Application of Firefly Algorithm for Combined Economic Load and Emission Dispatch

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***Abstract*—**This paper presents an application of Firefly algorithm for multi-objective optimization problem in power system. By economic load scheduling the generations of different plants can be determined such that the total operating cost is minimum. Considering the environmental impacts that grow from the emissions produced by fossil fuelled power plant, the economic dispatch that minimizes only the total fuel cost can no longer be considered as single objective. Application of Firefly algorithm in this paper is based on mathematical modelling to solve combined economic and emissions dispatch problems by a single equivalent objective function. Firefly algorithm has been applied to two realistic systems at different load conditions. Results obtained with proposed method are compared with other techniques presented in literature. Firefly algorithm is easy to implement and much superior to other algorithms in terms of accuracy and efficiency.

Keywords*—Economic dispatch; Firefly algorithm; Genetic algorithm; Combined economic and emission dispatch;*

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I. INTRODUCTION

This paper introduces economic dispatch problem in a power system to determine the optimal combination of power output for all generating units which will minimize the total fuel cost while satisfying load and operational constraints. The economic dispatch problem is very complex to solve because of a non-linear objective function, and a large number of constraints.

Well known long-established techniques such as integer programming (2), dynamic programming (3), and lagarangian relaxation (4) have been used to solve the economic dispatch problem. Recently other optimization methods such as Simulated Annealing (5), Genetic Algorithm, Particle Swarm optimization and Tabu Search Algorithm are presented to solve the economic dispatch problem.

Recently, various modern heuristics multi-objective evolutionary algorithms such as Non-dominated Sorting Genetic Algorithm- II (NSGA-II) (9), Evolutionary Programming algorithm (EP) (10), Strength Pareto Evolutionary Algorithm (SPEA) (11) and Multi-Objective Particle Swam Optimization algorithm (MOPSO) (12) may prove to be efficient in solving EED problem by tackling both two objectives of EED problem simultaneously as competing objectives. But all these methods seem to be lack of ability to find the Pareto-optimal front due to their drawbacks: NSGA-II and SPEA may obtain only near Pareto-optimal front with long simulation time when applied to solve EED problem because of the premature convergence of Genetic Algorithm (GA) which they are based on EP suffers from the oscillation of the solution and computational time may be too long when applying EP to solve EED problem, the premature convergence of PSO may lead optimization progresses of MOPSO methods to the local Pareto-optimum front, which would degrade their performance in solving EED problem. In [13-15] including emission constrains to the economic dispatch and unit commitment problems have been presented, under cost-minimization environment.

In this paper a multi-objective optimization problem i.e., Firefly algorithm is proposed to solve combined economic and emissions dispatch problems is presented and the effectiveness of proposed algorithm is demonstrated using three and six generating unit test systems.

II. COMBINED ENVIRONMENTAL ECONOMIC DISPATCH

The traditional economic dispatch problem has been defined as minimizing of an objective function i.e., the generation cost function subject to equality constraints (total power generated should be equal to total system load plus losses for all solutions) and inequality constraints (generations should lie between their respective maximum and minimum specified values). The objective function (1) is minimised subjected to equality constraint (2) and inequality constraints (3).

$$\varphi(x,P)\varphi_t(P_i) = \sum_{i=1}^{n} \varphi_i(P_i) \quad (1)$$

$$g(x,P) \sum_{i=1}^{n} P_i - P_L - P_D = 0 \quad (2)$$

$$H(x,P) \le 0 \quad P_{imin} \le P_i \le P_{imax} \quad (3)$$

Where x is a state variable, Pi is the control variable, i.e., real power setting of i_{th} generator and n is the number of units or generators.

There are several ways to include emission into the problem of economic dispatch. Reference [15] summarizes the various algorithms for solving environmental dispatch problem with different constraints. One approach is to include the reduction of emission as an objective. In this work, only NO_x reduction is considered because it is a significant issue at the global level. A price penalty factor (h) is used in the objective function to combine the fuel cost, Rs/hr and emission functions, kg/hr of quadric form.

The combined economic and emission dispatch problem can be formulated as to minimize

$$\varphi_i = \sum_{i=1}^{n} E_i(P_i)\ Rs/hr \quad (4)$$

$$\varphi_i = \sum_{i=1}^{n}(a_i\, P_i^{\,2} + b_i P_i + c_i) + h \sum_{i=1}^{n}(d_i\, P_i^{\,2} + e_i P_i + fi)Rs/hr \quad (5)$$

Subject to equality and inequality constraint defined by equations (2), (3). Once price penalty factor (h) is known, equation (5) can be rewritten as

$$\varphi_i = \sum_{i=1}^{n}\{(a_i + h\, d_i)P_i^{\,2} + (b_i + he_i)P_i + (c_i + fi)\}\ Rs/hr \qquad (6)$$

This has the resemblance of the familiar fuel cost equation, once h is determined. A practical way of determining h is discussed by [8]. Consider that the system is operating with a load of PD MW, it is necessary to evaluate the maximum cost of each generator at its maximum output, i.e.

(i) Evaluate the maximum cost of each generator at its maximum output, i.e.,

$$F_i(P_{imax}) = (a_i\, P_{imax}{}^{2} + b_{imax}\, P_i + c_{imax})\ Rs/hr \qquad (7)$$

(ii) Evaluate the maximum NO_x emission of each generator at its maximum output, ie,

$$E_i(P_{imax}) = (d_i\, P_{imax}{}^{2} + e_{imax}\, P_i + f_{imax})\ \ kg/hr \qquad (8)$$

(iii) Divide the maximum cost of each generator by its maximum NO_x emission, i.e.,

$$\frac{F_i(P_{imax})}{E_i(P_{imax})} = \frac{(a_i\, P_{imax}{}^{2} + b_{imax}\, P_i + c_{imax})}{(d_i\, P_{imax}{}^{2} + e_{imax}\, P_i + f_{imax})}\, Rs/kg \qquad (9)$$

Recalling that

$$\frac{F_i(P_{imax})}{E_i(P_{imax})} = h_i \ \ \text{Rs/kg} \qquad (10)$$

(iv) Arrange hi (I = 1,2,......,n) in ascending order.

(v) Add the maximum capacity of each unit, one at a time, starting from the smallest h_i unit until total demand is met as shown below.

$$\sum_{i=1}^{n} P_{imax} \geq P_D \qquad (11)$$

At this stage, hi associated with the last unit in the process is the price penalty factor h Rs/Kg for the given load.

Arrange hi in ascending order. Let 'h' be a vector having 'h' values in ascending order.

$$h = [h_1, h_2, h_3, \ldots., h_n] \qquad (12)$$

For a load of PD starting from the lowest hi value unit, maximum capacity of unit is added one by one and when this total equals or exceeds the load, hi associated with the last unit in the process is the price penalty factor for the given PD. Then equation (6) can be solved to obtain environmental economic dispatch using lambda iteration method.

III. FIREFLY ALGORITHM

Over the last 20 years new meta-heuristic algorithm has been introduced almost every year. The nature-inspired ones have become very interesting and distinguished.

The Firefly Algorithm (FFA) is a meta-heuristic nature-inspired population-based optimization algorithm, introduced in 2010 by X. S. Yang [2]. It is based on the firefly bugs behaviour, including the light emission, light absorption and the mutual attraction, which was developed to solve the continuous optimization problems. The Firefly Algorithm is inspired from a mating phase of the firefly bioluminescent communication. Bioluminescent signals are known to serve as element of courtship rituals, methods of prey attraction, social orientation or as a warning signal to predators.

In comparison with the other evolutionary algorithms, FFA has many major advantages in solving complex nonlinear optimization problems. Some of these advantages are simple concepts, usage of real random numbers, easy implementation, higher stability mechanism, depends on the global communication among the swarming particles and less execution efforts.

The development of firefly-inspired algorithm was based on three idealized rules

1. Artificial fireflies are unisex so that sex is not an issue for attraction.
2. Attractiveness is proportional to their flashing brightness which decreases as the distance from the other firefly increases due to the fact that the air absorbs light. Since the most attractive firefly is the brightest one, to which it convinces neighbors moving toward. In case of no brighter one, it freely moves any direction.
3. The brightness of the flashing light can be considered as objective function to be optimized. For maximization problems, the light intensity is proportional to the value of the objective function.

A. Attractiveness

Suppose it is a night with absolute darkness, where the only visible light is the light produced by fireflies. The light intensity of each firefly is proportional to the quality of the solution, it is currently located at. In order to improve own solution, the firefly needs to advance towards the fireflies that have brighter light emission than is his own. Each firefly observes decreased light intensity than the one firefly actually emit, due to the air absorption over the distance.

There are two important issues in the firefly algorithm, variation of light intensity and formulation of the attractiveness. For simplicity, we can always assume that the attractiveness of a firefly is determined by its brightness. Attractiveness of a firefly abides the law

$$\beta(r) = \beta_0 * \exp\left(-\gamma r_{ij}^{n}\right) \qquad \text{With } n \geq 1 \qquad (13)$$

Where, r is the distance between any two fireflies, β0 is the initial attractiveness at r =0, and γ is an absorption coefficient which controls the decrease of the light intensity.

B. Distance

The distance r between firefly i and j at positions xi and xj respectively and is defined as Cartesian distance

$$r_{ij} = \| x_j - x_i \| \qquad (14)$$

C. Movement

The movement itself consists of two elements: approaching the better local solutions and the random step. Moreover, the movement of firefly i which is attracted by a more attractive or brighter firefly j is given by i.e., brighter firefly j is given by

$$x_{inew} = x_{iold} + \beta_0 e^{-\gamma r_{ij}^2}(x_j - x_i) + \alpha * \left[rand - \tfrac{1}{2}\right] \quad (15)$$

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]. The parameter γ characterizes the variation of the attractiveness and its value is important to determine the speed of the convergence and how the FA behaves. For the most cases of implementations, β0 = 1.

IV. RESULTS AND DISCUSSIONS

The applicability and efficiency of FFA algorithm for practical applications has been tested on two test cases. The programs are developed using MATLAB 7.9.

The Parameters for FFA algorithm considered here are: noff=40, α=0.5, β_0=1, β_{min}=0.2, γ=1.

Test case 1: The system consists of three thermal units. The parameters of all thermal units are adapted from [1].

TABLE I. COMPARISON OF TEST RESULTS FOR THREE GENERATING UNITS

Load demand	***h*, Rs/kg***	***Performance***	***Conventional Method [7]***	***SGA [7]***	***RGA [7]***	***FFA***
400MW	44.788	Fuel cost, Rs/hr	20898.83	20831.54	20801.81	20838.26
		Emission, kg/hr	201.5	201.35	201.21	200.2
		Power loss, MW	7.41	7.69	7.39	7.41
		Total cost, Rs/hr	29922	29820	29812	29805.8
500MW	44.788	Fuel cost, Rs/hr	25486.64	25474.56	25491.64	25494.7
		Emission, kg/hr	312.0	311.89	311.33	311.1
		Power loss, MW	11.88	11.80	11.70	11.69
		Total cost, Rs/hr	39458	39441	39433	39430.7
700MW	47.82	Fuel cost, Rs/hr	35485.05	35478.44	35471.4	35464
		Emission, kg/hr	652.55	652.04	651.60	651.5
		Power loss, MW	23.37	23.29	23.28	23.36
		Total cost, Rs/hr	66690	66659	66631	66622.6

Table I shows the summarized result of Combined Economic load and Emission Dispatch (CEED) problem for load demand of 400MW, 500MW and 700MW are obtained by the proposed FFA algorithm with stopping criteria based on maximum generation=100.

Form Table I, it is clear that FFA algorithm gives optimum result in terms of minimum fuel cost, emission level and the total operating cost compared to other algorithms.

Table II gives the best optimum power output of generators for CEED problem using FFA algorithm for load demand 400MW, 500MW and 700MW.

TABLE II. OPTIMUM POWER DISPATCH RESULTS BY FFA METHOD FOR THREE UNITS SYSTEM

Load demand, MW	***Algorithm***	***P1***	***P2***	***P3***
400MW	FFA	102.5412	153.731	151.140
500MW	FFA	128.8134	192.5802	190.300
700MW	FFA	182.6037	271.2863	269.476

Test case II: The system consists of six thermal units. The parameters of all thermal units are adapted from [1]. The summarized result of CEED problem for load demand of 500MW and 900MW are obtained by the proposed FFA algorithm with stopping criteria based on maximum-generation=100 is presented in Table III.

 ISSN: 2321-8169
2448 – 2452

TABLE III. COMPARISON OF TEST RESULTS FOR SIX GENERATING UNIT SYSTEM

Load demand	*h^*, Rs/kg*	*Performance*	*Conventional Method [9]*	*RGA [9]*	*Hybrid GA [9]*	*Hybrid GTA [9]*	*FFA*
500MW	43.898	Fuel cost, Rs/hr	27638.300	27692.1	27695	27613.4	27613.3
		Emission, kg/hr	262.454	263.472	263.37	263.00	263.0
		Power loss, MW	8.830	10.172	10.135	8.93	8.93
		Total cost, Rs/hr	39159.500	39258.1	39257.5	39158.9	39158.9
900MW	47.822	Fuel cost, Rs/hr	48892.900	48567.7	48567.5	48360.9	48353.4
		Emission, kg/hr	701.428	694.169	694.172	693.570	693.729
		Power loss, MW	35.230	29.725	29.718	28.004	28.004
		Total cost, Rs/hr	82436.580	81764.5	81764.4	81529.1	81529.01

Form Table III, it is clear that FFA algorithm gives the optimum result in terms of minimum fuel cost, emission level and the total operating cost compared to other algorithms.

Table IV gives the best optimum power output of generators for CEED problem using FFA algorithm for load demand 500MW and 900MW.

TABLE IV. OPTIMUM POWER DISPATCH RESULTS BY FFA APPROACH FOR SIX UNIT SYSTEM

Load demand, MW	*Algorithm*	*P1*	*P2*	*P3*	*P4*	*P5*	*P6*
500	FFA	33.2855	26.8885	89.91413	90.3852	135.7150	132.7453
900	FFA	92. 3460	98. 5154	150. 2357	148. 5466	220. 3483	218. 0120

V. CONCLUSION

In this paper, a new optimization of firefly algorithm has been proposed for Combined Economic load and Emission Dispatch problem. In order to prove the effectiveness of algorithm it is applied to CEED problem with three and six generating unit. The results obtained by proposed method were compared to those obtained conventional method, RGA and SGA and Hybrid GA. The comparison shows that firefly algorithm performs better than above mentioned methods. The firefly algorithm has superior features, including quality of solution, stable convergence characteristics and good computational efficiency. Therefore the results shows that firefly optimization is a promising technique for solving complicated problems in power system.

REFERENCES

[1] Gaurav Prasad Dixit, Hari Mohan Dubey, Manjaree Pandit, B. K. Panigrahi, "*Artificial Bee Colony Optimization for Combined Economic Load and Emission Dispatch*", International Conference on Sustainable Energy and Intelligent System (SEISCON 2011) ,Dr. M.G.R. University, Maduravoyal, Chennai, Tamil Nadu, India. July. 20-22, 2011.

[2] 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. 209-21.

[3] Wood, A. J. and Wollenberg, B. F., Power Generation, Operation, and Control, 1996, Wiley, New York, 2nd Ed.

[4] K.P. wang, C.C. Fung, "*Simulated annealing based economic dispatch algorithm*," IEE Proc. C 140, volume. 6, Nov. 1993 pp. 507-513.

[5] L.G. Damousis, A.G. Bakirtzis, S. Dokopoulos, , "*Networkconstraint economic dispatch using real coded genetic algorithm,*" IEEE Trans. Power Syst., volume 1, Feb 2003 pp. 198-205.

[6] C. Palanichamy, K. Srikrishna, "*Economic thermal power dispatch with emission constraint*" J. Institute of Engg. (India) volume-72, April-1991, 11.

[7] M. Sudhakaran, S.M.R Slochanal, R. Sreeram and N Chandrasekhar, "*Application of Refined genetic Algorithm to Combined Economic and Emission Dispatch*" J. Institute Of Engg. (India) volume-85, Sep. 2004pp. 115-119.

[8] A. Immanuel Selva kumar, K. Dhanushkodi, J. Jaya Kumar, C. Kumar Charlie Pual, "*Particle swarm optimization solution to emission and economic dispatch problem,*" IEEE Conference Tencon, paper ID-075 Oct.2003.

[9] M. Sudhakaran and S.M.R Slochanal, "*Integrating Genetic Algorithm and Tabu Search for Emission and Economic Dispatch Problem*" J. Institute of Engg. (India) volume-86, June.2005, pp-22-27.

[10] Rughooputh HCS, King RTFA., "Environmental economic dispatch of thermal units using an elitist multi-objective evolutionary algorithm" *In Proceeding of the IEEE international conference on Indus trial technology, ICIT'03, Maribor, Slovenia;*. December 10–14, 2003 pp. 48–53.

[11] Tsay MT, Lin WM., "*Application of evolutionary programming for economic dispatch of cogeneration systems under emission constraints. Electr Power Syst volume*: 23(8): pp.805–12. 2001.

ISSN: 2321-8169
2448 – 2452

[12] Abido MA., "*Environmental/economic power dispatch using multi-objective evolutionary algorithms*." IEEE Trans Power Syst. volume: 18(4): 2003, pp.1529–37.

[13] C.M. Huang,Y.C. Huang,Anovel "*Approach to real-time economic emission power dispatch*", IEEE Trans. Power Systems , volume-18,no. 1 (2003) pp.288–294.

[14] M. Muslu, "*Economic dispatch with environmental considerations: trade off curves and emission reduction rates*", Electric Power Syst. Res. 71 no. 2, 2004, pp 153–158

[15] K. Senthil and K. Manikandan, "*Economic Thermal Power Dispatch with emission constraint and valve point effect Loading using improved Tabu search algorithm*" Int. Journal of Computer App. ,volume.3, no.9, July-2010, pp.6-11.

*h values are considered based on literature.