Combined Economic and Emissions Dispatch with Valve Point Effect using a Novel Moth Flame Optimization and Bat Hybrid Algorithm

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DOI: 10.29322/IJSRP.9.03.2019.p8728
http://dx.doi.org/10.29322/IJSRP.9.03.2019.p8728

Abstract- This paper presents the application of a novel Moth flame optimization and Bat hybrid algorithm (MFO_BAT) in the area of combined economic and emissions dispatch with the consideration of valve point effect. Combined economic and emissions dispatch is a crucial area due to rise of environmental pollution caused by greenhouse gases from thermal power plants and other human activities. Also, the cost of generation of electric power by using thermal power plant is at elevated level due to high expenses incurred on fuels. In this paper the valve point effect is considered whereby modern steam generators are incorporated with this technology for increasing the efficiency. Furthermore, three primary emissions from thermal power plants which are CO_x, NO_x and SO_x are considered. The six units and ten units test systems are used for implementing the study. The results of a novel Moth Flame Optimization and Bat hybrid algorithm are compared with other methods reported in the literature and found to be promising.

Index Terms- Bat Algorithm, Economic Dispatch, Emissions Dispatch, Moth Flame Optimization, Multi-Objective Optimization

I. Introduction

Traditional economic dispatch used to depends on the fuel cost whereby the power output of each generating unit was determined with the purpose of minimizing the expenses incurred on fuel used for generating electric power [1]. With the increase of electric energy generation by using fuels, the amount of pollutants gases from thermal power plants have been increasing year after year as a result thermal electric generation is accounted as one among the major contributors of air pollution globally [2]. After the issue of emissions from thermal power plants became more sensitive, nowadays the economic dispatch is no longer depending on fuel cost only but also the factor of emissions is considered, thus gave rise to the study of combined economic and emissions dispatch whereby the cost of electric power generation depends on both fuel expenses and the amount of emissions from thermal power plants as recommended by Clean Air Act Amendments (CAAA) of 1990[3]. With the concern of increasing the efficiency of thermal power plants, nowadays the fact of valve point effects technology is taken into account which results into adopting the ripple form cost function and further modification of the economic dispatch objective function [4]. For finding the best compromise solution between the economic dispatch and emissions dispatch, max-max price penalty factor method has proven to be more effective in converting the multi-objective optimization problem into a single objective optimization problem [5].

The combined economic and emissions dispatch have been solved by using different kinds of methods. Among these methods are conventional methods which are Liner Programming [6], Interval Gradient (IG) method[7], Newton Raphson (NR) method[8] etc. These methods are weak when dealing with non-convex objective functions since they tend to suffer from local convergence (premature convergence). On the other hand, artificial intelligence methods have been also used in solving the optimization problems of combined economic and emissions dispatch. These methods includes Biogeography-Based Optimization (BBO) [9], Genetic Algorithm[10], hybrid Artificial Bee Colony and Simulated Annealing Algorithm (ABC_SA) [11], Particle Swarm Optimization[12] etc. Using the stochastic approach for facilitating the random search of the search space, the artificial intelligence methods are very effective in finding the optimal solution for both convex and non-convex objective functions however still they are not effective in finding the precisely global optimal solution.

For improving the quality of solutions, this paper presents the application of Moth Flame Optimization and Bat hybrid algorithm in the area of combined economic and emissions dispatch when considering the valve point effect and both three primary emissions from thermal power plants which are CO_x,

NO_x and SO_x,. The novel Moth Flame Optimization and Bat hybrid algorithm is developed from two recent algorithm which are Moth Flame Optimization and Bat Algorithms. Based on their strength, the Moth Flame Optimization is used for exploration whereby the Bat algorithm is used for exploitation. The results of the novel Moth Flame Optimization and Bat hybrid algorithm are compared with other methods' results reported in the literature which are Biogeography-Based Optimization (BBO) and hybrid Artificial Bee Colony and Simulated Annealing Algorithm (ABC_SA) and found to be promising.

The organization of this paper is as follows, Section II presents the formulation of combined economic and emissions dispatch objective function with the consideration of valve point effect and both three primary emissions from thermal power plants, also the hybridization of Moth Flame Optimization and Bat algorithms is presented under this section. Section III presents the test systems and section IV presents the results and discussion while the conclusion of this paper is presented under section V.

II. PROBLEM FORMULATION

The formulation of combined economic and emissions dispatch objective function with the valve point effect is achieved by converting the multi-objective optimization problem into a single objective function by using the max-max price penalty factor. Mathematically it is as follows;

$$Minimize(Total\ cost) = \sum_{i=1}^{NG} A + hB \qquad (\$/hr) \qquad (1)$$

Where A, B and h are economic dispatch objective function, emission dispatch objective function and price penalty factor defined by equation (2), (3) and (4).

$$A = a_i P_i^2 + b_i P_i + c_i + \left| e_i \sin(f_i (P_i^{\min} - P_i)) \right| \qquad (\$/hr) \qquad (2)$$

$$B = \alpha_i P_i^2 + \beta_i P_i + \gamma_i + \eta_i \exp(d_i \times P_i) \qquad (Kg/hr) \qquad (3)$$

$$h_i = \frac{a_i P_{i(\max)}^2 + b_i P_{i(\max)} + c_i + \left| e_i \sin(f_i (P_{i(\min)} - P_{i(\max)})) \right|}{\alpha_i P_{i(\max)}^2 + \beta_i P_{i(\max)} + \gamma_i + \eta_i \exp(d_i \times P_{i(\max)})} \qquad (\$/Kg) \qquad (4)$$

Where a_i, b_i, c_i are fuel cost coefficient of i^{th} unit, $\alpha_i, \beta_i, \gamma_i$ are coefficient of emissions of the i^{th} generating unit, e and f are fuel cost coefficient of valve point effect while d and η are the emission coefficient of valve point effect. P_i is generated power by i^{th} unit and NG is the total number of generating units.

Considering three primary emissions from thermal power plants which are CO_x, NO_x and SO_x, the objective function is formulated as follows;

$$minimize(Total\ cost) = \sum_{i=1}^{NG} F_f + h_N E_N + h_S E_S + h_C E_C \qquad (\$/hr) \qquad (5)$$

Whereby F_f, E_N, E_S and E_C are fuel cost, NO_X emissions, SO_X emissions and CO_X emissions objective functions given by equation (6), (7), (8) and (9) respectively

$$F_f = a_i P_i^2 + b_i P_i + c_i \qquad (\$/hr) \qquad (6)$$

$$E_N = \alpha_{i(N)} P_i^2 + \beta_{i(N)} P_i + \gamma_{i(N)} \qquad (Kg/hr) \qquad (7)$$

$$E_S = \alpha_{i(S)} P_i^2 + \beta_{i(S)} P_i + \gamma_{i(S)} \qquad (Kg/hr) \qquad (8)$$

$$E_C = \alpha_{i(C)} P_i^2 + \beta_{i(C)} P_i + \gamma_{i(C)} \qquad (Kg/hr) \qquad (9)$$

Where

$\alpha_{i(N)}$, $\beta_{i(N)}$ and $\gamma_{i(N)}$ are coefficients of NO_X emission of the i^{th} generating unit

$\alpha_{i(S)}$, $\beta_{i(S)}$ and $\gamma_{i(S)}$ are coefficients of SO_X emission of the i^{th} generating unit

$\alpha_{i(C)}$, $\beta_{i(C)}$ and $\gamma_{i(C)}$ are coefficients of CO_X emission of the i^{th} generating unit

The price penalty factors h_N, h_S and h_C of NO_X emissions, SO_X emissions and CO_X emissions are given by equation (10), (11) and (12) respectively.

$$h_{i(N)} = \frac{a_i P_{i(\max)}^2 + b_i P_{i(\max)} + c_i}{\alpha_{i(N)} P_{i(\max)}^2 + \beta_{i(N)} P_{i(\max)} + \gamma_{i(N)}} \qquad (\$/Kg) \qquad (10)$$

$$h_{i(S)} = \frac{a_i P_{i(\max)}^2 + b_i P_{i(\max)} + c_i}{\alpha_{i(S)} P_{i(\max)}^2 + \beta_{i(S)} P_{i(\max)} + \gamma_{i(S)}} \qquad (\$/Kg) \qquad (11)$$

$$h_{i(C)} = \frac{a_i P_{i(\max)}^2 + b_i P_{i(\max)} + c_i}{\alpha_{i(C)} P_{i(\max)}^2 + \beta_{i(C)} P_{i(\max)} + \gamma_{i(C)}} \qquad (\$/Kg) \qquad (12)$$

The optimization problems in this paper are subjected to two system constraints which are equality constraints and inequality constraints as given in (13) and (15).

$$P_G = \sum_{i=1}^{NG} P_D + P_L \qquad (13)$$

Whereby P_G, P_D and P_L are total generation, power demand and losses of the system

Using Kron's formula [13], total losses of the system (P_L) are given in (14).

$$P_L = \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_i B_{ij} P_j + \sum_{i=1}^{NG} B_{io} P_i + B_{oo} \qquad (MW) \qquad (14)$$

Where B, Bio and Boo are loss coefficients matrices and P_i is the generated power by unit $i^{th.}$

Based on the generators' maximum and minimum limits, the inequality constraint is given by;

$$P_{i(\min)} \le P_i \le P_{i(\max)} \quad (15)$$

Given that P_i is the power generated by unit i^{th}

ALGORITHMS

The development of Moth Flame Optimization and Bat hybrid algorithm through combining MFO and Bat algorithm is presented under this sub-section.

Moth Flame Optimization

Moth Flame Optimization is the bio-inspired algorithm which was developed by Seyedali Mirjali in 2015 [14], by nature the moths normally navigate at a certain angle with reference to the moon position at night. Based on moths' behaviors, in this algorithm the moths' navigations are assumed to be in transverse movement around the flame which is the best solution.
In this algorithm, each moth navigates around its flame while searching for a solution and due to this property the Moth Flame Optimization becomes the most effective algorithm in exploration of the search space. The Moths' positions updating is achieved by using equation (16) while the distance between the moth and flame (D) is computed by using equation (17) [14].

$$S\left(M_i, F_j\right) = D_i e^{bt} \cos\left(2\pi t\right) + F_j \quad (16)$$

$$D_i = \left|F_j - M_i\right| \quad (17)$$

Where
b is a constant of defining the shape of logarithmic spiral
t is random number in [-1, 1]
l *is* current number of iterations
N is a maximum number of flames
F_j is a position of j[th] flame
M_i is a position of i[th] moth
The number of flames is normally updated iteratively by removing the flame with the poor solution; thus is attained by using equation (18).

$$Flame(number) = round\left(N - l \times \frac{N - l}{T}\right) \quad (18)$$

Where
T is a maximum number of iterations
l *is* current number of iterations
N is a maximum number of flames

Bat Algorithm

The bat algorithm is the population based algorithm which is inspired from the behavior of micro bats. The micro bat uses the reflected sound (echo) for locating their prey as well as the précised location of the concerned prey. This algorithm was developed by Xin sheng Yang in 2010 based on the echolocation mechanism of micro bat [16].

In this algorithm, the solution of optimization is represented by the bat position where by the fitness computation is achieved through bats' positions implementation in the given objective function. The solution of Bat algorithm which is the bat position is obtained through frequency and velocity parameters as shown in equation (19-21).

$$f_i = f_{\min} + (f_{\max} - f_{\min})\beta \quad (19)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_*) f_i \quad (20)$$

$$x_i^t = x_i^{t-1} + v_i^t \quad (21)$$

Where f, v and x are frequency, velocity and position of bat respectively

Using (22) and (23), the Loudness (A) and pulse rate (r) of bat algorithm are normally updated iteratively as follows;

$$A_i^{t+1} = \alpha A_i^t \quad (22)$$

$$r_i^{t+1} = r_i^0 [1 - \exp(-\gamma t)] \quad (23)$$

With the condition that $0 < \alpha < 1$ and $\gamma > 0$

Hybridization of Moth Flame Optimization and Bat Algorithms

Bat algorithm is the very effective algorithm in exploiting the possible best solution of optimization problem but vulnerable to local stagnation, at the same time Moth Flame Optimization is a strong algorithm in terms of exploration of the search space but limited to exploitation capability [17]. This paper addresses the discussed strength and weakness of the concerned algorithms through hybridizing the strengths of Moth Flame Optimization and that of Bat Algorithm which are exploration and exploitation respectively, thus results into the development of the novel Moth Flame Optimization and Bat hybrid algorithm.

Through adjusting the values of loudness and pulse rate, the Bat algorithm is tuned into exploitation mode [18] while Moth Flame Optimization is tuned into full exploration mode through adjusting the value of "*b*" in (16) [17].

Moth Flame Optimization and Bat Algorithm Hybridization Steps Based on Combined Economic and Emissions Dispatch

Step 1: Define the load demand and generators' power limits (maximum and minimum).
Step 2: Define the objective function and equality constraints based on power balance.
Step 3: Define the generators' power in terms of moths' and bats' positions.
Step 4: Define the dimensions of searching agents with reference to the number of generating units.
Step 5: State the population

Step 6: Define the frequency (maximum and minimum), loudness and pulse rate of bats.
Step 7: Initialize the frequency and velocity of bats
Step 8: Initialize the moths' positions based on generators' limits (maximum and minimum).
Step 9: While taking into account the equality constraints, compute the power losses and evaluate the fitness of the objective function (combined economic and emissions dispatch) using Moth position.
Step 10: Select the global best value based on minimization based optimization problem.
Step 11: Set iteration to 1
Step 12: Update number of flames using (18).
Step 13: If the number of iteration is equal to 1, perform the sorting of moths' positions and assign them as sorted population (F_j).
Step 14: If the number of iteration is greater than 1, perform the sorting of moths' positions based on the previous iteration and current iteration and assign them as sorted population (F_j).
Step 15: Calculate "a" using equation (24)

$$a = (-1 + current\ iteration) \times \left(\frac{-1}{Maximum\ iteration} \right) \quad (24)$$

Step 16: Calculate "t" by using equation (25)

$$t = (a - 1) \times rand + 1 \quad (25)$$

Step 17: Compute the distance of month with reference to the corresponding flame using equation (17)
Step 18: Update moths' positions by using equation (16) .
Step 19: Check the inequality constraints by using generator power limits for bringing back the moths which are outside the search space.
Step 20: Updating frequencies and velocites of bats by using equation (26) and (27) respectively

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (26)$$

$$v_i^t = v_i^{t-1} + (Moth\_position_i^t - x_*)\, f_i \quad (27)$$

Step 21: Update the bats positions by using equation (28).

$$x_i^t = Moth\_position_i^{t-1} + v_i^t \quad (28)$$

Step 22: Generate the best position of bat if the random number is greater than the pulse rate.
Step 23: By using the generators' power limits, bring back the bats which are outside the search space.
Step 24: Calculate the power losses and then evaluate the objective function by using bats positions while satisfying the equality constraints.
Step 25: Update local best values.
Step 26: Update the global best fitness and global best position
Step 27: Repeat step 12-26 until the maximum iteration is attained.
Step 28: Display the global best fitness of the objective function (total cost/fuel cost/emissions) and global best position (power generated in each unit).

III. TEST SYSTEM

This study is implemented in MATLAB 2016 using ten units test system and six units test system with the load demand of 2000MW and 1800MW respectively. The population used is 40 while tuning parameters for the case of Moth Flame Optimization and Bat hybrid algorithm (MFO_BAT) are set at *b*=5 for Moth Flame Optimization part while for the part of Bat algorithm $A = 0.9$ and $r = 0.001$.
The dispatch coefficients (Economic and emissions) and transmission losses coefficients matrix were taken from [11] for the case of ten units test system while the valve point effect is considered and from [9] for the case of six units test system with the consideration of both CO_x, NO_x and SO_x emissions.

IV. RESULTS AND DISCUSSION

This section discusses the results obtained from the application of the developed Moth Flame Optimization and Bat hybrid algorithm in combined economic and emissions dispatch optimization problem. The obtained results are compared with the results of parents' algorithms which are Moth Flame Optimization and Bat Algorithm based on the same kind of optimization problem and loading conditions. Further validation of the results is done by comparing the results of MFO_BAT with other results reported in the literature.

Table 4.1: Combined economic and emissions dispatch with valve-point effect solution at a load of 2000MW

Generator	MFO	BAT	MFO_BAT
P1(MW)	55.0000	54.1105	55.0000
P2(MW)	79.8402	77.0934	79.2991
P3(MW)	83.9132	111.2782	80.7951
P4(MW)	82.8854	51.3847	82.5905
P5(MW)	159.4891	153.7636	160.0000
P6(MW)	239.8765	210.1091	239.9998
P7(MW)	288.2326	241.3386	288.6319
P8(MW)	302.9969	305.4816	300.4299
P9(MW)	393.5197	426.8086	399.7160
P10(MW)	395.8419	452.5424	395.2387
Emission NOx (Kg/hr)	3,934.9	4,128.6	3,933.2
Fuel cost ($/hr)	116,390	115,150	116,400
Losses (MW)	81.6	83.9	81.7
generation	2,081.6	2,083.9	2,081.7
Total cost ($/hr)	321160.6533	330000.7742	321079.5708

Table 4.1 presents the results of combined economic and emissions dispatch with the valve point effect at a load of 2000MW. The utilized test system is the ten units test system while the results produced by MFO_BAT are compared with the results of MFO and Bat algorithms. Focusing on the total cost of generation, the cost found by implementing MFO_BAT in combined economic and emissions dispatch with valve point effect is 81.0825 $/hr and 8921.2034 $/hr lower than MFO and BAT respectively. The NO_x emissions produced when employing the MFO_BAT is 1.7 Kg/hr lower than MFO emissions and 195.4 Kg/hr lower than the emissions produced when using Bat algorithm.
Figure 4.1 shows the convergence curve of the optimization problem of the combined economic and emissions dispatch with the valve point effect. The red curve presents the optimization by using the BAT algorithm while the blue and green curves present the optimization by using MFO and MFO_BAT respectively.

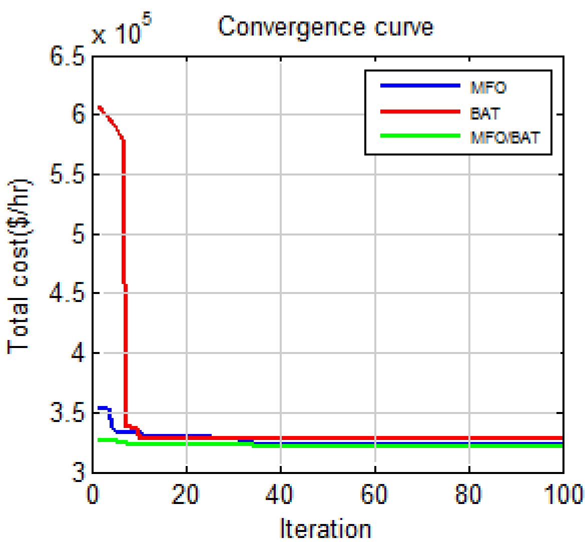

Figure 4.1: Convergence curve of combined economic and emissions dispatch with valve point effect at a load of 2000MW

Making the study more realistic, three primary emissions from thermal power plants which are NO_x, CO_x and SO_x are considered. The six units test system with sufficient information on the coefficients of emissions under consideration is used to achieve the objective at a load demand of 1800 MW. As presented in Table 4.2, the total generation cost when using MFO_BAT is 388.4194 $/hr and 139.0782 $ lower than MFO and BAT total generation cost. For the case of emissions, the NOx emissions produced when using MFO_BAT are 2.3 Kg/hr and 2.7 Kg/hr lower than the emissions found when using MFO and BAT respectively while the SOx emissions produced when using MFO_BAT are 179 Kg/hr higher than that of MFO and 123 Kg/hr lower than the emissions produced by BAT algorithm. The COx emissions produced by MFO_BAT algorithm are 2611 Kg/hr lower than MFO emissions but 67 Kg/hr higher than the emission produced by the BAT algorithm. The convergence curve of this optimization problem is presented in Figure 4.2.

Table 4.2: Combined economic and emissions dispatch solution considering CO_X, NO_X and SO_X emissions at a load of 1800MW

Generator	MFO	BAT	MFO-BAT
P1 (MW)	249.7788	279.6535	270.3457
P2 (MW)	293.0410	307.2588	300.0209
P3 (MW)	600.0000	546.4570	539.3338
P4 (MW)	133.7144	144.5592	140.1550
P5 (MW)	439.3485	444.3207	451.0824
P6 (MW)	228.6593	221.4659	244.3550
Total cost ($/hr)	81312.0483	81062.7071	80923.6289
Emission NOx (Kg/hr)	2417.6	2412.6	2415.3
Emission SOx (Kg/hr)	13327	13629	13506
Emission COx (Kg/hr)	71378	68700	68767
Fuel cost($/hr)	18959	18907	18932
Losses (MW)	144.5	143.7	145.3
Total generation (MW)	1944.5	1943.7	1945.3

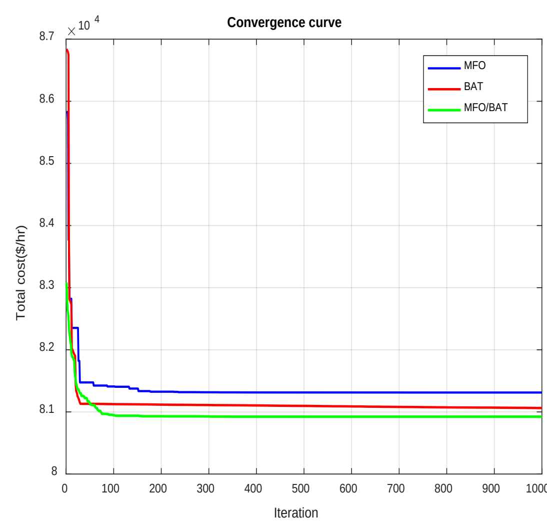

Figure 4.2: Convergence curve of combined economic and emissions dispatch solution considering CO_X, NO_X and SO_X emissions at a load of 1800MW.

Table 4.3: Results validation of combined economic and emissions dispatch with valve point effect at a load of 2000MW

Generating unit	ABC_SA [11]	MFO_BAT
P1(MW)	55.00	55.0000
P2(MW)	70.32	79.2991
P3(MW)	81.18	80.7951
P4(MW)	96.47	82.5905
P5(MW)	159.72	160.0000
P6(MW)	155.92	239.9998
P7(MW)	229.31	288.6319
P8(MW)	337.57	300.4299
P9(MW)	431.34	399.7160
P10(MW)	467.57	395.2387
Total generation (MW)	2,084.45	2,081.7
Losses (MW)	84.45	81.7
Fuel cost ($/hr)	113510	116,400
Emission(kg/hr)	4169	3,933.2
Total cost($/hr)	330210	321079.5708

The results validation is done by comparing the results produced by the developed method with those reported in the literature. As it shown in Table 4.3, the results of MFO_BAT is compared with the results of hybrid Artificial Bee Colony and Simulated Annealing algorithm (ABC_SA) reported in [11]. When using the MFO_BAT, the total cost found was 9,130.4292 $/hr lower than the cost which was found by ABC_SA while the emissions produced by MFO_BAT was 235.8 Kg/hr lower than that of ABC_SA

Table 4.4 presents the results validation of the application of MFO_BAT algorithm to a test system which consists of CO_X, NO_X and SO_X emissions. For the case of the total cost, the total generation cost found when using MFO_BAT was 1.33 $/hr lower than that of BBO. The emissions produced by MFO_BAT were 0.83 Kg/hr of NO_X and 50.33Kg/hr of CO_X lower than that of BBO but 14.07 Kg/hr of SO_X higher than that produced by BBO.

Table 4.4: Results validation of combined economic and emissions dispatch considering CO_X, NO_X and SO_X emissions at a load of 1800MW

Generator	BBO [9]	MFO_BAT
P1 (MW)	270.398419	270.3457
P2(MW)	299.351832	300.0209
P3(MW)	538.382133	539.3338
P4(MW)	139.632475	140.1550
P5(MW)	452.562062	451.0824
P6(MW)	245.197113	244.3550
Total cost ($/hr)	80,924.967912	80923.6289
Emission NOx (Kg/hr)	2416.130219	2415.3
Emission SOx (Kg/hr)	13,491.924811	13506
Emission COx (Kg/hr)	68,817.333954	68,767
Fuel cost($/hr)	18,934.704952	18932
Losses (MW)	145.524034	145.3
Total generation (MW)	1945.524034	1945.3

V. CONCLUSION

This paper has presented the development of a novel Moth Flame Optimization and Bat hybrid algorithm through hybridizing two recent algorithms which are Moth Flame Optimization and Bat algorithm. The developed MFO_BAT algorithm was used to solve the combined economic and emissions dispatch for finding the better solution. The method was implemented in ten units test system and six units test system with COx, NO_x and SO_x emissions. The results obtained when using MFO_BAT were validated by using other results from literature and found to be promising in terms of the main objective which is the reduction of electric power generation cost and emissions from thermal power plants.

As part of future work, the developed Moth Flame Optimization and Bat hybrid algorithm can be used for solving multi-objective optimization problem having more than two objective functions for realizing its usefulness in complex problems.

REFERENCES

[1] J. Zhu, *Optimization of power system operation*, Second Edt. Hoboken,New Jersey: John Wiley & Sons, Inc, 2015.

[2] International EnergyAgency, “Power generation from coal,” Paris, 2010.

[3] J. Gunda and P. Acharjee, “Multi Objective Economic Dispatch Using Pareto Frontier Differential Evolution,” *Int. J. Eng. Sci. Technol.*, vol. 3, no. 10, pp. 7389–7396, 2011.

[4] K. Murali and T. Jayabarathi, “Solution to economic dispatch problem

with valve-point loading effect by using catfish PSO algorithm," *Res. Artic.*, vol. 8, no. 3, pp. 290–296, 2014.

[5] R. Chellappan, "Economc and Emission Load Dispatch using Cuckoo Search Algorithm," no. 2, pp. 1–7, 2017.

[6] A. Ashfaq and A. Z. Khan, "Optimization of Economic Load Dispatch problem by Linear Programming modified Methodology," *2nd Int. Conf. Emerg. Trends Eng. Technol. (ICETET'2014), May 30-31, 2014 London (United Kingdom)*, 2014.

[7] S. Ray, "Economic Load Dispatch Solution using Interval Gradient Method," *Adv. Res. Electr. Electron. Eng.*, vol. 1, no. 4, pp. 55–58, 2014.

[8] J. S. Dhillon, S. C. Parti, and D. P. Kothari, "Stochastic economic emission load dispatch," *Electr. Power Syst. Res.*, vol. 26, no. 3, pp. 179–186, 1993.

[9] P. Taylor, A. Bhattacharya, and P. K. Chattopadhyay, "Electric Power Components and Systems Application of Biogeography-based Optimization for Solving Multi-objective Economic Emission Load Dispatch Problems Application of Biogeography-based Optimization for Solving Multi-objective Economic Emission Load Dispatch Problems," no. December 2012, pp. 37–41, 2010.

[10] E. Engineering and E. Engineering, "An Application of Environmental Economic Dispatch Using Genetic Algorithm," vol. 6, no. 1, pp. 1–4, 2016.

[11] S. Arunachalam, R. Saranya, and N. Sangeetha, "Hybrid Artificial Bee Colony Algorithm and Simulated Annealing Algorithm for Combined Economic and Emission Dispatch Including Valve Point Effect," pp. 354–365, 2013.

[12] A. S. R. M Vijay Karthik, "Particle Swarm Optimization to solve Economic Dispatch considering Generator Constraints M Vijay Karthik , 2 , Dr A Srinivasula Reddy F P □," *IJES*, pp. 94–100, 2014.

[13] S. K. Soni and V. Bhuria, "Multi-objective Emission constrained Economic Power Dispatch Using Differential Evolution Algorithm," vol. 2, no. 1, pp. 120–125, 2012.

[14] S. Mirjalili, "Moth-Flame Optimization Algorithm : A Novel Nature-inspired Heuristic Paradigm," *Knowledge-Based Syst.*, no. July, 2015.

[15] O. Bozorg-haddad, *Advanced optimization by Nature-Inpired algorithms*. Gateway East: Spring Nature, 2017.

[16] A. Latif and P. Palensky, "Economic Dispatch Using Modified Bat Algorithm," *Algorithms mdpi*, no. July, 2014.

[17] W. Ruta, M. Saulo, and N. O. Abungu, "Emission Constrained Economic Dispatch Using Moth Flame Optimization and Bat Hybrid Algorithm," vol. 11, no. 5, pp. 827–843, 2018.

[18] X. Yang, *Nature-Inspired Optimization Algorithms*, First. London: Elsevier Inc., 2014.

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