the dimensions.

### 5.3 Movement

The movement of a firefly i which is attracted to a more attractive firefly j is given by the following equation:

$$X_i = x_i + \beta_0 * \exp(-\gamma r_{ij}{}^2) * (x_j - x_i) + a * (rand - 0.5) \qquad (4.7)$$

The first term being the present position of a firefly, the second term is the firefly's attractiveness to light intensity as observed by the adjacent fireflies. The coefficient $\alpha$ is a randomization parameter which varies from 0 to 1, 0 being the least random value and 1 the most.

For the implementation of this algorithm we have taken $\beta_0$ =1.0, $\alpha \in [0,1]$ and $\gamma$=1.0.

### 5.4 Pseudo code of Firefly Algorithm

***Function Firefly***

*Objective function f(X), X=($x_1$… $x_d$)*
*Generate an initial population of fireflies*
*Evaluate light intensity $I_i$ for firefly at $X_i$ by using f($X_i$) for all fireflies*
*Iteration=1;*
*While (Iteration≤max_iteration)*
*{*
*For (i=1; i≤population_size; i++)*
*{*
*For (j=1; j≤population_size; j++)*
*{*
*If ($I_i$>$I_j$) Move firefly i towards j in d-dimension;*
*Attractiveness varies with distance r via exp[-r];*
*Evaluate light intensity of new solutions;*
*}*
*Update current best solution;*
*Iteration++; }*
*Return current best solution;*

***End Function***

## 6. RESULTS AND DISCUSSION

The effectiveness of the Firefly method in the proposed problem has been tested in 3 unit and 6 unit systems. It has been compared with the lambda iteration algorithm and the PSO algorithm for the 3 unit system and with PSO algorithm for the 6 unit system.

For the 3 unit system the analysis has been done for both with and without losses while for the 6 unit system only the case considering losses has been shown. A loss coefficient matrix has been considered for the cases including losses.

### 6.1 Unit System

The B-coefficient matrix, generation cost coefficients and the generator limits have been tabulated below in table 1. The results of the firefly method for the 3 unit system with and without losses have been shown in tables 2 and 3 The comparison of the fuel costs between the three methods applied has been shown in tables 4 and 5 respectively

Table 1: Cost coefficients and power limits of the 3-unit system

| Sl. No | $a_n$ | $b_n$ | $c_n$ | $P_{min}$ | $P_{max}$ |
|---|---|---|---|---|---|
| 1 | 0.00165 | 7.97 | 555 | 100 | 700 |
| 2 | 0.00183 | 7.74 | 315 | 100 | 350 |
| 3 | 0.00467 | 7.92 | 79 | 70 | 150 |

The loss coefficient matrix of the 3 unit system

$$B = 1e-4 * \begin{bmatrix} 0.750 & 0.050 & 0.075 \\ 0.050 & 0.150 & 0.100 \\ 0.075 & 0.100 & 0.450 \end{bmatrix}$$

Table 2: Test results of the Firefly Algorithm for the 3 unit system without losses

| Load | P1 | P2 | P3 | Cost in Rs/Hr |
|---|---|---|---|---|
| 500 | 190.0756 | 231.3862 | 78.5378 | 5063.2479 |
| 600 | 220.8085 | 279.7328 | 99.4583 | 5931.5287 |
| 700 | 273.3869 | 325.8556 | 100.7571 | 6813.0581 |
| 800 | 335.5984 | 345.8385 | 118.5621 | 7709.58 |

Table 3: Test results of the Firefly Algorithm for the 3 unit system with losses

| Load | P1 | P2 | P3 | Ploss | Cost in Rs/Hr |
|---|---|---|---|---|---|
| 500 | 166.6954 | 253.0087 | 84.7251 | 4.4296 | 5103.3907 |
| 600 | 200.2648 | 310.9032 | 95.1978 | 6.3662 | 5990.8563 |
| 700 | 244.0672 | 345.5630 | 119.3750 | 9.0056 | 6897.67 |
| 800 | 324.3814 | 350 | 139.0015 | 13.3834 | 7831.9386 |

Table 4: Comparison between the results obtained by 3 methods for the 3 unit system without loss

| Load | Cost in Rs/Hr(Lambda Iteration) | Cost in Rs/Hr(PSO) | Cost in Rs/Hr(FA) |
|---|---|---|---|
| 500 | 5063.75 | 5063.25 | 5063.2479 |
| 600 | 5932.9 | 5932.6 | 5931.5287 |
| 700 | 6813.73 | 6813.2 | 6813.0581 |
| 800 | 7710.32 | 7709.6 | 7709.58 |

Table 5: Comparison between the results obtained by 3 methods for the 3 unit system with loss

| Load | Cost in Rs/Hr(Lambda Iteration | Cost in Rs/Hr(PSO) | Cost in Rs/Hr(FA) |
|---|---|---|---|
| 500 | 5103.623 | 5103.5 | 5103.3907 |
| 600 | 5991.934 | 5991 | 5990.8563 |
| 700 | 6898.230 | 6897.7 | 6897.67 |
| 800 | 7832.89 | 7832 | 7831.9386 |

## 6.2 Unit System

The loss coefficients, cost coefficients and the generator limits of the 6 unit system has been tabulated in table 7.6

Table 6: Cost coefficients and power limits of the 3-unit system

| Sl.No | $a_n$ | $b_n$ | $c_n$ | $P_{min}$ | $P_{max}$ |
|---|---|---|---|---|---|
| 1 | 0.15240 | 38.53973 | 756.79886 | 10 | 125 |
| 2 | 0.10587 | 46.15916 | 451.32513 | 10 | 150 |
| 3 | 0.02803 | 40.39655 | 1049.9977 | 35 | 225 |
| 4 | 0.03546 | 38.30553 | 1243.5311 | 35 | 210 |
| 5 | 0.02111 | 36.32782 | 1658.5596 | 130 | 325 |
| 6 | 0.01799 | 38.27041 | 1356.6592 | 125 | 315 |

The loss coefficient matrix of the 6 unit system:

$$B = 1e-5* \begin{bmatrix} 14 & 1.7 & 1.5 & 1.9 & 2.6 & 2.2 \\ 1.7 & 6.0 & 1.3 & 1.6 & 1.5 & 2.0 \\ 1.5 & 1.3 & 6.5 & 1.7 & 2.4 & 1.9 \\ 1.9 & 6.0 & 1.7 & 7.1 & 3.0 & 2.5 \\ 2.6 & 1.5 & 2.4 & 3.0 & 6.9 & 3.2 \\ 2.2 & 2.0 & 1.9 & 2.5 & 3.2 & 8.5 \end{bmatrix}$$

Table 7: Test results of the Firefly Algorithm for the 3 unit system with losses

| Load | P1 | P2 | P3 | P4 | P5 | P6 | Ploss | Cost in Rs/Hr |
|---|---|---|---|---|---|---|---|---|
| 700 | 22.5099 | 11.1441 | 121.7384 | 126.4386 | 200.2323 | 236.5289 | 19.5139 | 36911 |
| 800 | 47.8347 | 13.95 | 140.89 | 142.6068 | 231.1695 | 247.2754 | 24.9373 | 41895 |
| 900 | 44.8710 | 35.6759 | 150.2167 | 174.897 | 245.0795 | 278.8254 | 31.3358 | 47060 |
| 1000 | 48.44 | 26.73 | 176.855 | 169.41 | 300.97 | 315 | 39.6992 | 52265 |
| 1100 | 46.2477 | 40.8562 | 210.058 | 210.3641 | 325.1906 | 315 | 47.3025 | 57884 |

Table 8: Comparison between the results obtained by PSO and FA for the 6 unit system with loss

| Load | Ploss(PSO) | Ploss(FA) | Cost in Rs/Hr (PSO) | Cost in Rs/Hr (FA) |
|---|---|---|---|---|
| 700 | 19.9086 | 19.5139 | 36956 | 36911 |
| 800 | 25.8176 | 24.9373 | 41913 | 41895 |
| 900 | 32.1807 | 31.3358 | 47065 | 47060 |
| 1000 | 40.1681 | 39.6992 | 52390 | 52265 |
| 1100 | 47.2048 | 47.2025 | 57889 | 57884 |

From the above tabulated results we can observe that the efficiency of the firefly method is more compared to both the lambda iteration method and PSO. It was capable of obtaining generator scheduling solutions while obtaining lower losses and fuel cost compared to the other two methods.

## 7. CONCLUSION

Economic Load Dispatch problem is solved by using Lambda iteration method, PSO method and Firefly Algorithm. The programs are written in MATLAB software package. The solution algorithm has been tested for two test systems with three and six generating units. The results obtained from Firefly Algorithm are compared with the results of both Lambda iteration method and PSO method. Comparison of test results of both methods reveals that Firefly Algorithm is able to give more optimal solution than Lambda iteration method and PSO method. Thus, it develops a simple tool to meet the load demand at minimum operating cost while satisfying all units and operational constraints of the power system.

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