Comparitive Analysis of Lambda Iteration Method and Particle Swarm Optimization for Economic Emission Dispatch Problem

Vipandeep Kour
Assistant Professor,
Electrical Engineering Department,
IET Bhaddal, Ropar, India

Lakhwinder Singh
Professor,
Electrical Engineering Department,
BBSBEC, Fatehgarh Sahib, India

***Abstract* - With the increase in energy demands, it becomes necessary to operate the thermal power plants most economically, which gives rise to Economic Load Dispatch (ELD) problem. The problem of ELD in power system is to plan the power output for each committed generating unit in such a way that operating cost is minimized while meeting load demand, power operating limits. In present scenario, expansion in power generation has resulted to increase in emissions in the environment which is the prime concern for power system planners. In order to get clean energy, emission control has become an important operational objective in addition to minimization of operating cost. The combination of both the objectives i.e. economic dispatch and emission dispatch have resulted in multi-dimensional power system optimization problem called Economic Emission Dispatch (EED) problem. In this paper, EED problem has been solved using Lambda Iteration Method and Particle Swarm Optimization (PSO) technique. Both the solution methodologies have been validated on three generator system and five generator system. Comparative analysis of the results obtained by both the methods has been performed.**

Keywords— Economic Load Dispatch, Economic Emission Dispatch, Lambda Iteration Method, Particle Swarm Optimization.

I. INTRODUCTION

The modern power system is a vast interconnected system in which the main task is to allocate the load demand among participating generators at minimum possible cost. Planning the output of each generator in a power system while minimizing the fuel cost and satisfying various system constrains is termed as economic dispatch. The system constraints include matching the power generation with the load, operating the generators within permissible limits and maintaining system stability. When fossil fuels are burnt, toxic gases are released, such as oxides of carbon, oxides of sulphur and oxides of nitrogen [1]. These gases cause pollution in atmosphere and hence disturb the ecological balance leading to global warming. With the increasing energy production to meet the increasing demands, the emission of pollutants has also increased, thus making the environment unfit for the survival of living beings. To meet clean energy requirement, there is need to minimize the emissions along with the fuel cost which is termed as emission dispatch. While minimizing the emissions, there is need to satisfy the system constraints. When economic dispatch and emission dispatch problems are combined together becomes as Economic Emission Dispatch (EED) problem [2].

Different techniques have been reported in the literature pertaining to solution of economic emission dispatch problem. Senthil *et al.* gave an improved Tabu search algorithm of three generator system, six generator system with emission constraints and thirteen generator system with valve point effect loading [3]. Abido presented a multi-objective evolutionary algorithm for environmental/economic power dispatch problem as non-linear constrained multi-objective optimization problem and used Strength Pareto Evolutionary Algorithm (SPEA) to solve the formed multi-objective problem [4]. In another attempt, Abido also presented a Multi-Objective Particle Swarm Optimization (MOPSO) for environmental/economic dispatch problem [5].

Thakur *et al.* used PSO algorithm to solve the problem of Combined Economic and Emission Dispatch (CEED) with use of penalty factors. The authors focused on reducing NO_2 and SO_2 emissions [6]. Valle *et al.* provided a detailed literature on PSO, its concepts, variants and application in the field of power systems. The authors have performed a vast study on this optimization technique [7]. Arunachalam et al. presented a new approach to solve CEED problem using a Hybrid Particle Swarm Optimization (HPSO) and Firefly algorithm where a multi-objective optimization problem with the valve point effect using a price based penalty factor was solved [8]. Das *et al.* used PSO and Teaching Learning Based Optimization (TLBO) for solution of ELD problem used to find the optimum solution with lowest fuel cost for four different network consisting of three, six, fifteen, and twenty generating units respectively for different load demand. Results obtained using PSO and TLBO are compared with the results obtained using lambda iteration method [9].

Particle swarm optimization is a population based stochastic optimization technique developed by Eberhart and Kennedy in 1995 to optimize nonlinear functions [10]. It is inspired by the social behavior of bird flocking or fish schooling while searching for food. PSO optimizes problem by having a population of particles, moving these particles around in the search space according to simple mathematical formula over the particle's position and velocity. Each particle's movement is influenced by its local best known position and is also guided toward the best known positions in the search space, which are updated as better positions are found by other particles. This moves the swarm toward the best solutions.

Each particle keeps track of its coordinates in the solution space, which are associated with the best solution (fitness) that has been achieved so far by that particle. This value is called personal best, P_{best}. Another best value that is tracked by the PSO is the best value obtained so far by any other particle in the neighborhood of that particle. This value is called G_{best}. The basic concept of PSO lies in accelerating each particle toward P_{best} and the G_{best} locations, with a random weighted acceleration at each time. Each particle tries to modify its position using the following information: current positions, current velocities, distance between the current position and P_{best}, and distance between the current position and the G_{best}.

PSO has a flexible and well balanced method to adapt the global exploration abilities with faster convergence rates [10]. The efficiency of PSO is due to the fact that each particle uses the information of the best particle and improves itself accordingly. PSO has been successfully implemented to solve power system problems including EED and many other multi-objective functions [11-14]. The key objectives of PSO over other optimization techniques can be listed as [15]:

- Unlike other algorithms, it is derivative free algorithm.
- It does not depends on the nature of objective function, i.e. continuity and convexity.
- The solution is not trapped in the local minima.
- It does not require an initial solution to start the algorithm.

In PSO, the individuals of the swarm are not created or destroyed, that is, the population remains stable and the particles follow the path of cooperation over competition. The particles while moving within the search space retains a memory of its best point ever attained. This best position is communicated to all other particles.

The intent of the paper is to implement PSO to optimize EED problem and to compare traditional lambda iteration method with PSO in order to prove the better computational efficiency of later over the former.

II. PROBLEM FORMULATION

A. Economic Dispatch

Consider a system of N thermal-generating units connected to a single bus-bar serving the electrical load is shown in fig. 1. The input to each unit is F_i. The output of each unit is P_{gi}. The total cost of this system is the sum of the costs of each of the individual units. The essential constraint on the operation of this system is that the sum of the output powers must equal the load demand [16].

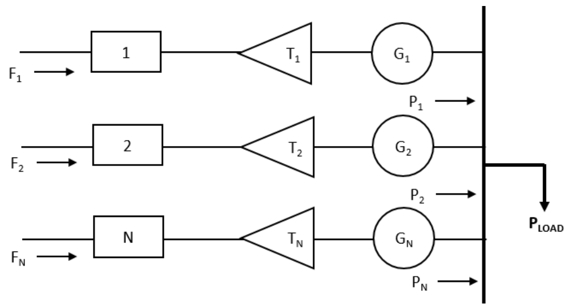

Fig. 1. N thermal units committed to serve a load P_{LOAD}

The objective function (F_T) is equal to the total cost for supplying the indicated load (P_{LOAD}). The problem is to minimize function (F_T) subject to the constraint that the sum of the power generated must equal the load. When transmission losses are neglected, the total fuel cost (F_T), is stated as

$$F_T = F_1 + F_2 + \cdots + F_N \tag{1}$$

$$F_T = \sum_{i=1}^{n} F_i(P_{gi}) \tag{2}$$

The operating cost of plant can be represented as shown in fig. 2. This cost is usually approximated by one or more quadratic segments. So, the fuel cost curve is a quadratic curve in active power generation. The fuel cost function without valve-point loading of the generating unit is given by

$$F_i(P_{gi}) = a_i P_{gi}^2 + b_i P_{gi} + c_i \quad \text{Rs/hr} \tag{3}$$

The economic load dispatch problem can be described as an optimization (minimization) process with the following objective function

$$Min \sum_{i=1}^{n} F_T \tag{4}$$

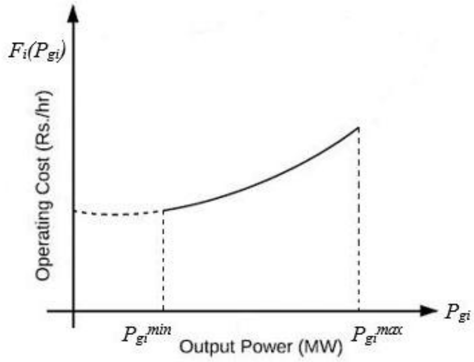

Fig. 2. Operating cost characteristics of fossil fuel fired generator

B. Emission Dispatch

Fossil fuels constitute a significant repository of carbon. Burning such fuels, result in the conversion of carbon to carbon dioxide, which is then released into the atmosphere causing an increase in the earth's levels of atmospheric carbon dioxide, which enhances the greenhouse effect and contributes to global warming. Other emissions produced from a generating station are oxides of sulphur and oxides of nitrogen. Sulphur and nitrogen oxides cause smog and acid rain [17-18]. Very tall flue-gas stacks can be built on plants, so that pollutants would get diluted when they are put in the atmosphere. While this helps in reducing local contamination, it does not help in solving the global issues. Total emissions of the system shown in fig. 1 are given by E_T, such that

$$E_T = E_1 + E_2 + \cdots + E_N \tag{5}$$

$$E_T = \sum_{i=1}^{n} E_i(P_{gi}) \tag{6}$$

The emission of the thermal power plant can be formulated as a second order polynomial function as

$$E_i(P_{gi}) = \alpha_i P_{gi}^2 + \beta_i P_{gi} + \gamma_i \quad \text{Kg/hr} \tag{7}$$

The emission dispatch problem can be described as an optimization (minimization) process with the following objective function

$$Min \sum_{i=1}^{n} E_T \quad (8)$$

III. System Constraints

Optimization of a given function is done when certain constraints are being satisfied. The constraints that are considered during the optimization of cost function and emission function formulated in eq. 4 and eq. 8 are:

A. Equality Constraints

The equality constraints are represented by the power balance constraint, that is, the power balance equation, where the total power generation must cover the total power demand and the power loss.

$$\sum_{i=1}^{n} Pgi = P_D + P_{LOSS} \quad (9)$$

B. Inequality Constraints

The inequality constraints are power generation limits of thermal power generators. Upper and lower bounds on the generation of each generator are to be fulfilled and can be expressed as

$$P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{\max} \quad (i = 1, 2, \ldots, n) \quad (10)$$

IV. Solution Methodology

The purpose is to solve economic emission dispatch problem using the conventional optimization technique, lambda iteration method, and compare the results obtained by solving the same using PSO algorithm.

A. Lambda Iteration Method

Lambda iteration method is an iterative type of computational technique shown in fig. 3. The optimum operating point of any generator set, within a specified limits, is found using this method.

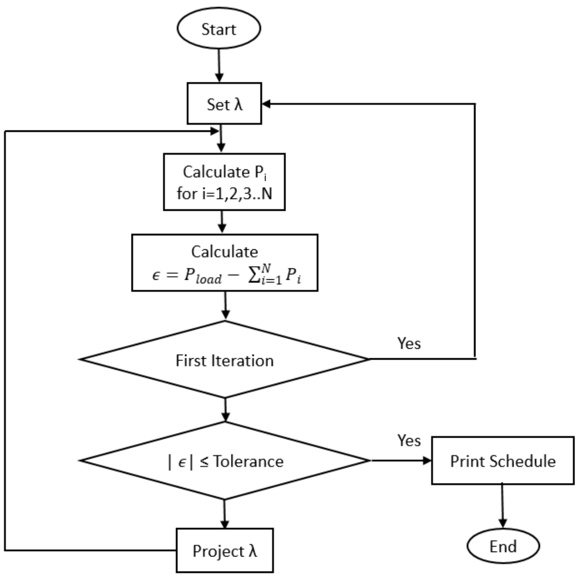

Fig. 1. Lambda iteration method

B. Particle Swarm Optimization

In the PSO algorithm, a random population of particles is created and the optimization is achieved by the movement of particles towards the global best position. The particles update their position and velocity according to their self-experience as well as the social interaction between other particles. Economic emission dispatch problem is solved by implementing PSO.

The modified velocity and position of each particle can be derived using the present velocity and the distance from $P_{best\ id}$ to $G_{best\ d}$ by the velocity and position equations as given in the following equations:

$$V_{id}^{(t+1)} = w.v_{id}^{t} + c_1 r_1 (P_{best\ id} - x_{id}^{t}) + c_2 r_2 (G_{best\ d} - x_{id}^{t}) \quad (11)$$

$$x_{id}^{(t+1)} = x_{id}^{t} + v_{1d}^{(t+1)} \quad (12)$$

Where, x represents the position of particle, v represents velocity of the particle, and the i^{th} particle is denoted as $x_i = (x_{i1}, x_{i2}, \ldots, x_{id})$ in the d^{th} dimensional search space. The previous best position of the i^{th} particle is stored in memory and represented by $P_{best\ i} = P_{best\ i1}, P_{best\ i2}, \ldots, P_{best\ id}$. Also, for a particle, the description of rate of velocity is denoted as $v_i = v_{i1}, v_{i2}, \ldots, v_{id}$. The best position among the P_{best} is represented as $G_{best\ d}$. Fig. 4 shows the flow chart of PSO algorithm.

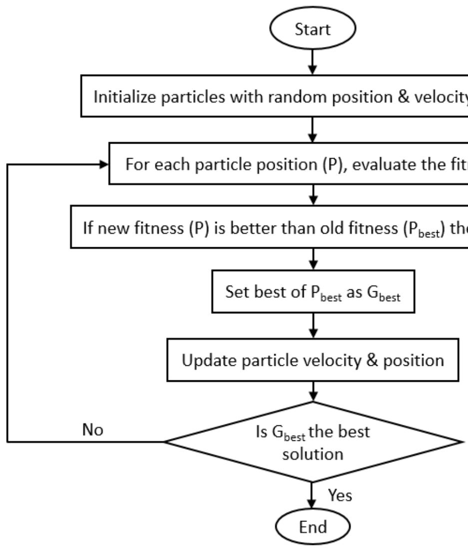

Fig. 2. Basic PSO algorithm

V. Results and Discussion

Economic emission dispatch problem has been solved using lambda iteration method and particle swarm optimization technique. The validity of the proposed techniques has been verified on two generator sets: 3 generator set for a demand of 350, 400 and 450 MW and 5 generator set for a demand of 400, 500 and 600 MW [3][19].

Equations (4) and (8) were solved using the proposed optimization techniques to get desired results for the two generator sets. All the PSO based optimization was done in MATLAB R2015a on 32 bit Intel Core i3 Computer with 2GB RAM with Windows 7 operating system.

A. *Results for 3 Generator Set*

Table 1 shows the values of powers generated and fuel cost in three generator set calculated from Lambda iteration method for economic dispatch. Table II shows the power output and total emissions for emission dispatch calculated from lambda iteration method.

TABLE I
POWER OUTPUT & FUEL COST FOR A 3 GENERATOR SET FOR ECONOMIC DISPATCH CALCULATED FROM LAMBDA ITERATION METHOD

Demand (MW)	P_1	P_2	P_3	Fuel cost (Rs/hr)
350	200.52	94.00	56.32	1487.34
400	200	119.32	81.00	1716.09
450	200	144	106	1957.34

TABLE III
POWER OUTPUT & FUEL COST FOR A 3 GENERATOR SET FOR EMISSION DISPATCH CALCULATED FROM LAMBDA ITERATION METHOD

Demand (MW)	P_1	P_2	P_3	Total Emissions (kg/hr)
350	109.52	96.51	144.4	694.93
400	123.41	109.23	167.32	655.83
450	142.89	127.07	180	753.98

Table III shows the values of powers generated by each of the generator in three generator set calculated from PSO for economic dispatch. Table IV shows the power output of each unit for emission dispatch calculated from PSO.

TABLE IIII
POWER OUTPUT & FUEL COST FOR A 3 GENERATOR SET FOR ECONOMIC DISPATCH CALCULATED FROM PSO

Demand (MW)	P_1	P_2	P_3	Fuel cost (Rs/hr)
350	182.185	107.258	60.082	1406.273
400	192.716	122.60	84.148	1715.771
450	195.891	142.719	110.775	1956.557

TABLE IVV
POWER OUTPUT & FUEL COST FOR A 3 GENERATOR SET FOR EMISSION DISPATCH CALCULATED FROM PSO

Demand (MW)	P_1	P_2	P_3	Total Emissions (kg/hr)
350	185.636	82.935	81.427	682.891
400	124.3	114	160.751	654.3982
450	143	126.651	179.518	752.412

B. *Results for 5 Generator Set*

Table V shows the values of powers generated and fuel cost in five generator set calculated from Lambda iteration method for economic dispatch. Table VI shows the power output and total emissions for emission dispatch calculated from lambda iteration method.

TABLE V
POWER OUTPUT & FUEL COST FOR A 5 GENERATOR SET FOR ECONOMIC DISPATCH CALCULATED FROM LAMBDA ITERATION METHOD

Demand (MW)	P_1	P_2	P_3	P_4	P_5	Fuel cost (Rs/hr)
400	105.45	69.98	85	30	110.0	1169.19
500	153.99	82.98	85	30	149.23	1418.58
600	187.06	93.48	108.73	30.22	180.6	1632.54

TABLE VI
POWER OUTPUT & FUEL COST FOR A 5 GENERATOR SET FOR EMISSION DISPATCH CALCULATED FROM LAMBDA ITERATION METHOD

Demand (MW)	P_1	P_2	P_3	P_4	P_5	Total Emissions (kg/hr)
400	68.78	55.02	116.95	52.93	106.31	318.99
500	88.40	70.72	139.38	66.01	135.75	451.89
600	118.67	40	173.95	86.17	181.12	670.01

Table VII shows the values of powers generated by each of the generator in five generator set calculated from PSO for economic dispatch. Table VIII shows the power output of each unit for emission dispatch calculated from PSO.

TABLE VII
POWER OUTPUT & FUEL COST FOR A 5 GENERATOR SET FOR ECONOMIC DISPATCH CALCULATED FROM PSO

Demand (MW)	P_1	P_2	P_3	P_4	P_5	Fuel cost (Rs/hr)
400	123.30	61.20	87.23	32.32	91.74	1168.33
500	189.33	70.47	84.78	75.33	80.00	1430.66
600	185.38	93.15	99.69	44.68	175.28	1631.85

TABLE VIII
POWER OUTPUT & FUEL COST FOR A 5 GENERATOR SET FOR EMISSION DISPATCH CALCULATED FROM PSO

Demand (MW)	P_1	P_2	P_3	P_4	P_5	Total Emissions (kg/hr)
400	70.35	53.52	115.34	54.45	105.53	317.32
500	89.58	135.64	135.42	68.53	69.76	450.28
600	116.45	55.64	170.53	88.53	170.45	652.91

C. *Comparison of Results obtained from Lambda Iteration Method and PSO technique*

The results from both the techniques were compared and the comparison results are presented in Table IX for three generator set and in Table X for five generator set.

TABLE IX
COMPARISON BETWEEN LAMBDA ITERATION METHOD & PSO FOR 3 GENERATOR SET

Demand (MW)	Fuel Cost (Rs/hr)		Total Emissions (Kg/hr)	
	Lambda Iteration Method	PSO	Lambda Iteration Method	PSO
200	858.43	858.38	446.08	443.33
250	1060.27	1058.22	472.26	471.70
300	1273.27	1273.21	515.74	510.07

TABLE X
COMPARISON BETWEEN LAMBDA ITERATION METHOD & PSO FOR 5 GENERATOR SET

Demand (MW)	Fuel Cost (Rs/hr)		Total Emissions (Kg/hr)	
	Lambda Iteration Method	PSO	Lambda Iteration Method	PSO
400	1169.19	1168.34	318.99	317.33
500	1418.58	1403.66	451.89	450.28
600	1632.54	1631.85	670.02	652.91

VI. CONCLUSION

In this paper, two optimization techniques (lambda iteration and PSO) have been implemented to solve economic emission dispatch problem and the obtained results have been compared. Lambda iteration method is a conventional method but PSO is a new optimization technique which is a population based search algorithm. PSO shows better results along with fast convergence characteristics hence the optimized results of PSO are better than lambda iteration method. As far as fuel cost is concerned, it is small for three generators set but it is reasonably good for five generators set.

APPENDIX

The Particle Swarm Optimization parameters used are:

Population size : 100
No. of iterations : 80
Cognitive coefficient, C_1 : 2
Social coefficient, C_2 : 2
Inertia weight, w : 1 for 3 gen. set, 1.5 for 5 gen. set

REFERENCES

[1] D.P. Kothari and J.S. Dhillon, Power system optimization, *Prentice Hall of India*, New Delhi, 2011.

[2] L. Singh and J. S. Dhillon, “Interactive fuzzy approach for economic-environmental electric power load dispatch”, *IEEE International Conference on Power Systems Technology (POWERCON 2016)*, University of Wollongong, NSW, Australia, September 28 to October 1, 2016, pp. 1-6.

[3] K. Senthil and K. Manikandan ‘Economic thermal power dispatch with emission constraint and valve point effect loading using improved tabu search algorithm,” *International Journal of Computer Applications*, vol. 3, no. 9, 2010.

[4] M. A. Abido, “Environmental/Economic power dispatch using multi objective evolutionary algorithms,” *IEEE Trans. on Power Syst.*, vol. 18, no. 4, pp. 1529-1537, November 2003.

[5] M. A. Abido,“Multi objective particle swarm optimization for environmental/economic dispatch problem,” *Elsevier – Electr. Power Res.*, vol. 79, pp. 1105-1113, 2009.

[6] T. Thakur, K. Sem, S. Saini and S. Sharma, “A particle swarm pptmization solution to NO_2 and SO_2 emissions for environmentally constrained economic dispatch problem,” in *Proc. of IEEE/PES Transmission & Distribution Conference and Exposition: Latin America*, pp. 1-5, 2006

[7] Y. Valle, G. Venayagamoorthy, S. Mohagheghi, J. C. Hernandez, and R.G. Harley, “Particle swarm optimization: basic concepts, variants and applications in power systems”, *IEEE Transactions on Evolutionary Computation*, vol. 12, no. 2, pp. 171-195, April, 2008.

[8] S. Arunachalam, T. AgnesBhomila and M. Ramesh Babu, "Hybrid particle swarm optimization algorithm and firefly algorithm based combined economic and emission dispatch including valve point effect," *Springer Link - Lecture Notes in Computer Science*, vol. 8947, pp. 647-660, 2015.

[9] B. Das and T. K. Sengupta, “Economic load dispatch using PSO and TLBO” in *Micheal Faraday IET Int. Summit*, pp. 212-219, 2015.

[10] J. Kennedy and R. C. Eberhart, “Particle swarm optimization”, in *Proc. of IEEE Int. Conf. on Neural Networks*, vol. IV, pp. 1942-1948. IEEE service centre, Piscataway, NJ, 1995.

[11] M. A. Abido, “Multi-objective particle swarm optimization for environmental/economic dispatch problem,” *Electrical Power System Research*, vol. 79, no. 7, pp. 1105-1113.

[12] M. R. Al-Rashidi and M. El-Hawary, “Hybrid particle swarm optimization approach for solving the discrete opf problem considering the valve loading effects,” *IEEE Trans. on Power System*, vol. 22, no. 4, pp. 2030-2038, 2007.

[13] 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 Trans. Power system*, vol. 20, no.1, pp .34-42, 2005.

[14] A. Sakthidasan, “Firefly algorithm for economic emission dispatch with normalized objective function,” *Int. Journal of Development Research*, vol. 4, no.3, pp. 560-564, 2014.

[15] M. R. Al-Rashidi and M. El-Hawary, “A survey of particle swarm optimization applications in electric power systems,” *IEEE Trans. on Evolutionary Computation*, vol. 13, no.4, pp. 913-918, 2009.

[16] A. J. Wood and B. F. Wollenberg, "Characteristics of power generation units," in *Power Generation Operation & Control*, New York, John Wiley & Sons, Inc., pp. 8-11, 1996.

[17] D. P. Kothari, S. K. Maheshwari and K. G. Sharma, “Minimization of air pollution due to thermal power plants,” *Journal Institution of Engineering (India)*, vol.EN-57(2), pp.65-68, Feb 1977.

[18] L. Singh and J. S. Dhillon, “Surrogate worth trade off method for economic emission dispatch,” *IEEE Power System Conf.*, pp.230-235, 2006.

[19] L. Devi, and O. V. Krishna, “Combined economic and emission dispatch using evolutionary algorithms-a case study,” *ARPN Journal of Engineering and Applied Sciences*, vol. 3, no. 6, pp.28-35, 2008.