International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 05, May-2015

Particle Swarm Optimization Based Economic Load Dispatch with Valve Point Loading

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Abstract- **Economic load dispatch (ELD) problem is a quite important task in the operational planning of a power system, where fuel cost is minimized by allocating generation to the committed units subject to the constraints imposed. A small change in the formulation of objective function will come into picture with the introduction of valve point loading effects. In this paper an effective and reliable particle swarm optimization (PSO) technique is proposed for the economic load dispatch problem. The results have been demonstrated for Economic Load Dispatch of standard 3-generator and 10-generator systems with and without consideration of the transmission losses.**

Keywords- **Economic Load dispatch, Particle Swarm Optimization, Valve Point Loading Effects.**

I. INTRODUCTION

The classical economic dispatch (ED) problem is most important, very well known and heavily researched problem in the power system. The operating cost is reduced by proper allocation of the amount of power to the committed units subject to the equality and inequality constraints [1].

Traditionally, economic dispatch (ED) problems are solved using Lagrangian multipliers [2] and require the units with monotonically increasing piecewise linear cost functions. Unfortunately, this assumption is not applicable practically since modern units' input-output characteristics are inherently highly non-linear due to valve- point loading, multiple fuel-effects and other type of constraints. It can be solved using either deterministic or stochastic methods. However, deterministic methods such as lambda iteration, base-point participation, hill climbing, gradient methods and others depend on the simplicity-based concept that assumes the ED problem's generator cost curves to be convex. Hence, using quadratic or piecewise quadratic, monotonically increasing cost functions, the solutions of the ED problem were used to be estimated. However, with the addition of the practical system constraints, such as the valve-point effects, the generator cost curves are no longer convex and the ED problem becomes non-convex constrained optimization problem. Thus, there is a wide trend of adopting stochastic algorithms which are able to effectively solve the economic dispatch problem. Propitious results have been reported during the past few years and several methods like genetic algorithm (GA) [3], evolutionary programming (EP) [4], tabu search (TS) [5], simulated annealing (SA) [6], differential evolution (DE) [7] and many other methods were successfully implemented in practical ED problems significantly improving the existing results of the problem.

In this paper, the PSO method is used in solving the non-convex economic dispatch problem. The results of experiments performed on standard practical test systems of 3 and 10 generators are reported and discussed. It is also important to mention that undoubtedly many established research papers have properly applied PSO in ED problem with non-convex characteristic. But many of these research works have not properly studied the effect of transmission losses in the load dispatch problems. Moreover parameter tuning is the most important factor in this algorithm that is applied up to the best level in this paper. In next section formulation of economic load dispatch problem is discussed and in third section PSO algorithm and its implementation is discussed. In ensuing section, test problems as well as the experimental results are reported. The paper is summarized in Section V.

II. ED PROBLEM FORMULATION

The classic economic dispatch problem aims to supply the required quantity of power at the lowest possible cost [8]. The dispatch problem can be stated mathematically as follows:

To minimize the total fuel cost at thermal plants:

Minimize

$$F(P_{gi}) = \sum_{i=1}^{NG} F(P_{gi}) \quad (1)$$

$$F(Pgi) = a_i P_{gi}^2 + b_i P_{gi} + C_i \quad (2)$$

subject to the equality real power balance constraints:

$$\sum_{i=1}^{NG} P_{gi} = P_D + P_L \quad (3)$$

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{oi} P_i + B_{oo}{}^2 \quad (4)$$

the inequality constraint of limits on the generator outputs is:

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max} \quad (5)$$

where a_i, b_i and c_i are the cost coefficients of the i-th generator and NG is the number of generators committed to the operating system. P_{gi} is the power output of the i-th generator, P_D is the load demand, P_L represents the transmission losses.

B_{ij} =ijth element of loss coefficient symmetric matrix B, B_{i0} =ith element of the loss coefficient vector and B_{00} =loss coefficient constant

However, the cost function of a generator is not always differentiable due to valve-point effects and/or change of fuels. The valve-point effects introduce ripples in the heat-rate curve. The fuel cost function with valve-point loadings of the generators is as shown in Fig 1:

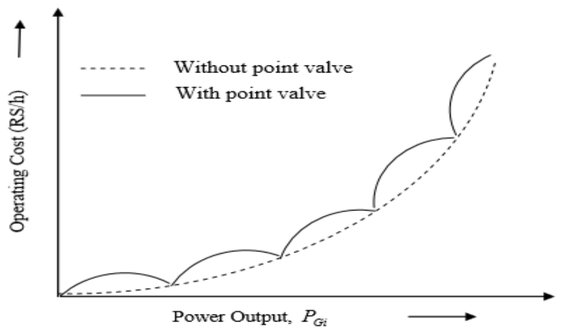

Fig. 1. The Valve-Point Effect

$$F = \sum_{i=1}^{NG} (c_i + b_i P_{gi} + a_i P_{gi}^2) + \left| e_i \sin\left(f_i\left(P_{gi}^{min} - P_{gi}\right)\right)\right| \quad (6)$$

where a_i, b_i, c_i, e_i and f_i are the fuel cost coefficients of generator i with valve-point loading effects.

III. PROPOSED ALGORITHMS

A. Introduction

This section describes the proposed Particle Swarm Optimization method. It is an optimization and search technique based on the principles of social behavior of animals. The method was developed in 1995 by James Kennedy and Russell Eberhart [9]. PSO is very good at finding good enough solutions for a large range of problems, such as constrained optimization problems, multi-objective optimization problems, etc. It is a simple and powerful optimization tool which scatters random particles, i.e., solutions in the problem space. These particles, called swarms collect information from each array constructed by their respective positions. The particles update their positions using the velocity of particles. Position and velocity are both updated in a heuristic manner using guidance from particles' own experience and the experience of its neighbors. The PSO algorithm requires less computation time and less memory because of its inherent simplicity.

Most important factor in PSO algorithm is the setting or adjusting the value of parameters given in equation (7):

$$v_i^{(t+1)} = wv_i^t + c_1 rand\left(p_i^{lb} - x_i^t\right) + c_2 rand\left(p_i^{gb} - x_i^t\right) \quad (7)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (8)$$

Here w describes inertia weight that controls the momentum of the particle by weighing the contribution of the previous velocity–basically controlling how much memory of the previous flight direction will influence the new velocity. C_1, C_2 are the acceleration coefficients. In a classical PSO, Kennedy and Eberhart [10] described that a relatively high value of the cognitive component, compared with the social component, will result in excessive wandering of individuals through the search space. In contrast, a relatively high value of the social component may lead particles to rush prematurely toward a local optimum. Moreover, they suggested setting either of the acceleration coefficients at 2, in order to make the mean of both stochastic factors unity, so that particles would overfly only half the time of search. Since then, this suggestion has been extensively used for most studies. Suganthan [11] tested a method of linearly decreasing both acceleration coefficients with time, but observed that the fixed acceleration coefficients at 2 generate better solutions. p_i^{lb} and g_i^{gb} are the particles' personal and global best values respectively. A flowchart showing general algorithm of PSO is drawn below:

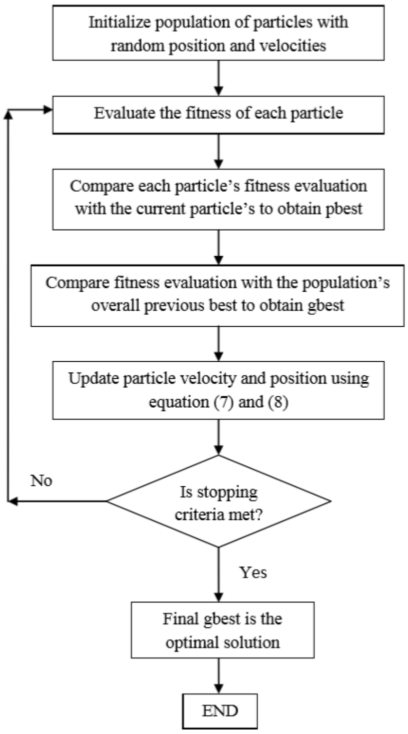

Fig. 2. Flowchart showing PSO Algorithm

B. Implementation of PSO to ELD Problem

In this paper, an algorithm is developed to solve a constrained and unconstrained ED problem using PSO to obtain a high quality solution. The PSO algorithm is utilized mainly to determine the optimal allocation of power among the committed units, thus minimizing the total generation cost. To implement the PSO algorithm to solve the ED problem, mentioned steps should be followed:

Step I: Initialize randomly the velocity of particles, generation of each generator according to the limit of each unit. These initial individuals must be feasible candidate solutions that satisfy the practical operation constraints.

Step 2: Each set of solution in the space should satisfy the following equation (3). If any combination doesn't satisfy the constraints then they are set according to the power balance equation:

$$P_d = P_D + P_L - \sum_{\substack{i=1 \\ i \neq d}}^{NG} P_{gi} \tag{9}$$

Step 3: The objective is to be evaluated for each individual i.e. fitness of each individual is to be calculated.

Step 4: Compare fitness of each individual with its pbest. The best fitness value among the pbests is denoted as gbest.

Step 5: Modify the member velocity 'v' of each individual Pg, according to equation (7).

Step 6: The velocity components constraint occurring in the limits from the following conditions are checked.

$$V_{min} = -0.5*P_{min}$$
$$V_{max} = +0.5*P_{max}$$

Step 7: Modify the member position 'x' of each individual Pg according to equation (8).

Step 8: If the fitness value of each individual is better than the previous pbest value, the current value is set to be pbest. If the best pbest is better than gbest, the value is set to be gbest.

Step 9: If the number of iterations reaches the maximum, then go to step 10.Otherwise, go to step 3.

Step 10: The individual that generates the final gbest is the optimal generation power of each unit with the minimum total generation cost.

IV. EXPERIMENTAL RESULTS

In this section, the results of ELD after the implementation of proposed algorithm based on PSO are discussed. The programme is implemented in MATLAB 7.5.0. The developed algorithm for ELD problem based on PSO, have been discussed in Section III. The main objective is to minimize the cost of generation of plants considering valve point loading effects. The performance is evaluated with and without considering transmission losses using two generator test systems, i.e. three generator test system and ten generator test system and results are compared for with and without valve loading effects and for with and without transmission losses.

A. Case I- 3 Generator test system

Electric power system of three generators has been studied. In this case, the load demand, P_D is taken as 850MW. Operating cost coefficients for each generator are given in Table I

TABLE I. Cost Coefficients of 3-Unit System

Unit	**1**	**2**	**3**
a_i	0.001562	0.00194	0.00482
b_i	7.92	7.85	7.97
c_i	561	310	78
e_i	300	200	150
f_i	0.0315	0.042	0.063
P_i^{max}	600	400	200
P_i^{min}	100	100	50

B-Coefficient Matrix:

$$B = \begin{matrix} 0.000075 & 0.000005 & 0.0000075 \\ 0.000005 & 0.000015 & 0.0000100 \\ 0.0000075 & 0.0000100 & 0.000045 \end{matrix}$$

The Table II and Table III compare the results giving minimum costs with and without transmission losses. In Run 1 and Run 2, valve point loading effects are not considered. In Run 3 and 4, valve loading effects are also considered. Here in

PSO parameters C1 and C2 are set at 2 and w is taken as 0.7. However the no. of particles and maximum iterations are set at 100.

Table II. Comparison of Results using PSO without Valve Point Loading Effects

Unit No.	Without Losses Run 1	With Losses Run 2
1	423	376.1
2	313	376.1
3	114	104
Total Generation (MW)	850	856.3144
Minimum Cost ($/hr.)	8196.9	8257.9

Table III. Comparison of Results using PSO with Valve Point Loading Effects

Unit No.	Without Losses Run 3	With Losses Run 4
1	481	401
2	279	276
3	90	181
Total Generation (MW)	850	857.9054
Minimum Cost ($/hr.)	8217	8290

Figure3 and 4 shows the convergence characteristics of the cost function for with and without transmission losses, without valve loading effects. Figure 5 and 6 are the convergence characteristics with valve loading effects.

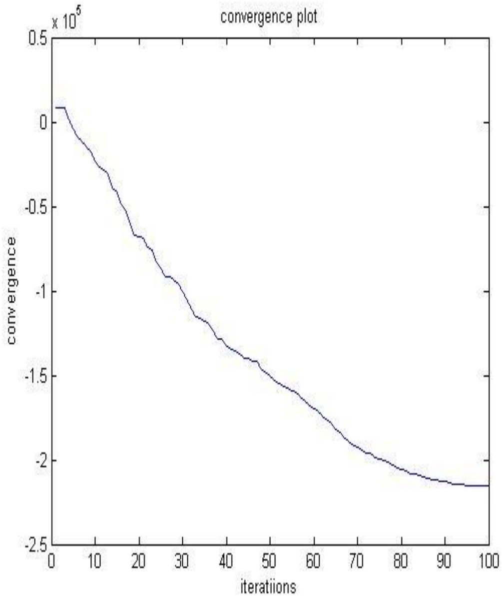

Fig. 3. Convergence characteristics for 3-unit system without losses and without valve loading.

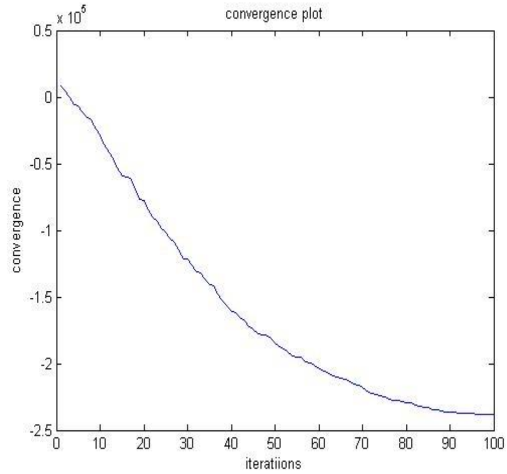

Fig. 4. Convergence characteristics for 3-unit system with losses and without valve loading.

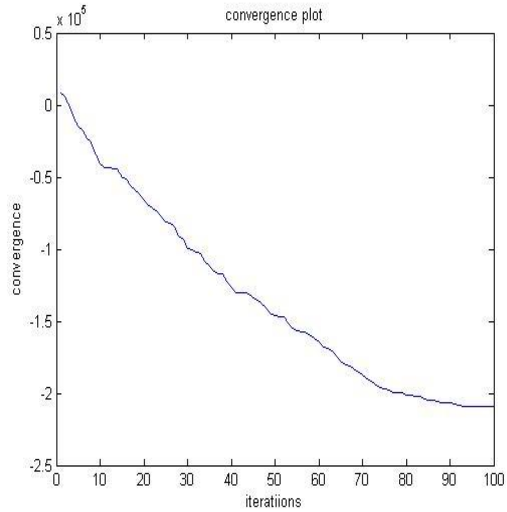

Fig. 5. Convergence characteristics for 3-unit system without losses and with valve loading.

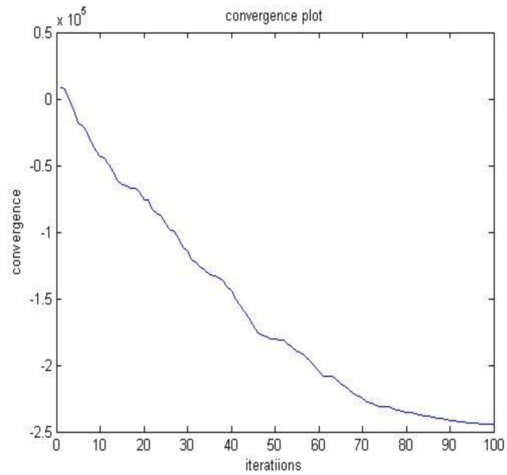

Fig. 6. Convergence characteristics for 3-unit system with losses and with valve loading.

ISSN: 2278-0181
Vol. 4 Issue 05, May-2015

B. Case II- 10 Generator System

Electric power system of ten generators has been studied in this case. Here, the load demand, P_D is taken as 2000 MW. Operating cost coefficients for each generator are given in Table IV.

Table IV. Cost Coefficients of 10- unit system

Gen. No.	Generator limits		Fuel cost coefficients				
	P_{gi}^{min} (MW)	P_{gi}^{max} (MW)	a_i (\$/MW^{2}h)	b_i (\$/MWh)	c_i (\$/hr)	e_i (\$/hr)	f_i (MW^{-1})
1	10	55	0.12951	40.5407	1000.403	33	0.0174
2	20	80	0.10908	39.5804	950.606	25	0.0178
3	47	120	0.12511	36.5104	900.705	32	0.0162
4	20	130	0.12111	39.5104	800.705	30	0.0168
5	50	160	0.15247	38.539	756.799	30	0.0148
6	70	240	0.10587	46.1592	451.325	20	0.0163
7	60	300	0.03546	38.3055	1243.531	20	0.0152
8	70	340	0.02803	40.3965	1049.998	30	0.0128
9	135	470	0.02111	36.3278	1658.569	60	0.0136
10	150	470	0.01799	38.2704	1356.659	40	0.0141

B- coefficient matrix is shown in nest column for considering the transmission losses.

The Table V and Table VI compare the results giving minimum costs with and without transmission losses. In Run 1 and Run 2, valve point loading effects are not considered. In Run 3 and 4, valve loading effects are also considered. Here in PSO parameters C1 and C2 are set at 2 and w is taken as 0.7. However the no. of particles and maximum iterations are set at 100.

Figure 7 and 8 shows the convergence characteristics of the cost function of 10- generator system for with and without transmission losses, without valve loading effects. Figure 9 and 10 are the convergence characteristics with valve loading effects.

B- coefficient matrix = $10^{-4} * B$

B:

$$
\begin{bmatrix}
.49 & .14 & .15 & .15 & .16 & .17 & .17 & .18 & .19 & .2 \\
.14 & .45 & .16 & .16 & .17 & .15 & .15 & .16 & .18 & .18 \\
.15 & .16 & .39 & .1 & .12 & .12 & .14 & .14 & .16 & .16 \\
.15 & .16 & .1 & .4 & .14 & .1 & .11 & .12 & .14 & .15 \\
.16 & .17 & .12 & .14 & .35 & .11 & .13 & .13 & .15 & .16 \\
.17 & .15 & .12 & .1 & .11 & .36 & .12 & .12 & .14 & .15 \\
.17 & .15 & .14 & .11 & .13 & .12 & .38 & .16 & .16 & .18 \\
.18 & .16 & .14 & .12 & .13 & .12 & .16 & .4 & .15 & .16 \\
.19 & .18 & .16 & .14 & .15 & .14 & .16 & .15 & .42 & .19 \\
.2 & .18 & .16 & .15 & .16 & .15 & .18 & .16 & .19 & .44
\end{bmatrix}
$$

Table V. Comparison of Results using PSO without Valve Point Loading Effects

Unit No.	Without losses Run 1	With losses Run 2
1	52.8	51.3
2	73.9	76.9
3	109	116
4	112	112
5	92.3	98.7
6	100	89.9
7	297	297
8	324	334
9	467	469
10	366	454
Total generation	2004.8	2099
Minimum cost(\$/hr)	107390	112340

ISSN: 2278-0181
Vol. 4 Issue 05, May-2015

Table VI. Comparison of Results using PSO with Valve Point Loading Effects

Unit No.	Without losses Run 3	With losses Run 4
1	53.1	51.1
2	79.2	76.9
3	112	118
4	121	128
5	98.8	125
6	100	138
7	299	287
8	320	337
9	467	405
10	356	468
Total generation (MW)	2006.8	2134
Minimum cost ($/hr)	107620	115680

It is clear from the Table V and VI that cost is significantly improved with the consideration of transmission losses and with valve loading effects.

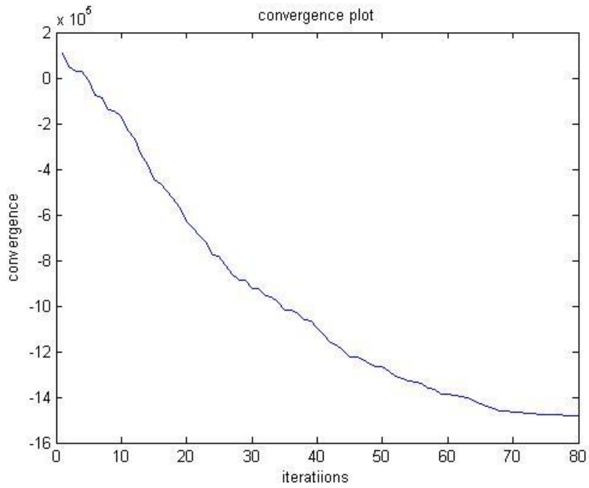

Fig. 7. Convergence characteristics for 10-unit system without losses and without valve loading.

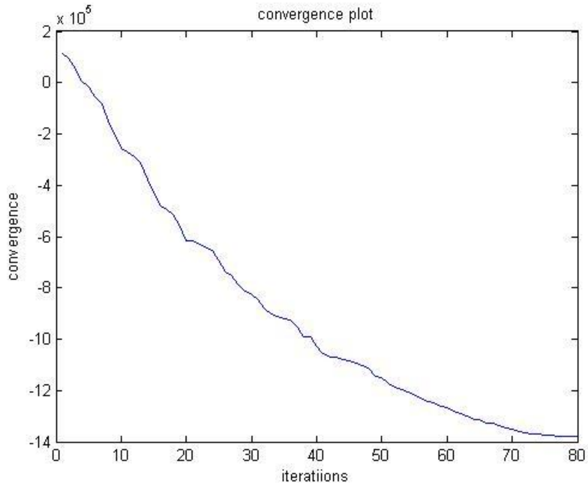

Fig. 8. Convergence characteristics for 10-unit system with losses and without valve loading.

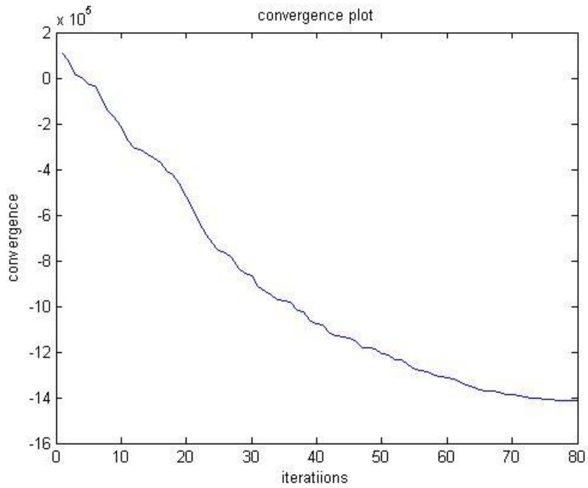

Fig. 9. Convergence characteristics for 10-unit system without losses and with valve loading.

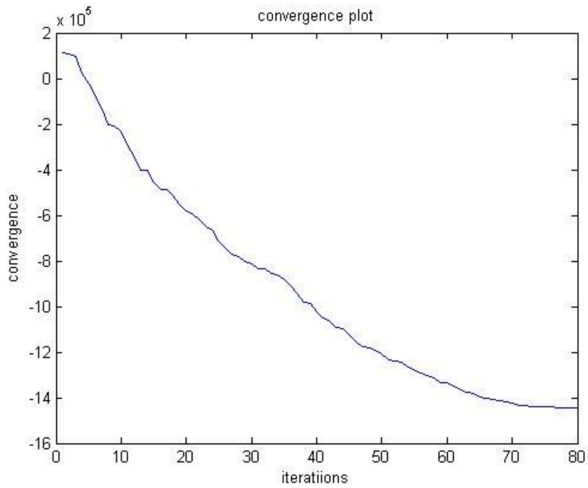

Fig. 10. Convergence characteristics for 10-unit system with losses and with valve loading.

V. CONCLUSION

The non-convex economic problem of power dispatch is solved using PSO strategy. These results are compared with the results available in literature for 3-generator system [12, 13] and for 10-generator system [14] and it is found that results are significantly improved by the proposed algorithm. Tuning of various parameters of PSO is important and it is found that the values of parameters in this paper are perfect for the improvement of results. The results demonstrate that PSO out performs other methods, particularly for non-convex cases, in terms of solution quality, dynamic convergence, computational efficiency, robustness and stability. The proposed algorithm can be applied to other non-convex, and non-smooth cost function having different constraints like prohibited operating zones, ramp rates and multi-fuel options. The proposed algorithm can also be applied to other power system optimization problems like dynamic economic dispatch and reactive power dispatch.

REFERENCES

[1] Abdilahi, A.M., Mustafa, M.W., Jamian, J.J. and Usman, J., "Empirical Study of Particle Swarm Optimization for Economic Load Dispatch with Valve-Point Effects", *IEEE 8th International Power Engineering and Optimization Conference (PEOCO2014)*, Langkawi, The Jewel of Kedah, Malaysia, pp. 467-472, 2014.

[2] Chen, C.H. and Yeh, S.N., "Particle Swarm Optimization for Economic Power Dispatch with Valve-Point Effects", *Transmission & Distribution Conference and Exposition*, Caracas, pp. 1-5, 2006.

[3] Walters, D.C. and Sheble', G.B., "Genetic Algorithm Solution of Economic Dispatch with Valve Point Loading", *IEEE Transactions on Power Systems,* Vol. 8, No. 3, pp. 1325-1332, 1993.

[4] Sinha, N., Chakrabarti, R. and Chattopadhyay, P.K., "Evolutionary programming techniques for economic load dispatch", *IEEE Transactions on Evolutionary Computation*, Vol. 7, No. 1, pp. 83–94, 2003.

[5] Min, L.W., Sheng, C.F. and Tong, T.M., "An improved tabu search for economic dispatch with multiple minima," *IEEE Transactions on Power Systems*, vol. 17, pp. 108-112, 2002.

[6] Wong, K.P. and Fung, C.C., "Simulated annealing based economic dispatch algorithm," *Generation, Transmission and Distribution, IEEE Proceedings C,* vol. 140, pp. 509-515, 1993.

[7] Khamsawang, S. and Jiriwibhakorn, S., "Solving the Economic Dispatch Problem by Using Differential Evolution", *International Science Index,* Vol. 3, No.4, pp. 550-554, 2009.

[8] Wood, A.J. and Wollenberg, B.F., "*Power Generation, Operation and Control*", 2nd edition, Wiley, New York, 1996.

[9] Kennedy, J. and Eberhart, R.C., "Particle swarm optimization", *Proceedings of IEEE International Conference on Neural Networks*, Perth, Australia, vol. 4, pp. 1942–1948, 1995.

[10] Eberhart, R. and Kennedy, J., "A new optimizer using particle swarm theory", *Proceedings of 6th Symposium on MicroMachine and Human Science, Nagoya, Japan,* pp. 39–43, 1995.

[11] Suganthan, P.N., "Particle swarm optimizer with neighbour-hood operator", *Proc. IEEE Int. Congr. Evolutionary Computation*, Vol.3, pp. 1958–1962, 1999.

[12] Singh, N. and Kumar, Y., "Economic Load Dispatch with Valve Point Loading Effect and Generator Ramp Rate Limits Constraint using MRPSO", *International Journal of Advanced Research in Computer Engineering & Technology (IJARCET),* Vol.2, No. 4, pp. 1472-1477, 2013.

[13] Chandrakala, G., Ramakrishna, V. and Shaik, J.B., "Solving economic dispatch with valve point loading effects by using optimization techniques", *International Journal of Engineering Science Invention,* Vol. 3, No. 9, pp. 01-011, 2014.

[14] Manteaw, E.D., Odero, N.A., 2012. "Combined Economic and Emission Dispatch Solution Using ABC_PSO Hybrid Algorithm with Valve Point Loading Effect", *International Journal of Scientific and Research Publications*, Vol. 2, No. 12, pp. 1-9, 2012.