Economic Load Dispatch Using Firefly Algorithm

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ABSTRACT

Economic Load Dispatch (ELD) problem in power systems has been solved by various optimization methods in the recent years, for efficient and reliable power production. This paper introduces a solution to ELD problem using a new metaheuristic nature-inspired algorithm called Firefly Algorithm (FFA). The proposed approach has been applied to various test systems. The results proved the efficiency and robustness of the proposed method when compared with the other optimization algorithms.

Keywords - Economic Load Dispatch, Firefly Algorithm.

1.Introduction

Economic Load Dispatch (ELD) seeks the best generation schedule for the generating plants to supply the required demand plus transmission loss with the minimum generation cost. 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. Therefore more interests have been focused on the application of artificial intelligence (AI) technology for solution of these problems. Several AI methods, such as Genetic Algorithm[2] Artificial Neural Networks[3], Simulated Annealing[4], Tabu Search[5], Evolutionary Programming[6], Particle Swarm Optimization[7], Ant Colony Optimization[8], Differential Evolution[9], Harmony search Algorithm[10], Dynamic Programming[11], Bio-geography based optimization[12], Intelligent water drop Algorithm[13] have been developed and applied successfully to small and large systems to solve ELD problems in order to find much better results. Very recently, in the study of social insects behavior, computer scientists have found a source of inspiration for the design and implementation of optimization algorithms. Particularly, the study of fireflies' behavior turned out to be very attractive to develop problem solving algorithms. In the Firefly algorithm[14][15][16], the objective function of a given optimization problem is associated with the flashing light or light intensity which helps the swarm of fireflies to move to brighter and more attractive locations in order to obtain efficient optimal solutions.

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:

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

Where, F_T : total generation cost (Rs/hr)
n : number of generators
P_n : real power generation of n^{th} generator (MW)
$F_n(P_n)$: generation cost for P_n

Subject to a number of power systems network equality and inequality constraints. These constraints include:

2.2. System Active Power Balance

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

$$P_D + P_L - \sum_{n=1}^{n} P_n = 0$$

Where, P_D : total system demand (MW)

P_L: transmission loss of the system (MW)

2.3. Generation Limits

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

$$P_{n,min} \leq P_n \leq P_{n,max} \quad (2.3)$$

Where, $P_{n,min}$: minimum power output limit of n^{th} generator (MW)

$P_{n,max}$: maximum power output limit of n^{th} generator (MW)

The generation cost function $F_n(P_n)$ is usually expressed as a quadratic polynomial:

$$F_n(P_n) = a_n P_n^2 + b_n P_n + c_n \quad (2.4)$$

Where, a_n, b_n and c_n are fuel cost coefficients.

2.4. Network Losses

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:

$$P_L = \sum_m \sum_n P_m B_{mn} P_n \quad (2.5)$$

Where B_{mn} are constants called B coefficients or loss coefficients

3. The Firefly Algorithm

3.1. Description

The Firefly Algorithm is a metaheuristic, nature-inspired optimization algorithm which is based on the social flashing behavior of fireflies. It is based on the swarm behavior such as fish, insects or bird schooling in nature. 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. Its main advantage is that it uses mainly real random numbers, and it is based on the global communication among the swarming particles called as fireflies.

The firefly algorithm has three particular idealized rules which are based on some of the major flashing characteristics of real fireflies.

The characteristics are as follows:

i) All fireflies are unisex and they will move towards more attractive and brighter ones regardless their sex.

ii) The degree of attractiveness of a firefly is proportional to its brightness which decreases as the distance from the other firefly increases. This is 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.

iii) 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 given by the following monotonically decreasing function:

$$\beta(r) = \beta_0 * \exp(-\gamma r_{ij}^m) \text{ with } m \geq 1 \quad (3.1)$$

Where, r is the distance between any two fireflies,

β_0 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 x_i and x_j respectively can be defined as :

$$r_{ij} = \|x_j - x_i\| \quad (3.2)$$

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.

3.4. Movement

The movement of a firefly i which is attracted by a more attractive i.e., brighter firefly j is given by :

$$x_i = x_i + \beta_0 * \exp(-\gamma r_{ij}^2) * (x_j - x_i) + \alpha * \left(rand - \frac{1}{2}\right) \quad (3.3)$$

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 used for the random movement of a firefly in case there are no brighter ones. The coefficient α is a randomization parameter determined by the problem of interest, rand is a random number generator uniformly distributed in the space [0,1].

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***, α_{max}, α_{min}, β_0, γ_{min}, γ_{max} and ***itermax*** (maximum number of iterations).

Step 3: Generate ***noff*** number of fireflies (x_i) randomly between λ_{min} and λ_{max} .

Step 4: Set iteration count to 1.

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

Step 6: 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 r_{ij} values of each firefly using the following equation:

r_{ij}= ***GbestFV*** **-FV**

r_{ij} is obtained by finding the difference between the best fitness value ***GbestFV*** (***GbestFV*** is the best fitness value i.e., 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:

$$x_{i(new)} = x_{i(old)} + \beta_0 * \exp\left(-\gamma r_{ij}^2\right) * \left(x_j - x_i\right) + \alpha(iter) * \left(rand - \frac{1}{2}\right) \quad (4.1)$$

Where, β_0 is the initial attractiveness

γ is the absorption co-efficient

r_{ij} is the difference between the best fitness value ***GbestFV*** and fitness value **FV** of the i^{th} 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, $x \rightarrow \lambda$

Step 10: Iteration count is incremented and if iteration count is not reached maximum then go to step 5

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.

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.

	a_n	b_n	c_n	$P_{n,min}$	$P_{n,max}$
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

$$B_{ij} = \begin{bmatrix} 0.000071 & 0.000030 & 0.000025 \\ 0.000030 & 0.000069 & 0.000032 \\ 0.000025 & 0.000032 & 0.000080 \end{bmatrix}$$

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

Sl. No.	Power Demand (MW)	λ	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_{loss} (MW)	Fuel Cost (Rs/hr)
1	350	44.4387	70.3012	156.267	129.208	5.77698	18564.5
2	400	45.4762	82.0784	174.994	150.496	7.56813	20812.3
3	450	46.5291	93.9374	193.814	171.862	9.61271	23112.4
4	500	47.5977	105.88	212.728	193.306	11.9144	25465.5
5	550	48.6824	117.907	231.738	214.831	14.4769	27872.4
6	600	49.7836	130.021	250.846	236.437	17.3040	30334.0
7	650	50.9017	142.223	270.053	258.124	20.3997	32851.0
8	700	52.0371	154.514	289.360	279.894	23.7680	35424.4

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	18564.5
2	400	20817.4	20812.3
3	450	23146.8	23112.4
4	500	25495.2	25465.5
5	550	27899.3	27872.4
6	600	30359.3	30334.0
7	650	32875.0	32851.0
8	700	35446.3	35424.4

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	a_n	B_n	C_n	$P_{n,min}$	$P_{n,max}$
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

$$B_{ij}=\begin{bmatrix} 0.000022 & 0.000020 & 0.000019 & 0.000025 & 0.000032 & 0.000085 \\ 0.000026 & 0.000015 & 0.000024 & 0.000030 & 0.000069 & 0.000032 \\ 0.000019 & 0.000016 & 0.000017 & 0.000071 & 0.000030 & 0.000025 \\ 0.000015 & 0.000013 & 0.000065 & 0.000017 & 0.000024 & 0.000019 \\ 0.000017 & 0.000060 & 0.000013 & 0.000016 & 0.000015 & 0.000020 \\ 0.00014 & 0.000017 & 0.000015 & 0.000019 & 0.000026 & 0.000022 \end{bmatrix}$$

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

Sl. No.	Power Demand (MW)	λ	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_6 (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	32094.7
2	650	48.1731	26.0679	10	107.264	109.668	216.775	196.954	16.7281	34482.6
3	700	49.0146	28.2908	10	118.958	118.675	230.763	212.745	19.4319	36912.2
4	750	49.8451	30.4756	11.2265	130.446	127.515	244.466	228.182	22.3108	39384.0
5	800	50.6613	32.5863	14.4843	141.548	136.045	257.664	243.009	25.3312	41896.9
6	850	51.4839	34.7102	17.7675	152.708	144.614	270.897	257.859	28.556	44450.3
7	900	52.3162	36.8481	21.0775	163.93	153.227	284.17	272.737	31.9881	47045.3
8	950	53.1585	38.9998	24.4145	175.214	161.882	297.481	287.64	35.6295	49682.1

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

Sl no.	Power Demand(MW)	Fule Cost (Rs/hr)	
		Lambda iteration method	Firefly Algorithm
1	600	32129.8	32094.7
2	650	34531.7	34482.6
3	700	36946.4	36912.2
4	750	39422.1	39384.0
5	800	41959.0	41896.9
6	850	44508.1	44450.3
7	900	47118.2	47045.3
8	950	49747.4	49682.1

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.

References

[1]. Tkayuki S, Kamu W. "Lagrangian relaxation method for price based unit commitment problem" *Engineering Optimization -Taylor & Francis Journal*, 36(6): 705-19.

[2]. P. H. Chen and H. C. Chang, "*Large-Scale Economic Dispatch by Genetic Algorithm,*" *IEEE Transactions on Power System, Vol. 10, No. 4*, 1995, pp. 1919-1926.

[3]. C.-T. Su and C.-T. Lin, "*New Approach with a Hopfield Modeling Framework to Economic Dispatch*," *IEEE Transaction on Power System, Vol. 15, No. 2*, 2000, pp. 541-545.

[4]. Basu M. "A simulated annealing based goal attainment method for economic emission load dispatch of fixed head hydrothermal power systems" *International Journal of Electrical Power and Energy Systems 2005;27(2)*:147–53.

[5]. W. M. Lin, F. S. Cheng and M. T. Tsay, "*An Improved Tabu Search for Economic Dispatch with Multiple Minima,*" *IEEE Transaction on Power Systems, Vol. 17, No. 1*, 2002, pp. 108-112.

[6]. T. Jayabarathi, G. Sadasivam and V. Ramachandran, "*Evolutionary Programming based Economic dispatch of Generators with Prohibited Operating Zones,*" *Electrical Power System Research, Vol. 52, No. 3*, 1999, pp. 261- 266.

[7]. J.B. Park, K. S. Lee, J. R. Shin and K. Y. Lee, "*A Particle Swarm Optimization for Economic Dispatch with Non Smooth Cost Functions,*" *IEEE Transaction on Power Systems, Vol. 8, No. 3*, 1993, pp. 1325-1332.

[8]. Huang JS. "*Enhancement of hydroelectric Generation scheduling using ant colony system based optimization approache*". *IEEE Transactions on Energy* Conversion 2001;16(3):296–301.

[9]. N. Nomana and H. Iba, "*Differential Evolution for Economic Load Dispatch Problems,*" *Electric Power Systems Research, Vol. 78, No. 8*, 2008, pp. 1322-1331.

[10]. Z.W. Geem, J.H. Kim, and G.V. Loganathan, "*A new heuristic optimization algorithm: harmony search,*" *Simulation, Vol. 76, No. 2*, pp. 60-68, 2001.

[11].Z. X. Liang and J. D. Glover, "*A Zoom Feature for a Dynamic Programming Solution to Economic Dispatch including Transmission Losses,*" *IEEE Transactions on Power Systems, Vol. 7, No. 2*, 1992, pp. 544-550.

[12]. A. Bhattacharya and P. K. Chattopadhyay, "*Biogeography- Based Optimization for Different Economic Load Dispatch Problems,*" *IEEE Transactions on Power Systems, Vol. 25, No. 2*, 2010, pp. 1064-1077.

[13]. S. R. Rayapudi, "*An Intelligent Water Drop Algorithm for Solving Economic Load Dispatch Problem,*" *International Journal of Electrical and Electronics Engineering, Vol. 5, No. 2*, 2011, pp. 43-49.

[14] Yang, X. S., "*Firefly algorithm for multimodal optimization*", in Stochastic Algorithms Foundations and Appplications

(Eds O. Watanabe and T. eugmann), SAGA 2009, LectureNotes in Computer Science, 5792, Springer-Verlag,Berlin,2009,pp.169-178.

[16] N. Chai-ead, P. Aungkulanon and P. Luangpaiboon "*Bees and Firefly Algorithms for Noisy Non-Linear Optimisation Problems*", proceedings of international multi conference of engineers and computer scientits 2011 Vol II IMECS 2011 March 16-18, Hong Kong.

[15] X.-S. Yang, "*Firefly Algorithm, Levy Flights and Global Optimization*", Research and Development in Intelligent Systems XXVI (Eds M. Bramer, R. Ellis, Petridis), Springer London, 2010, pp. 209-218.