

An Effectively Modified Firefly Algorithm for Economic Load Dispatch Problem

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Abstract

This paper proposes an effectively modified firefly algorithm (EMFA) for searching optimal solution of economic load dispatch (ELD) problem. The proposed method is developed by improving the procedure of new solution generation of conventional firefly algorithm (FA). The performance of EMFA is compared to FA variants and other existing methods by testing on four different systems with different types of objective function and constraints. The comparison indicates that the proposed method can reach better optimal solutions than other FA variants and most other existing methods with lower population and lower maximum iteration. As a result, it can lead to a conclusion that the proposed method is potential for ELD problem.

Keywords: firefly algorithm, economic load dispatch, single fuel, multi fuels

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1. Introduction

In ELD problem, the thermal units can use either only one fuel type or multi fuel types and their fuel cost function form is dependent on the option of use. In case that only one fuel type is used for purpose of electricity generation, fuel cost function is approximately represented as a second order equation [1-3]. Besides, when multi fuel types including coal, natural gas and oil can be used for a unit, fuel cost function is mathematically formulated as a segmented-piecewise quadratic function [4-8].

Traditionally, deterministic methods have been used for solving the ELD problem, such as Lagrange relaxation [9] and Hopfield network based methods [10]. The methods have the same potential ability such as short execution time, few parameters and one optimal solution. However, these methods also own the same disadvantages such as limited applicability for problems with complicated constraints and less efficiency for large scale problem. To avoid overlapping such drawbacks of deterministic methods, many meta heuristic approaches have been constructed to deal with the ELD problem such as teaching and learning based algorithm (TLBA) [1], cuckoo search algorithm (CSA) [2-3, 11-12], hybrid real coded genetic algorithm (HRCGA) [4], differential evolution (DE) [5], genetic Algorithm (GA) [5], particle swarm optimization (PSO) [5], improved evolutionary programming (IEP) [6], clonal algorithm (CA) [7], hybrid integer coded differential evolution (HICDE)[8], bee colony optimization (BCO) [13], biogeography-based optimization (BBO) [14], chaotic jaya algorithm (CJA) [15], firefly algorithm (FA) [16], memetic firefly algorithm (MFA) [16], FA with adaptive parameter α (ASPF) [16], modified firefly algorithm (α -MFA) [17], seeker optimization algorithm (SOA) [18], krill herd algorithm (KHA) without using genetic operation (KHA1) [19], KHA using crossover operation (KHA2) [19], KHA using mutation operation (KHA3) [19] and KHA using crossover operation and mutation operation (KHA4) [19]. These methods have shown their powerful search ability via testing on different problems with different conditions such as different constraints related to thermal units and different constraints associate with power systems.

Firefly algorithm is also population based meta-heuristic algorithm like GA, PSO and other methods. The method was constructed by Yang in 2008 for solving optimization

problems [20]. The method has been demonstrated effectively but its effectiveness and robustness have not met researchers' demand. Thus, several improvements of the method have been carried out in refs. [17, 21-24]. α -MFA was developed in [17] by applying modifications on distance of each two fireflies and on step parameter α . In [21], Kazemzadeh-Parsi has proposed improved firefly algorithm (IFA) by applying three modifications. In [22], the memetic firefly algorithm (MFA) has been developed by balance of exploration acting as global search and exploitation acting as local search. In [23], FA with adaptive parameter α (ASPFA) was proposed by suggesting adaptive equation for updating α based on current and highest iterations. Quasi-chaos FA was developed in [24] by using Quasi-chaotic phenomenon and its performance was tested on different benchmark functions. In [16], Moustafa et al have run four methods consisting of FA, IFA, MFA and ASPFA on ELD problem with 3-unit system and 6-unit system. The final comparison has reported that IFA in [21] was the best method and FA was the worst method. However, the authors have not compared these methods with other existing methods to give more evidences for conclusion.

In the paper, we propose a new technique for generating new solutions of FA to construct an effectively modified FA (EMFA) for dealing with different study cases of ELD problem and comparing with existing FA methods and other existing methods. The new technique will choose the best way for newly updating each considered solution based on their quality. If a considered solution is close to good solution group with low fitness function, its new solution will be produced by searching nearby its current position. In case that the considered solution is far away the good solution group, its new solution is found nearby the current best solution. The new technique can determine a better search zone for each considered solution in aim to fast converge to optimal solution and avoid falling into local optimal solutions. The effectiveness of the EMFA method is investigated by testing on different systems with different constraints. Consequently, in the paper our main contributions are as follows:

- a. Point out disadvantages of conventional FA and propose modifications for improving performance
- b. Demonstrate advantages of the proposed method over other improved versions of FA, which are available in other studies
- c. Contribute a potential method for ELD problem

2. Problem Formulation

2.1. Objective Function

In ELD with single fuel, the fuel cost of each generating unit is expressed as a quadratic function of its power output. The objective of the problem is to minimize the total fuel cost of N available units and can be written as follows:

$$\text{Min } F = \sum_{s=1}^N F_s(P_s), \quad (1)$$

where P_s is real power output of generator s ; F_s is the fuel cost function of thermal unit s and it can be represented in equation 2 and equation 3 corresponding to single fuel and multi fuel cases [4].

$$F_s(P_s) = a_s + b_s P_s + c_s P_s^2 \quad (\$/h), \quad (2)$$

$$F_s(P_s) = \begin{cases} a_{s1} + b_{s1} P_s + c_{s1} P_s^2, \text{ fuel } 1, P_{s,\min} \leq P_s \leq P_{s1,\max} \\ \vdots \\ a_{sNF_s} + b_{sNF_s} P_s + c_{sNF_s} P_s^2, \text{ fuel } NF_s, P_{sNF_s,\min} \leq P_s \leq P_{s,\max} \end{cases} \quad (3)$$

where a_s , b_s , and c_s are fuel cost coefficients of unit s with single fuel option; $P_{s,\min}$ and $P_{s,\max}$ represent the lowest value and the highest generations; NF_s represents the number of fuel options of thermal unit s .

2.2. Set of Constraints

Active power balance: Total energies generated by all generating units must satisfy electricity load and power losses dropped in transmission lines

$$\sum_{s=1}^N P_s = PD + PLoss, \quad (4)$$

where PD is demanded power by load; $PLoss$ is power loss obtained by [1]:

$$PLoss = \sum_{i=1}^N \sum_{j=1}^N P_i B_{ij} P_j + \sum_{i=1}^N B_{0i} P_i + B_{00}, \quad (5)$$

where B_{ij} , B_{0i} , B_{00} are the coefficients of power loss matrix. *Limitations of thermal generating units:* Power output of each thermal generating unit must follow the rule.

$$P_{s,\min} \leq P_s \leq P_{s,\max} \quad (6)$$

3. Proposed Method

3.1. Conventional Firefly Algorithm

A firefly i is also a solution i , which is represented as a position X_i of firefly i . Each firefly i will fly to other fireflies with better brightness. Thus, there is a possibility that each solution i will own different positions X_{ij} and the equation to determine X_{ij} for firefly i is obtained as follows:

$$X_{ij}^{new} = X_i + \beta \cdot \Delta X_{ij} + rand_i, \quad (7)$$

where ΔX_{ij} and β are step size and the attractiveness of firefly i calculated by:

$$\Delta X_{ij} = (X_j - X_i) \quad (8)$$

$$\beta = \beta_0 e^{-\gamma R_{ij}^2}, \quad (9)$$

Where β_0 is initial attractiveness; and R_{ij} is the distance between fireflies i and j obtained by:

$$R_{ij} = \sqrt{(X_i - X_j)^2}. \quad (10)$$

The whole search procedure of FA can be described as the following steps:

Step 1: Enter necessary data of optimization problems

Step 2: Select maximum iteration (G) and population (N_F), and produce population randomly

Step 3: Calculate fitness and determine the best solution $Gbest$. Set current iteration (C) to 1

Step 4: Start solution X_i ($i=1$)

Step 5: Generate X_{ijnew} by using (7)-(10)

Step 6: Calculate fitness function of X_{ijnew}

Step 7: Set X_{ijnew} with the best fitness function to X_{inew}

Step 8: If $i=N_F$, go to next step. Otherwise, set $i=i+1$ and back to step 5.

Step 9: Compare X_i and X_{inew} to keep better one. Determine the best solution $Gbest$

Step 10: If C is equal to G , stop the search process. Otherwise, set $C=C+1$ and back to step 4.

3.2. The Proposed EMFA Method

In the proposed method, we propose a new technique to generate updated step size and new solutions. At the beginning, ΔFF_i and ΔFF_{mean} are determined by the following equations:

$$\Delta FF_i = \frac{FF_i - FF_{Best}}{FF_{Best}} \quad (11)$$

$$\Delta FF_{mean} = \frac{FF_{mean} - FF_{Best}}{FF_{Best}} \quad (12)$$

Where FF_i , FF_{Best} and FF_{mean} are the fitness function of solution i , the best solution and the population on average. Corresponding to the result of comparison between ΔFF_i and ΔFF_{mean} , the updated step size is calculated and then the new solutions of X_i can be determined. As a result, the new proposed technique is described in detail as below

If $\Delta FF < \Delta FF_{mean}$

$$\Delta X_{ij} = X_j - X_i \quad (13)$$

else

$$\Delta X_{ij} = (X_j - X_i + X_{r1} - X_{r2}) \quad (14)$$

$$X_{ijnew} = Gbest + randn \cdot \beta \cdot \Delta X_{ij} + randn, \quad \% X_{r1} \text{ and } X_{r2} \text{ are two randomly chosen solutions} \quad (15)$$

End

The whole search process of the proposed method is also implemented similarly to that of FA; however, there is only one difference of the two methods that is the new solution generation procedure.

4. The Implementation of EMFA for ELD Problem

4.1. Selecting Decision Variables and Handling Active Power Balance Constraint

Each solution or each position of firefly i contains active power of $(N-1)$ thermal units. Solution X_i is mathematical modeled in Equation 17.

$$X_i = [P_{2,i}, P_{3,i}, \dots, P_{N,i}]; \quad i=1, \dots, N_F \quad (17)$$

Furthermore, X_i must always meet the following rule:

$$X_{min} \leq X_i \leq X_{max}, \quad (18)$$

$$\text{Where } X_{min} = [P_{2,min}, P_{3,min}, \dots, P_{N,min}] \text{ and } X_{max} = [P_{2,max}, P_{3,max}, \dots, P_{N,max}] \quad (19)$$

Finally, power output of the first thermal unit is calculated by [12]:

$$P_{1,i} = PD + P_{Loss} - \sum_{s=2}^N P_{s,i}. \quad (20)$$

4.2. Fitness Function

Fitness function of each solution must be obtained for evaluating the quality of solution. Generally, the function is composed of objective function and punishment of the violation of dependent variables. For ELD problem, it is established as follows:

$$FF_i = \sum_{s=1}^N F_s(P_s) + PF \times (Punishment_i)^2 \quad (21)$$

where PF is a factor; and $Punishment_i$ is the violation punishment determined by:

$$Punishment_i = \begin{cases} P_{1,i} - P_{1,max} & \text{if } P_{1,i} > P_{1,max} \\ P_{1,min} - P_{1,i} & \text{if } P_{1,i} < P_{1,min} \\ 0 & \text{if } P_{1,min} \leq P_{1,i} \leq P_{1,max} \end{cases} \quad (22)$$

5. Numerical Results

The proposed EMFA is tested on four systems and obtained results are compared to FA methods and other existing methods. The detail of four test systems is described as follows:

Case 1: Six-unit test system neglecting and considering power losses

Case 2: Six-unit test system considering prohibited working zones and power losses

Case 3: Twenty-unit test system considering power losses

Case 4: Ten-units with multi fuels and four load cases of 2400, 2500, 2600 and 2700 MW corresponding to cases 4.1, 4.2, 4.3 and 4.4.

For each study case, EMFA is run fifty independent trials by using Matlab and computer with 4GB of Ram and 2.4Ghz processor.

5.1. Result Comparisons for the First System

In the section, the proposed method is compared to other FA methods reported in [16]. For running the proposed method, population and maximum iteration are set to 10 and 30 for the proposed method while authors in [16] have set 25 and 150 for the two parameters for FA, IFA, ASPFA and MFA. Table 1 and Table 2 show the comparison for different loads with the case of neglecting and considering power losses, respectively. The comparison can see that the proposed method can reach less cost than FA, IFA, ASPFA and MFA by \$43.37, \$1.37, \$130.37 and \$35.37 for 600MW load. Equally, the proposed method also reaches better cost than other methods for other cases. As a result, it can lead to a conclusion that the proposed method is more potential than other FA methods in terms of less population, less iteration and better optimal solutions.

Table 1. The Best Cost Comparisons (\$/h) for the First System without Power Losses

PD (MW)	FA [16]	IFA [16]	ASPFA [16]	MFA [16]	EMFA
600	31489	31447	31576	31481	31445.62
700	36075	36006	36036	36021	36003.12
800	40739	40676	40701	40740	40675.97

Table 2. The Best Cost Comparisons (\$/h) for the First System with Power Losses

PD (MW)	FA [16]	IFA [16]	ASPFA [16]	MFA [16]	EMFA
600	32122	32098	32159	32109	32094.7
700	37004	36914	36960	36978	36912.1
800	41939	41898	41976	41930	41896.6

5.2. Result Comparisons for the Second System

For the system with POZ and power loss constraint, the proposed method is compared to FA and other methods. The results in terms of the best cost, mean cost and the worst cost, and the control parameters consisting of N_F and G are also given in Table 3. It is surprised to note that the minimum cost of α -MFA is the best value among the reported methods but the real cost, which is recalculated, is \$15443.23. Clearly, the accuracy of the number is not confirmed certainly. In comparisons with FA, we have set its maximum iteration to 60 while that of the proposed method has been set to 15; however, all the costs of the proposed method were less than those of FA. Clearly, the proposed method could reach better results than FA including optimal solutions and convergence speed.

For comparison with other methods, the proposed method has reached the best results with lower best cost, lower mean cost and lower worst cost meanwhile it has used the lowest

population and the lowest maximum iteration. In summary, the proposed method is much better than FA and other methods regarding optimal solution, convergence speed and stable search ability for the system with POZ and power loss constraints.

Table 3. Result Comparisons for System 2

Method	Best cost (\$/h)	Mean cost (\$/h)	Worst cost(\$/h)	N_{FXG}
DE[5]	15,449.77	15,449.87	15,449.78	36x100
GA [5]	15,459	15,524	15,469	36x100
PSO [5]	15,450	15,492	15,454	36x100
KHA1 [19]	15,450.75	15,452.82	15,455.50	50x100
KHA2 [19]	15,448.21	15,450.83	15,453.40	50x100
KHA3 [19]	15,445.36	15,447.22	15,449.60	50x100
KHA4 [19]	15,443.08	15,443.19	15,443.30	50x100
α -MFA[17]	15442.9	-	-	12x100
FA	15445.087	15479.378	15575.613	10x60
EMFA	15443.075	15443.077	15443.12	10x15

5.3. Result Comparison for the Third System

In this section, FA and the proposed method are run on a test system with 20 unit considering power losses. In Table 4, result reported is only the best cost while other costs such as mean cost and maximum cost are neglected because most compared methods have not shown these values. In fact, only improved CSA (ICSA) [12] reported all values and its standard deviation cost is approximately equal to zero but its maximum iteration is 500 while that of the proposed method is 200. As we have increased the maximum iteration to 500, the standard deviation of the proposed method was also zero. In comparisons with other methods, it can reveal that the proposed method can also obtain approximate solution quality with CSA, ORCSA and better solution quality than BBO and FA; however, the result of (N_{FXG}) of the proposed method is much less than that of other ones. Clearly, the proposed method is more effective and faster than FA and other methods for the case.

Table 4. Result Comparisons for System 3

Method	Best Cost (\$/h)	N_{FXG}
CSA [12]	62456.633	10x500
ICSA [12]	62456.633	10x500
BBO [14]	62456.7926	50x400
FA	62458.881	10x1000
EMFA	62456.633	10x200

5.4. Result Comparisons for the Fourth System

In this section, FA and the proposed method are run on a test system with ten units using multi fuels. Four loads of 2400, 2500, 2600 and 2700 MW are employed in turn. For the system, population of FA and the proposed method are set to 10 but the maximum iteration of FA is set to 300 whereas that is set to 50 for the proposed method. Clearly, the purpose of the selection aims to demonstrate the outstanding convergence speed of the proposed method over FA. As a result, the best cost, the population and the maximum iteration from FA, the proposed method and other methods are reported in Table 5. It is clear that the proposed method has found better cost than FA and approximate cost with other methods but the result of (N_{FXG}) of the proposed method is much less than that of FA and other methods. The comparisons can result in a conclusion that the proposed method has the same solution quality with other methods but reaches the fast convergence speed.

Table 5. The Result Comparison for System 4 with Different Loads

Method	2400 MW	2500 MW	2600 MW	2700 MW	N_{FG}
HRCGA [4]	481.723	526.238	574.3808	623.809	10x800
RCGA [4]	481.723	526.239	574.3966	623.809	10x800
DE [5]	481.723	526.239	574.381	623.809	60x200
IEP [6]	481.779	526.304	574.473	623.851	-
CA [8]	481.723	526.24	574.381	623.809	30x100
HICDE [7]	481.723	526.239	574.381	623.809	20x200
FA	485.6	528.1	577.0	627.89	10x300
EMFA	481.723	526.238	574.381	623.809	10x50

6. Conclusion

In this paper, an effectively modified firefly algorithm has been applied for solving four systems of ELD problem. In the four systems, different types of fuel cost function such as single fuel and multi fuels, and different constraints such as power losses and prohibited working zones are taken into account in aim to test the performance of the proposed method. The proposed method has used a new technique for searching new solutions that FA has coped with low quality solutions and low convergence. The result comparison can lead to a conclusion that the proposed method is much better than FA in terms of finding higher quality solution, using lower population and lower maximum iteration. Comparing the proposed method with other existing methods also results in the same evaluation that the proposed method can obtain better or approximate quality solution with faster convergence speed. Consequently, the proposed method is an effective and robust method for dealing with ELD problem.

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