Economic Load Dispatch Problem Using Firefly Algorithm

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Abstract— This paper presents an Efficient and Reliable Firefly Algorithm (FA) for solving Economic Load Dispatch Problem . The main objective is to minimize the total fuel cost of the generating units having quadratic cost characteristics subjected to limits on generator .In this paper we will show how the recently developed firefly algorithm can be used to solve the famous ELD optimization problem. This hard optimization problem constitutes one of the key problems in power system operation and planning in which a direct Solution cannot be found and therefore Meta heuristic approaches, such as the firefly algorithm, have to be used to find the near optimal solutions.

Index Terms— Firefly Algorithm; Economic Load Dispatch .

Introduction

Economic dispatch is the short-term determination of the optimal output of a number of electricity generation facilities, to meet the system load, at the lowest possible cost, while serving power to the public in a robust and reliable manner. The Economic Dispatch Problem is solved by specialized computer software which should honour the operational and system constraints of the available resources and corresponding transmission capabilities. Significant economical benefits can be achieved by finding a better solution to the ELD problem. So, a lot of researches have been done in this area. Previously a number of calculus-based approaches including Lagrangian Multiplier method [1] have been applied to solve ELD problems. These methods require incremental cost curves to be monotonically increasing/piece-wise linear in nature. But the input-output characteristics of modern generating units are highly non-linear in nature, so some approximation is required to meet the requirements of classical dispatch algorithms., This optimization problem deals with allocating loads to power generators of a plant for minimum total fuel cost while meeting the power demand and transmission losses constraints. this is numerous variation of this problem which model the one objective functions and the constraints in many different ways. Moreover, we will demonstrate how the firefly algorithm works and how this method can be easily adapted in order to solve this objective optimization problem. Therefore, we will discuss why this method is sufficiently accurate and easy to implement for real-time operation and control of power systems. For the efficiency and validation of this algorithm, we will use, as an example, a sample realistic test system having six power generators. We will also compare the solutions obtained with the ones obtained by alternative optimization techniques that have been successfully applied by many scientists in order to solve these types of problems, such as the goal attainment Genetic algorithm; Particle swarm optimization; Artificial Bee Colony optimization; Biogeography-Based Optimization ; Bacterial Foraging algorithms

In this research paper we will show how the firefly algorithm can be used to solve the economic load dispatch optimization problem. A brief description and mathematical formulation of ELD problem has been discussed in the following section. The concept of Firefly Algorithm is discussed in section 3. The respective algorithm and parameter setting of FFA has been provided in section 4. Simulation studies are discussed in section 5 and conclusion is drawn in section 6.

2. Formulation of the Economic Load Dispatch Problem

2.1. Economic Dispatch

The objective of economic load dispatch of electric power generation is to schedule the committed generating unit outputs so as to meet the load demand at minimum operating cost while satisfying all units and operational constraints of the power system. The economic dispatch problem is a constrained optimization problem and it can be mathematically expressed as follows:

$$\textbf{Minimize } F_T = \sum_{n=1}^{n} F_n(P_n) \tag{2.1}$$

Where, FT : total generation cost (Rs/hr)
n : number of generators

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Pn : real power generation of nth generator (MW)
Fn(Pn) : generation cost for Pn
Subject to a number of power systems network equality and inequality constraints. These constraints include:

2.2. Active Power Balance of The System

For power balance, an equality constraint should be satisfied. The total power generated should be the same as total load demand plus the total line losses

$$P_D + P_L - \sum_{n=1}^{n} P_n = 0 \qquad (2.2)$$

Where, PD : total system demand (MW)
PL: transmission loss of the system (MW)

2.3. Generation Limits of The System

Generation output of each generator should be laid between maximum and minimum limits. The corresponding inequality constraints for each generator are

$$P_n.\min \leq P_n \leq P_n.\max \qquad (2.3)$$

Where, Pn,min : minimum power output limit of nth generator (MW)
Pn,max : maximum power output limit of nth generator (MW) The generation cost function
Fn(Pn) is usually expressed as a quadratic polynomial:

$$F_n(P_n)=a_nP_n^2+b_nP_n+c_n \qquad (2.4)$$

Where, an, bn and cn are fuel cost coefficients.

2.4. Network Losses of The System

Since the power stations are usually spread out geographically, the transmission network losses must be taken into account to achieve true economic dispatch. Network loss is a function of unit generation. To calculate network losses, two methods are in general use. One is the penalty factors method and the other is the *B* coefficients method. The latter is commonly used by the power utility industry. In the *B* coefficients method, network losses are expressed as a quadratic function:

$$P_L= \sum_m \sum_n P_m \, B_{m\,n} P_n \qquad (2.5)$$

Where Bmn are constants called B coefficients or loss coefficients

3. The Firefly Algorithm

3.1. Description

The Firefly Algorithm (FA) is a metaheuristic, nature-inspired, optimization algorithm which is based on the social (flashing) behavior of fireflies, or lighting bugs, in the summer sky in the tropical temperature regions [1–3, 20]. It was developed by Dr. Xin-She Yang at Cambridge University in 2007, and it is based on the swarm behavior such as fish, insects, or bird schooling in nature. In particular, although the firefly algorithm has many similarities with other algorithms which are based on the so-called swarm intelligence, such as the famous Particle Swarm Optimization (PSO), Artificial Bee Colony optimization (ABC), and Bacterial Foraging (BFA) algorithms, it is indeed much simpler both in concept and implementation [2–4, 20]. Furthermore, according to recent bibliography, the algorithm is very efficient and can outperform other conventional algorithms, such as genetic algorithms, for solving many optimization problem; a fact that has been justified in a recent research, where the statistical performance of the firefly algorithm was measured against other well-known optimization algorithms using various standard stochastic test functions [1–3, 20]. Its main advantage is the fact that it uses mainly real random numbers, and it is based on the global communication among the swarming particles (i.e., the fireflies), and as a result, it seems more effective in multiobjective optimization such as the economic load dispatch problem in our case

The firefly algorithm has three particular idealized rules which are based on some of the major flashing characteristics of real fireflies [2–4, 20]. These are the following:

(1) all fireflies are unisex, and they will move towards more attractive and brighter ones regardless their sex.
(2) The degree of attractiveness of a firefly is proportional to its brightness which decreases as the distance from the other firefly increases due to the fact that the air absorbs light. If there is not a brighter or more attractive firefly than a particular one, it will then move randomly.
(3) The brightness or light intensity of a firefly is determined by the value of the objective function of a given problem. For maximization problems, the light intensity is proportional to the value of the objective function.

3.2 Attractiveness

In the firefly algorithm, the form of attractiveness function of a firefly is the following
monotonically decreasing function [2, 3, 20]:

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

where, *r* is the distance between any two fireflies, *β*o is the initial attractiveness at *r* = 0, and *γ* is an absorption coefficient which controls the decrease of the light intensity.

3.3 Distance

The distance between any two fireflies *i* and *j*, at positions *xi* and *xj* , respectively, can be defined as a Cartesian or Euclidean distance as follows [2, 3, 20]:

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

where $x_{i,k}$ is the *k*th component of the spatial coordinate x_i of the *i*th firefly and *d* is the number of dimensions we have, for *d* = 2, we have

$$r_{ij} = \sqrt{(xi - xj)^2 - (yi - yj)^2}$$

However, the calculation of distance *r* can also be defined using other distance metrics, based on the nature of the problem, such as Manhattan distance or Mahalanobis distance.

3.4 Movement

The movement of a firefly *i* which is attracted by a more attractive (i.e., brighter)firefly *j* is given by the following equation [2, 3, 20]:

$$Xi = xi + \beta 0 * \exp(-\gamma r_{ij}^2) * (xj - xi) + \alpha * (\text{rand} - ½)$$

where the first term is the current position of a firefly, the second term is used for considering a firefly's attractiveness to light intensity seen by adjacent fireflies, and the third term is 10 International Journal of Combinatorics used for the random movement of a firefly in case there are not any brighter ones. The coefficient α is a randomization parameter determined by the problem of interest, while rand is a random number generator uniformly distributed in the space [0,1]. As we will see in this implementation of the algorithm, we will use $\beta 0 = 1.0$, $\alpha \in [0, 1]$ and the attractiveness or absorption coefficient $\gamma = 1.0$, which guarantees a quick convergence of the algorithm to the optimal solution.

4. 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 ***noff***, αmax, αmin, β0, γmin, γmax and ***itermax*** (maximum number of iterations).

Step 3: Generate ***noff*** number of fireflies (xi) randomly between λmin and λmax .

Step 4: Set iteration count to 1
.

Step 5: Calculate the fitness values corresponding to ***noff*** number of fireflies.

Step6: Obtain the best fitness value ***GbestFV*** by comparing all the fitness values and also obtain the best firefly values ***GbestFF*** corresponding to the best fitness value ***GbestFV***.

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

α (iter)= α max -((α max - α min) (current iteration number)/ *itermax*)

Step 8: Determine the rij values of each firefly using the following equation:
rij= ***GbestFV*** **-FV**
rij is obtained by finding the difference between the best fitness value ***GbestFV***
(***GbestFV*** is the best fitness value i.e., jth firefly) and fitness value **FV** of the ith firefly.

Step 9: New xi values are calculated for all the fireflies using the following equation:

$$Xi = xi + \beta 0 * \exp(-\gamma r_{ij}^2) * (xj - xi) + \alpha * (\text{rand} - ½)$$

Where, β0 is the initial attractiveness γ is the absorption co-efficient rij is the difference between the best fitness value ***GbestFV*** and fitness value **FV** of the ith firefly. ***α (iter)*** is the randomization parameter (In this present work, ***α (iter)*** value is varied between 0.2 and 0.01) rand is the random number between 0 and 1.
In this present work, x → λ

Step 10: Iteration count is incremented and if iteration count is not reached maximum then go to step

Step 11: ***GbestFF*** gives the optimal solution of the Economic Load Dispatch problem and the results are printed.

5. Simulation Results

The effectiveness of the proposed firefly algorithm is tested with three and six generating unit systems. Firstly, the problem is solved by conventional Lambda iterative method and then Firefly algorithm optimization method is used to solve the problem

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A reasonable loss coefficient matrix of power system network was employed to draw the transmission line loss and satisfy the transmission capacity constraints. The program is written in MATLAB software package.

5.1 Three-Unit System

The generator cost coefficients, generation limits and B-coefficient matrix of three unit system are given below. Economic Load Dispatch solution for three unit system is solved using conventional Lambda iteration method and Firefly algorithm method. Test results of Firefly method are given in table 5.2. Comparison of test results of Lambda-iteration method and Firefly algorithm are shown in table 5.3.

Table 5.1 Cost coefficients and power limits of 3-Unit system.

	an	bn	cn	Pn,min	Pn,max
1	1243.5311	38.30553	0.03546	35	210
2	1658.5696	36.32782	0.02111	130	325
3	1356.6592	38.27041	0.01799	125	315

The loss coefficient matrix of 3-Unit system

$$Bij = \begin{matrix} 0.000071 & 0.000030 & 0.000025 \\ 0.000030 & 0.000069 & 0.000032 \\ 0.000025 & 0.000032 & 0.000080 \end{matrix}$$

Table 5.2 Test results of Firefly Algorithm for 3-Unit System

S. No.	Power Demand (MW)	λ	P1 (MW)	P2 (MW)	P3 (MW)	Ploss (MW)	Fuel Cost (Rs/hr)
1	350	44.4387	70.3012	156.267	129.208	5.77698	18563.9
2	400	45.4762	82.0784	174.994	150.496	7.56813	20811.7
3	450	46.5291	93.9374	193.814	171.862	9.61271	23110.8
4	500	47.5977	105.88	212.728	193.306	11.9144	25464.7
5	550	48.6824	117.907	231.738	214.831	14.4769	27871.8
6	600	49.7836	130.021	250.846	236.437	17.3040	30333.6
7	650	50.9017	142.223	270.053	258.124	20.3997	32850.9
8	700	52.0371	154.514	289.360	279.894	23.7680	35423.8

Table 5.3 Comparison of test results of Lambda- iteration method and Firefly Algorithm for 3-Unit System

Sl. No.	Power Demand(MW)	Fule Cost (Rs/hr)	
		Lambda iteration method	Firefly Algorithm
1	350	18570.7	18563.9
2	400	20817.4	20811.7
3	450	23146.8	23110.8
4	500	25495.2	25464.7
5	550	27899.3	27871.8
6	600	30359.3	30333.6
7	650	32875.0	32850.9
8	700	35446.3	35423.8

5.2 Six-Unit System

The generator cost coefficients, generation limits and B-coefficient matrix of six unit system are given below. Economic Load Dispatch solution for six unit system is solved using conventional Lambda iteration method and Firefly Algorithm method. Test results of Firefly method are given in table 5.5. Comparison of test results of Lambda-iteration method and Firefly Algorithm are shown in table 5.6.

Table 5.4 Cost coefficients and power limits of 6-Unit system

Unit	an	Bn	Cn	Pn,min	Pn,max
1	756.79886	38.53	0.15240	10	125
2	451.32513	46.15916	0.10587	10	150
3	1049.9977	40.39655	0.02803	35	225
4	1243.5311	38.30553	0.03546	35	210

5	1658.5696	36.32782	0.02111	130	325
6	1356.6592	38.27041	0.01799	125	315

The loss co-efficient matrix of 6-Unit system

B_{ij}=

0.000022	0.000020	0.000019	0.000025	0.000032	0.000085
0.000026	0.000015	0.000024	0.000030	0.000069	0.000032
0.000019	0.000016	0.000017	0.000071	0.000030	0.000025
0.000015	0.000013	0.000065	0.000017	0.000024	0.000019
0.000017	0.000060	0.000013	0.000016	0.000015	0.000020
0.000014	0.000017	0.000015	0.000019	0.000026	0.000022

Table 5.5 Test results of Firefly method for 6-Unit System

s no	Power Demand(MW)	λ	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P Loss (MW)	Fuel Cost (Rs/hr)
1	600	47.3419	23.8603	10	95.6389	100.708	202.832	181.198	14.2374	32093.8
2	650	48.1731	26.0679	10	107.264	109.668	216.775	196.954	16.7281	34481.9
3	700	49.0146	28.2908	10	118.958	118.675	230.763	212.745	19.4319	36911.7
4	750	49.8451	30.4756	11.2265	130.446	127.515	244.466	228.182	22.3108	39383.6
5	800	50.6613	32.5863	14.4843	141.548	136.045	257.664	243.009	25.3312	41895.7
6	850	51.4839	34.7102	17.7675	152.708	144.614	270.897	257.859	28.556	44449.8
7	900	52.3162	36.8481	21.0775	163.93	153.227	284.17	272.737	31.9881	47044.6
8	950	53.1585	38.9998	24.4145	175.214	161.882	297.481	287.64	35.6295	49681.4

Table 5.6 Comparison of test results of Lambda-iteration method and Firefly Algorithm for 6-Unit System

S no.	Power Demand(MW)	Fuel Cost (Rs/hr)	
		Lambda iteration method	Firefly Algorithm
1	600	32129.8	32093.8
2	650	34531.7	34481.9
3	700	36946.4	36911.7
4	750	39422.1	39383.6
5	800	41959.0	41895.7
6	850	44508.1	44449.8
7	900	47118.2	47044.6
8	950	49747.4	49681.4

From the tabulated results, we can observe that the Firefly Algorithm optimization method can obtain lower fuel cost than conventional Lambda iteration method.

6. Conclusions

Economic Load Dispatch problem is solved by using Lambda iteration 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 Lambda iteration method. Comparison of test results of both methods reveals that Firefly Algorithm is able to give more optimal solution than Lambda iteration 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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