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Combined economic-emission load dispatch solution using firefly algorithm and fuzzy approach

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ABSTRACT

This paper proposes Firefly Algorithm (FA) with fuzzy approach for solving combined economic-emission load dispatch (CEELD) problem in power generation. The main objective of the CEELD problem is to determine the optimal cost and emission level of power generation and fulfill the load demand and operational constraints. The CEELD problem used weighted sum method to combine two objective functions (cost and emission) into single objective. Then, the Fuzzy-based mechanism approach is integrated in FA to find the best compromise solution for both conflicting cost and emission level. The FA has been tested on IEEE 118-bus 14-unit test system for minimization both cost of power generation and emission level. The performance of FA for solving CEELD problem has been investigated in terms of optimal solution, convergence characteristics and Pareto front solution. From the comparison of the CEELD solutions, it found that FA can provide significant cost and emission reduction compared to other methods. Thus, it can be used as alternative approach for solving any optimization problems.

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1. INTRODUCTION

Nowadays, economic-emission problem is getting considered in today's electricity market and it is very crucial to control the emission resulted. The good quality power system will bring the great satisfaction to the consumer since most of the daily routine depends on electricity. Economic Load Dispatch (ELD) has become the critical problem in electrical power generation systems. The aim of ELD is to find an optimal power so that the generation cost will minimized while satisfying load demand and all other operational constraints [1].

Operating at minimum cost can no longer be considered alone since the consumer need a clean environment [2]. The environmental aspect need to be taken into consideration when burned the fossil fuels at thermal power plant. The emission released such as nitrogen oxide (NOx), carbon dioxide (CO2), Sulphur dioxide (SO2) and etc. are hazardous to the environment. This emission has become the main cause of air pollution [3]. The US Air Act Amendment of 1990 mandates that the electric utility industry should reduce its SO2 emissions by 10million tons/year and the NOx emission by 2 million tons/year from the 1980 level in order to reduce the environmental pollution [4]. It shows that the use of fossil fuels to generate electricity need to be minimized and controlled due to environmental pollution of burning fossil fuels [5, 6-8].

There are many different methods have been used as a mathematical tool for optimization problems. It can be divided into two categories which are traditional and metaheuristic methods. The Metaheuristic methods are recently used for many applications since it capable to find global optimal solution for economic-emission load dispatch (EELD) problems [1, 9-19]. In this project, Firefly Algorithm (FA) is applied to investigate the optimal cost and emission, robustness and convergence characteristics of EELD problem. The FA is first introduced by Xin-She Yang in 2008 and the behavior of the algorithm is inspired by fireflies' movement [3]. Moreover, the main advantages of FA are simple concept and easy to implement since it is based on the global communication among the swarming particles [20-22].

2. PROBLEM FORMULATION

Sustaining load demand while minimizing emission level and total generation cost requires big challenge as a multi-objective optimization problem. The elements of the load dispatch problem that include the objective functions and operation constraints are deeply explained as follows:

2.1. Economic Load Dispatch

The aim of Economic load dispatch (ELD) is to reduce the total generator cost while sustaining load demand and operational constraints. The formulation of ELD problem defined as [23]:

$$F_C = \sum_{i=1}^{ng} F_i(P_i) = \sum_{i=1}^{ng} a_i + b_i P_i + c_i P_i^2 \tag{1}$$

where, Fi (Pi) is generation cost function ($/h), ai, bi, ci are the cost coefficients for the ith generator, ng is the total number of dispatchable plants and Pi is the power output of ith plant.

The objective function of ELD with valve point effect can be represented as the sum of a quadratic and a sinusoidal function as follows [23]:

$$F_C = \sum_{i=1}^{ng} F_i(P_i) = \sum_{i=1}^{ng} (a_i + b_i P_i + c_i P_i^2) + |e_i \sin(f_i(P_i^{\min} - P_i))| \tag{2}$$

where, ei , fi are the cost coefficients for ith generator considering the valve-point effect.

2.2. Emission Load Dispatch

Emission load dispatch is to reduce the total stack emission of nitrogen oxide (NOx), sulphur oxide (SOx) and carbon dioxide (CO2) for the entire system. The objective function defined as [19]:

$$F_E = \sum_{i=1}^{ng} E_i(P_i) = \sum_{i=1}^{ng} \alpha_i P_i^2 + \beta_i P_i + \gamma_i \tag{3}$$

While, the objective function of emission load dispatch considering valve-point effect can be represented as follows [19]:

$$F_E = \sum_{i=1}^{ng} E_i(P_i) = \sum_{i=1}^{ng} \alpha_i P_i^2 + \beta_i P_i + \gamma + (\eta \times \exp(\delta_i \times P_i)) \tag{4}$$

where, Ei (Pi) is the total emission released in kg/h, $\alpha_i, \beta_i, \gamma_i$ are the emission coefficient of ith generating unit and η, δ_i are the emission coefficients of ith generator with valve-point effect.

2.3. Combined Economic and Emission Load Dispatch: Weighted Sum Method

The aim of combined economic and emission load dispatch to minimize total generator cost and emission level that produce energy in thermal power plant simultaneously. To handle this problem, the weighted sum method is used to find the set of optimal solutions between these two conflicting objectives based on weight factor (w) as follows [5]:

$$F = w\sum_{i=1}^{ng} F_i(P_i) + (1-w)h_i\sum_{i=1}^{ng} E_i(P_i) \quad (5)$$

The EELD problem is expressed in a single objective form that are formulated by combining two independent objectives which are total cost and emission level. The weighting factor (w) can be any number between 0 and 1 based our references. The price penalty factor hi is the ratio between maximum cost and maximum emission level of corresponding generator in $/kg [4, 19]:

$$h_i = \frac{F_C(P_i^{\max})}{F_E(P_i^{\max})}, \text{ i = 1,2,…,ng} \quad (6)$$

There following steps can be used to determine the price penalty factor for a particular load demand [19]:

Calculate the ratio between maximum generation cost and maximum emission level “hi” of each generator.

The values of “hi” must arrange in increasing value order.

Add the maximum generated power of each generator one by one starting with the smallest unit price penalty factor until $\sum P_i^{\max} \geq P_D$.

At the point, hi associated with the final unit in this process is the nearest price penalty factor equivalent for the given load.

2.4. Problem Constraints

There are two operational constraints will be used in this problem constraints such as equality and inequality. The power balance constraint is referred to an equality constraint which expressed the total generated power must equal the total power demand and total power losses in the system. The equality constraint is formulated as follows [24]:

$$\sum_{i=1}^{ng} P_i - P_D - P_L = 0 \quad (7)$$

where, PL is the total real power losses and PD is the total power demand.

The generating power limits is the inequality constraints based on minimum ($P_i^{\min}$) and maximum ($P_i^{\max}$) power output as follows:

$$P_i^{\min} \leq P_i \leq P_i^{\max} \quad (8)$$

The transmission network system losses are represented as function of the real power and the B-coefficient matrix using Kron’s loss formula as follows [24, 19]:

$$P_L = \sum_{i=1}^{ng}\sum_{i=1}^{ng}(P_i B_{ij} P_j) + \sum_{i=1}^{ng} B_{i0}P_i + B_{00} \quad (9)$$

where, Bij is the loss coefficient matrix.

3. FIREFLY ALGORITHM FOR SOLVING ECONOMIC-EMISSION LOAD DISPATCH

The main purpose for a firefly’s glow is to act as a prompt system to attract other fireflies. This algorithm is formulated by assuming three idealized rules [25]. The fireflies attractiveness of the fireflies is related to the light intensity and defined as follows [2]:

$$(\beta_r) = \beta_0 e^{-\gamma r^m}, \text{ with m} \geq 1 \quad (10)$$

where, β_0 is the attractiveness at r =0 and r is the distance between two fireflies.

The movement of Firefly Algorithm is defined as the following: [26]

$$x_i^{t+1} = x_i^{t} + \beta_r \ (x_j^{t} - x_i^{t}) + \alpha_t \varepsilon_i^t \tag{11}$$

where, x is the position of each fireflies, β_r is the attractiveness of the ith firefly receives from the jth fireflies, α_t is the randomization parameter and ε_i^t is the vector of random numbers drawn from Gaussian distribution on the tth iteration.

This section described about the implementation steps of Firefly Algorithm for combined economic and emission problem. The effectiveness of FA will be compared with other algorithms. The steps are implemented as follows:

Step 1: Define the objective function of economic-emission dispatch problem using (1) and (3).
Step 2: Set the parameter setting of FA which are α=0.3, β=0.1 and γ=1 and number of population is set to 30.
Step 3: Insert randomized with respect to maximum power generator (P_{max}) and minimum power generator (P_{min}).
Step 4” Evaluate the new solution of Firefly Algorithm with respect to objective function to consider losses. The implementation step for each objective function are:

a. For economic dispatch, (1) is used to minimize the cost of IEEE 118-bus 14-unit test system.
b. For emission, (3) is used to minimize the emission dispatch of IEEE 118-bus 14-unit test system.
c. For minimization of combined economic and emission load dispatch, (5) is used. The weighting factor are selected from 0 to 1 with steps of 0.1.

Step 5: Rank the new solutions from maximum to minimum depends on the objective function value and store the best solution.
Step 6: The constraints in (7), (8) and (9) can be satisfied by using Modification of Infeasible Particle (MIP) approach in [27].
Step 7: Get the movement of firefly which get the optimal solution using (10) and (11).
Step 8: Store the best solution respected to the maximum iterations. Step 4 is repeat until reached maximum number iterations.
Step 9: The best solutions are stored respected to the number of iteration using Fuzzy-based Mechanism.
Step 10: End of algorithm.

3.1. Best Compromise Solution: Fuzzy-Based Mechanism

The best compromise solution is selected among pareto optimal set can be determined using Fuzzy-based approach. Each of objective function is represented by a mechanism function μ_j as shown in (12) [28].

$$\mu_j = \begin{cases} 1 \ , F_j \leq F_j^{min} \\ \frac{F_j^{max} - F_j}{F_j^{max} - F_j^{min}} \ , F_j^{min} \leq F_j \leq F_j^{max} \\ 0 \ , F_j \geq F_j^{max} \end{cases} \tag{12}$$

where, F_j^{min}, F_j^{max} = minimum and maximum value of the j-th objective function.

A normalized mechanism function need to be evaluated for every solution i-th using (13), [28].

$$\mu_i = \frac{\sum_{j}^{n} \mu_{ij}}{\sum_{i=1}^{m} \sum_{j=1}^{n} \mu_{ij}} \tag{13}$$

The highest value of μ is chosen as the best compromise solution.

4. SIMULATION RESULTS

The objective of this result is to develop Firefly Algorithm for solving CEED problem using Weighted Sum Method and Fuzzy-Based Mechanism. The simulation and analysis were conducted to identify the performance of Firefly Algorithm on IEEE 118-Bus14-unit test system with total power demand is 950 MW. The parameters of Firefly Algorithm take the following values for all test system which are $\alpha = 0.3$, $\beta = 0.1$ and $\gamma = 1$. The maximum iteration and number of population are set to 1000 and 30, respectively. The generator data of cost and emission ARE taken from [28].

4.1. Minimizing Cost and Emission Individually of IEEE 118-Bus 14-Unit System

To validate the effectiveness of the proposed FA, each cost and emission objective function is solved individually. The results obtained this test system are shown in Table 1. It highlights the minimum cost and emission are 4303.6009 $/h and 25.2374 kg/h respectively. Table 2 presents the comparison of the FA with other method. The results show that the FA has achieved significantly better results compared to MHSA.

Table 1. Optimal Cost and Emission Obtained by FA

Generators	Minimize Cost	Minimize Emission
P_1 (MW)	104.6483	70.8384
P_2 (MW)	92.7271	50.0000
P_3 (MW)	50.0000	78.0791
P_4 (MW)	50.0000	88.8467
P_5 (MW)	50.0000	67.7914
P_6 (MW)	50.0000	50.0000
P_7 (MW)	50.0000	73.4668
P_8 (MW)	50.0000	72.3696
P_9 (MW)	59.4909	73.7123
P_{10} (MW)	64.6067	90.0105
P_{11} (MW)	64.1038	50.0000
P_{12} (MW)	176.9597	72.5723
P_{13} (MW)	50.0000	72.3089
P_{14} (MW)	50.0000	50.0000
Total Power (MW)	962.5366	959.9961
P_L (MW)	12.5366	9.9961
P_D (MW)	950.0000	950.0000
Total Cost ($/h)	**4303.6009**	4547.9254
Total Emission (kg/h)	394.1541	**25.2374**

Table 2. Comparison for Minimize Cost and Emission Individually between the Methods for Test System 2

Algorithm	Minimize Cost		Minimize Emission	
	Total Cost ($/h)	Total Emission (kg/h)	Total Cost ($/h)	Total Emission (kg/h)
MHSA [28]	4304.9500	357.3390	4539.2280	27.8920
Proposed FA	4303.6009	394.1541	4547.9254	25.2374

Figure 1 shows the convergence characteristics for the best result of cost and emission. It can be seen that the approximate optimal values reached at around 200 and 300 iterations for cost and emission minimization respectively. The figure proves the high-speed convergence of FA in solving EELD problem.

4.2. Combined Economic and Emission Load Dispatch of IEEE 118-bus 14-Unit System

The results obtained by FA for solving combined economic and emission dispatch are tabulated in Table 3 for different weight values. From the table, it clearly shows the value w=0 is minimize the emission while value w=1 is minimize the total generation cost.

Table 3. Pareto front Solutions

w	Cost	Emission	μc	μe	μ
0.0	4547.9254	25.2374	0.0000	1.0000	0.0714
0.1	4522.6029	26.5943	0.1036	0.9964	0.0786
0.2	4495.9941	31.8206	0.2125	0.9824	0.0854
0.3	4466.5354	43.5049	0.3331	0.9511	0.0918
0.4	4428.8999	66.2426	0.4871	0.8901	0.0984
0.5	4387.9832	103.7431	0.6546	0.7897	0.1032
0.6	4352.3001	146.6544	0.8006	0.6747	0.1054
0.7	4330.8089	186.7546	0.8885	0.5673	0.1040
0.8	4313.6995	245.1099	0.9586	0.4110	0.0979
0.9	4305.3779	282.4456	0.9926	0.3109	0.0932
1.0	4303.5753	398.5150	1.0000	0.0000	0.0715

Based on Figure 2, the total cost to generate electricity at thermal power plant is increased as the weighting factor is decreased from 1 to 0. Meanwhile, for the total emission released from the generator is decreased when the weighting factor decreased. It is shown that the total cost and emission are conflicting to each other. Therefore, the fuzzy based method in section 3.1 is used to determine the best compromise solution among the solutions in Figure 2.

Therefore, the optimal power output for best compromise solution obtained by fuzzy approach is at w=0.6. The total cost obtained for the best compromise solution is 4352.3001 $/h whereas the total emission produced is 146.6544 kg/h which correspond to w=0.6. The results obtained by proposed FA has been compared with the results of other algorithms such as NGSA-II, MHSA and HAS as shown in Table 4. It is obvious that the total cost achieved by proposed FA is significantly better than NGSA-II and MHSA in terms of cost while the emission level is slightly lower than HSA.

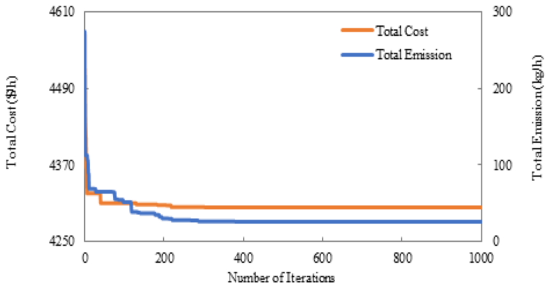

Figure 1. Convergence Characteristics of FA for minimizing Cost and Emission Individually

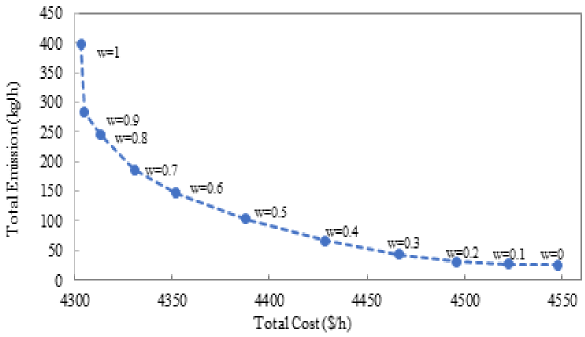

Figure 2. Pareto Front Obtained by FA with WSM

Table 4. Comparison of the Best Compromise Solutions Obtained by Different Methods

Algorithm	NGSA-II [29]	MHSA [29]	HSA [29]	Proposed FA
P_1 (MW)	69.4618	79.3683	99.2872	98.9649
P_2 (MW)	65.9624	62.1868	68.1241	64.1944
P_3 (MW)	51.9713	50.0000	63.5609	50.0000
P_4 (MW)	72.3437	61.1287	62.0231	67.3355
P_5 (MW)	73.6853	78.6284	56.3413	63.5035
P_6 (MW)	70.3004	51.5320	50.0000	50.0000
P_7 (MW)	67.5641	67.3322	50.0000	50.0000
P_8 (MW)	69.5526	50.0000	50.0000	50.0000
P_9 (MW)	69.4421	79.3041	82.4229	85.1549
P_{10} (MW)	81.1416	93.6602	100.2080	99.0745
P_{11} (MW)	71.3414	68.3105	51.5145	58.2738
P_{12} (MW)	70.7760	96.0040	126.6166	123.4539
P_{13} (MW)	69.9194	68.9558	50.0000	50.0000
P_{14} (MW)	68.5146	53.2431	50.0000	50.0000
P_D (MW)	900.0000	900.0000	900.0000	900.0000
Total Cost ($/h)	4534.3995	4432.298	4326.4785	4352.3001
Total Emission (kg/h)	122.5034	100.708	153.7821	146.6544

5. CONCLUSION

In this paper, the performance of Firefly Algorithm with fuzzy approach has been investigated to optimize the total generation cost and emission level in power dispatch. The proposed method used weighted sum method to combined both objective function (cost and emission level) and generate the set of possible solution based on various weighted values. From this solution, fuzzy mechanism is utilized to determine the best compromise solution for minimizing cost and emission of power generation simultaneously. The effectiveness of proposed algorithm has been tested on IEEE 118 nus with 14-unit system by using MATLAB software. From the simulation results, it highlights the effectiveness of proposed method in terms of optimal cost and emission, convergence characteristics, Pareto front solution and comparison of the best compromise solution. It found that FA affirms its good performances to obtain better optimal cost and emission for CEELD problems. Therefore, it can be concluded that FA confirms the effective high-quality solution for solving CEELD problem and can be used for solving any single and multi-objective problems.

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