ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 4, April 2015

Comparison of Particle Swarm Optimization with Lambda Iteration Method to Solve the Economic Load Dispatch Problem

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ABSTRACT: One of the most important tasks in power system is to determine and provide an economic condition for generating unit while satisfying all the constraints, which is known as Economic Load Dispatch (ELD). This paper presents particle swarm optimization technique for solving ELD problem. The proposed method is used to solve economic dispatch problem for three and six generating unit system with and without transmission losses. The result obtained by PSO method is compared with the result of the traditional lambda iteration method. The comparison shows that the PSO is capable of providing a higher quality solution with fast convergence in ELD problem.

KEYWORDS: Economic Load Dispatch (ELD), Particle Swarm Optimization (PSO), Lambda Iteration Method, Transmission Losses.

I. INTRODUCTION

One of the fundamental issues in power system is economic load dispatch (ELD) problems. In a practical power system, the plants are not situated at equal distance from load centre and their fuel costs are not same. In addition under normal running condition, the generating capability is higher than the total demand plus losses. Hence there are several options for scheduling generating units. Due to energy crisis in the world and nonstop increase in prices, it is very important to reduce the cost of electrical energy which is achieved by reducing the fuel consumption for meeting the load demand. Therefore, economic load dispatch is very important in power system. In ELD, the allocation of load between the selected units is done in such a way so as to minimize the overall fuel cost while satisfying equality and inequality constraints [1].

The ELD problem can be solved by conventional methods such as lambda iteration method, gradient search, the base point and participation method [2]. In all these conventional methods, the assumption of monotonically increasing cost function is made. For practical power system characteristics of generating units are nonlinear. Hence conventional methods face difficulties in solving ELD problem for the practical power system. For solving an optimization problem using this methods the selection of suitable starting point is very important. If wrong initial points were selected then the divergence or convergence of the algorithm to some local point may occur [1], [3]. The non-linear ELD problem can be solved by the dynamic programming method. In [4] the ED problem with valve-point modelling has been solved by using dynamic programming. But in DP method dimensionality of ELD problem may become very large, hence enormous computational efforts needed in this method. This problem can be overcome by the application of several evolutionary techniques such as genetic algorithm [4], evolutionary programming [5], tabu search, neural network, and particle swarm optimization [3], [5-10] etc.

Particle swarm optimization (PSO), first proposed by Kennedy and Eberhart, is a modern optimization technique and inspired by the behaviour of swarm of bird and fish schooling [11]. This is a population based optimization techniques. The advantages of PSO algorithms can be summarized as, simple concept, easy to implement, provide high quality solution with fast convergence. PSO can be used to solve nonlinear and discontinuous optimization problems.

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This paper presents PSO technique to solve ELD problem in power system. The proposed method was solved for a three unit and six unit systems and the result obtained by PSO method is compared with the traditional lambda iteration method. The results obtained with PSO are more accurate than the traditional technique and the proposed method converge in less number of iteration than the lambda iteration method.

II. PROBLEM FORMULATION

ELD is an optimization based problem. The main purpose of an ELD problem is to determine the allocation of load between selected units so as to minimize the total generation cost but at the same time satisfying the equality and inequality constraints. Generally the fuel cost curve of the generating unit is a quadratic function of the active power output of generator. In ELD the objective cost function is given by following equation

$$F(P_{gi}) = \sum_{i=0}^{N_g} F_i(P_{gi}) = \sum_{i=0}^{N_g} (a_i P_{gi}{}^2 + b_i P_{gi} + c_i) \tag{1}$$

Where,
$F(P_{gi})$ = Total fuel cost ($/h)
$F_i(P_{gi})$ = Fuel cost of i^th generator ($/h)
N_g = Number of generators
P_{gi} = Active power output of i^th generator (MW)
a_i, b_i, and c_i = Fuel cost coefficients of i^th generator.

Equation (1) showing the total fuel cost is minimized subject to equality constraint and generator constraints.

Equality constraint:

The cost function of any generator is dependent only on the active power output of that generator. According to equality constraint the total generated power must be always equal to the power demand plus transmission losses.

$$\sum_{i=0}^{N_g} P_{gi} = P_d + P_L \tag{2}$$

Where,
$\sum_{i=0}^{N_g} P_{gi}$ = Total real power generation
P_d = Total real power demand
P_L = Power transmission loss

Here, transmission loss can be expressed by loss coefficient method developed by Kron and Kirchmayer. So the transmission loss can be given as follows

$$P_L = \sum_{i=0}^{N_g} \sum_{j=0}^{N_g} P_{gi} B_{ij} P_{gj} \tag{3}$$

Where,
P_{gi}, P_{gj} = Real power generation at the i^th and j^th buses, respectively
$B_{ij} = B_{ji}$ = Loss coefficients

Generator constraint:

There is an upper and lower limit for each generator. Hence the output power of each generator must be within the limits.

$$P_{gi}{}^{min} \le P_{gi} \le P_{gi}{}^{max} \tag{4}$$

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Where,
P_{gi}^{min} = minimum limit of power generation of i^{th} plant
P_{gi}^{max} = maximum limit of power generation of i^{th} plant

III. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) was first introduced by Kennedy and Eberhart in 1995. PSO is population based algorithm and it is inspired by the social behaviour of bird flock and fish schooling [11]. The non-linear optimization problem can be successfully solved by using PSO algorithm. In particle swarm optimization the swarm of particles act as bird flock flies on the search space to find global solution. Each particle on search space communicates and exchanges information with each other. The best position achieved by particle during its flight in search space is called personal best of the particle or Pbest. The best among all Pbest is known as global best or Gbest. Each particle modifies its velocity depending upon its present velocity and its distance from Pbest and Gbest which is given by equation (5).

$$V_i^{k+1} = w \times V_i^k + c_1 \times r_1 \times \left(Pbest_i^k - X_i^k\right) + c_2 \times r_2 \times \left(Gbest_i^k - X_i^k\right) \quad (5)$$

$i = 1,2, \ldots, N_p$; $k = 1,2, \ldots, k_{max}$

Where,
k = Iteration count
i = Particle number
w = Inertia weight factor
c_1, c_2 = Acceleration coefficients
r_1, r_2 = Random numbers between 0 and 1
V_i^k = Velocity of particle i at k^{th} iteration
X_i^k = Position of particle i at k^{th} iteration
$Pbest_i^k$ = Best position of particle i until k^{th} iteration
$Gbest_i^k$ = Best position of group until k^{th} iteration
N_p = Number of particles
k_{max} = Maximum iteration number
Each particle moves from its current position to the next position through velocity in equation (5). So the updated position of particle is given by

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (6)$$

Figure 1 show that how particles are influenced by its Pbest and Gbest.

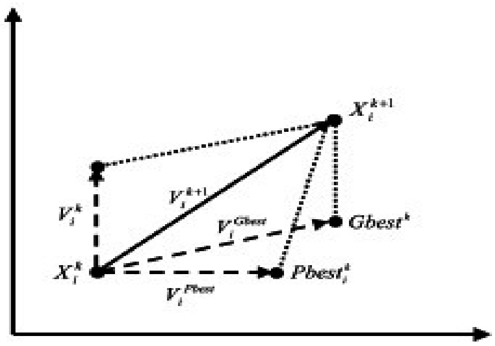

Fig. 1 Simple presentation of movement of particle in PSO

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ISSN (Online): 2278 – 8875

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To control particle speed inertia weight factor plays a very important role. Therefore careful selection of this factor is very important. The inertia weight w decreases linearly from 0.9 to 0.4 with increase in iteration count. The inertia weight can be given by following equation

$$w = w_{max} - \left(\frac{w_{max} - w_{min}}{iteration_{max}}\right) \times iteration_k \tag{7}$$

Where,
w_{max} , w_{min} = Initial and final weight repectively
$iteration_{max}$ = Maximum iteration number
$iteration_k$ = Current iteration number
The steps of PSO algorithm are as shown below:

Step 1. Select suitable value of various parameter of PSO.
Step 2. Initialize particles with random velocity and position in the search space.
Step 3. Evaluate the fitness of each particle, using its current position.
Step 4. Compare the fitness of each particle with its Pbest. If the present value is better than the Pbest, then set the current value as the Pbest of particle i.
Step 5. Identify the best among Pbest of particles and then set it as a Gbest of the swarm.
Step 6. Update the velocity and position of each particle according to the equation (5) and (6).
Step 7. Repeat from step 3 to step 6 until convergence.

The above steps can be summarized in the flowchart of figure 2.

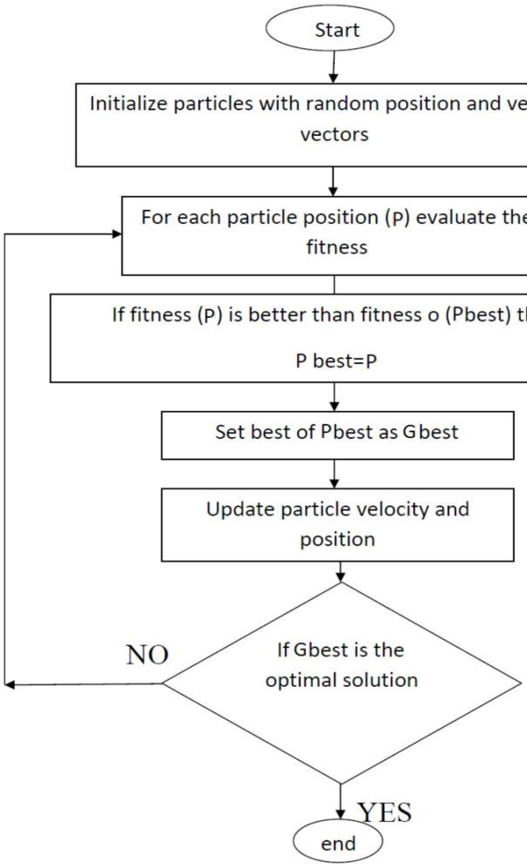

Fig. 2 Basic PSO algorithm

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ISSN (Online): 2278 – 8875

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Vol. 4, Issue 4, April 2015

IV. RESULT AND DISCUSSIONS

To verify the feasibility of PSO technique, two different cases were studied. In first case three unit system was considered while in the other case six unit system was considered. In both cases, ELD problem is solved with and without transmission losses. The B-loss coefficient matrix has been used for calculation of transmission loss. In this paper, ELD problem is solved by two methods. One is lambda iteration method and other is particle swarm optimization (PSO). Results obtained from PSO method are compared with the traditional lambda iteration method. All the calculation and programming has been done in MATLAB environment.

The PSO parameters used in this problem are

- Number of particles = 60
- Inertia weight factor w calculated by equation (7), where $w_{max} = 0.9$ and $w_{min} = 0.4$.
- Acceleration constant $c_1 = 2$ and $c_2 = 2$.

Case Study-1: 3-units system

In this case, three unit thermal power plant is considered which is solved for two different cases with and without losses. The cost coefficients and generator power limit are shown by table 1 [10].

Table 1. Generating Unit Capacity And Cost-Coefficients For Three Unit System

Unit	P_{gi}^{min}	P_{gi}^{max}	a_i	b_i	c_i
1	10	85	0.008	7	200
2	10	80	0.009	6.3	180
3	10	70	0.007	6.8	140

The loss coefficient matrix is given by [10]

$$B_{ij} = \begin{bmatrix} 0.000218 & 0.000093 & 0.000028 \\ 0.000093 & 0.000228 & 0.000017 \\ 0.000028 & 0.000017 & 0.000179 \end{bmatrix}$$

Table 2 and Table 3 present the results of ELD problem without transmission loss for 3-unit system using lambda iteration method and PSO method respectively. Both methods are tested for loads of 120 MW and 150MW. Comparison of result shows that solution quality of PSO is better than lambda iteration technique.

Table 2. Results Through Lambda Iteration Method (Without Loss)

S.No.	Load Demand (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	Fuel Cost ($/hr)
1.	120	22.0625	58.5	39.5	1357.2
2.	150	31.9375	67.2778	50.7857	1579.71

Table 3. Results Through PSO Method (Without Loss)

S.No.	Load Demand (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	Fuel Cost ($/hr)
1.	120	22.0419	58.4817	39.4764	1356.74
2.	150	31.9372	67.2775	50.7853	1579.7

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International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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Table 4 and Table 5 present the results of ELD problem with transmission loss for 3-unit system using lambda iteration method and PSO method respectively. Both methods are tested for loads of 120MW and 150MW. Comparison of result shows that solution quality of PSO is better than lambda iteration technique.

Table 4. Results Through Lambda Iteration Method (With Loss)

S.No.	Load Demand (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_L (MW)	Fuel Cost ($/hr)
1.	120	19.6325	59.7948	42.1983	1.5685	1368.81
2.	150	29.4433	68.6345	54.3407	2.38387	1598.02

Table 5. Results Through PSO Method (With Loss)

S.No.	Load Demand (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_L (MW)	Fuel Cost ($/hr)
1.	120	25.1615	55.3214	41.0485	1.53137	1368.19
2.	150	35.3084	64.3204	52.7259	2.35464	1597.58

Case Study-2: 6-units system

In this case, six unit thermal power plant is considered which is solved for two different cases with and without losses. The cost coefficients and generator power limit are shown by table 6 [10].

Table 6. Generating Unit Capacity And Cost-Coefficients For Six Unit System

Unit	P_{gi}^{min}	P_{gi}^{max}	a_i	b_i	c_i
1	100	500	240	7.00	0.0070
2	50	200	200	10.0	0.0095
3	80	300	220	8.50	0.0090
4	50	150	200	11.0	0.0090
5	50	200	220	10.5	0.0080
6	50	120	190	12.0	0.0075

The B-coefficient matrix for six unit system is given as

$$B_{ij} = \begin{bmatrix} 0.000017 & 0.000012 & 0.000007 & -0.000001 & -0.000005 & -0.000002 \\ 0.000012 & 0.000014 & 0.000009 & 0.000001 & -0.000006 & -0.000001 \\ 0.000007 & 0.000009 & 0.000031 & 0.000000 & -0.000010 & -0.000006 \\ -0.000001 & 0.000001 & 0.000000 & 0.000024 & -0.000006 & -0.000008 \\ -0.000005 & -0.000006 & -0.000010 & -0.000006 & 0.000129 & -0.000002 \\ -0.000002 & -0.000001 & -0.000006 & -0.000008 & -0.000002 & 0.000150 \end{bmatrix}$$

The above problem is solved lambda iteration method and PSO method for power demands of 600MW and 1263MW. Table 7 and Table 8 show results of six unit system without loss by lambda iteration method and PSO method respectively.

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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Vol. 4, Issue 4, April 2015

Table 7. Results Through Lambda Iteration Method (Without Loss)

S.No.	Load Demand (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	Fuel Cost ($/hr)
1.	600	271.879	50	128.128	50	50	50	7187.41
2.	1263	446.707	171.258	264.106	125.217	172.119	83.5933	15275.9

Table 8. Results Through PSO Method (Without Loss)

S.No.	Load Demand (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	Fuel Cost ($/hr)
1.	600	271.875	50	128.125	50	50	50	7187.34
2.	1263	446.707	171.258	264.106	125.217	172.119	83.5935	15275.9

Table 9 and Table 10 show results of six unit system with loss by lambda iteration method and PSO method respectively. Comparison of result shows that solution quality of PSO is better than lambda iteration technique.

Table 9. Results of Lambda Iteration Method (With Loss)

S.No.	Load Demand (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	P_L (MW)	Fuel Cost ($/hr)
1.	600	273.492	50	129.595	50	50	50	2.98958	7220.73
2.	1263	447.122	173.22	263.962	139.093	165.617	86.6583	12.4204	15446.1

Table 10. Results of PSO Method (With Loss)

S.No.	Load Demand (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	P_L (MW)	Fuel Cost ($/hr)
1.	600	273.135	50	129.853	50	50	50	2.98837	7219.67
2.	1263	452.268	182.651	267.523	136.175	155.992	80.8023	12.4104	15445.2

V. CONCLUSION

In this paper, the economic load dispatch problem is solved by most popular classical technique lambda iteration method and PSO method. Two test units three unit system and six unit system are solved for two different cases. In first case ELD problem has been solved by considering generator constraints without transmission loss and in second case ELD problem has been solved by considering generator constraints with transmission loss. The results obtained by PSO method are nearly equal to the results of lambda iteration technique. The comparison of above results shows that the solution quality of particle swarm optimization (PSO) is much better than the conventional lambda iteration method. Hence the PSO method is more reliable than the lambda iteration method.

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ISSN (Print) : 2320 – 3765
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(An ISO 3297: 2007 Certified Organization)

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