A Case Study of Economic Load Dispatch for a Thermal Power Plant using Particle Swarm Optimization

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Abstract: ***This paper discusses the possible applications of particle swarm optimization (PSO) in the Power system. One of the problems in Power System is Economic Load dispatch (ED). The discussion is carried out in view of the saving money, computational speed – up and expandability that can be achieved by using PSO method. The general approach of the method of this paper is that of Dynamic Programming Method coupled with PSO method. The feasibility of the proposed method is demonstrated, and it is compared with the lambda iterative method in terms of the solution quality and computation efficiency. The experimental results show that the proposed PSO method was indeed capable of obtaining higher quality solutions efficiently in ED problems.***

Keywords: Economic load dispatch, Particle Swarm Optimization, Dynamic Programming Method, Power Systems.

1. Introduction

Economic dispatch (ED) problem is one of the fundamental issues in power system operation. In essence, it is an optimization problem and its objective is to reduce the total generation cost of units, while satisfying constraints. Previous efforts on solving ED problems have employed various mathematical programming methods and optimization techniques. These conventional methods include the lambda-iteration method, the base point and participation factors method, and the gradient method [1, 2, 16, 17]. In these numerical methods for solution of ED problems, an essential assumption is that the incremental cost curves of the units are monotonically increasing piecewise-linear functions. Unfortunately, this assumption may render these methods infeasible because of its nonlinear characteristics in practical systems. These nonlinear characteristics of a generator include discontinuous prohibited zones, ramp rate limits, and cost functions which are not smooth or convex. Furthermore, for a large-scale mixed-generating system, the conventional method has oscillatory problem resulting in a longer solution time. A dynamic programming (DP) method for solving the ED problem with valve-point modelling had been presented by [1, 2]. However, the DP method may cause the dimensions of the ED problem to become extremely large, thus requiring enormous computational efforts.

In order to make numerical methods more convenient for solving ED problems, computational techniques, such as the neural networks, genetic algorithm, particle swarm optimization and etc., have been successfully employed to solve ED problems for units [3, 4]. However, neural network solution may suffer from excessive numerical iterations, resulting in huge calculations. In the past decade, a global optimization technique known as genetic algorithms (GA), has been successfully used to solve power optimization problems [1, 5–7]. The GA method is usually faster because the GA has parallel search techniques, which emulate natural genetic operations. Due to its high potential for global optimization, GA has received great attention in solving ED problems.

Though the GA methods have been employed successfully to solve complex optimization problems, recent research has identified some deficiencies in GA performance. This degradation in efficiency is apparent in applications with highly *epistatic* objective functions (i.e., where the parameters being optimized are highly correlated) [the crossover and mutation operations cannot ensure better fitness of offspring because chromosomes in the population have similar structures and their average fitness is high toward the end of the evolutionary process] [10,14]. Moreover, the premature convergence of GA degrades its performance and reduces its search capability that leads to a higher probability toward obtaining a local optimum [10]. Particle swarm optimization (PSO), first introduced by Kennedy and Eberhart, is one of the modern heuristic algorithms. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous nonlinear optimization problems [11-15]. The PSO technique can generate high-quality solutions within shorter calculation time and stable convergence characteristic than other stochastic methods [12-15]. Although the PSO seems to be sensitive to the tuning of some weights or parameters, many researches are still in progress for proving its potential in solving complex power system problems [14]. In this paper, a PSO method for solving the ED problem in power system is proposed. The feasibility of the proposed method was demonstrated [7,19], respectively, and compared with the Lambda iteration method.

2. Economic Load Dispatch

The Economic Dispatch (ED) is a nonlinear programming problem which is considered as a sub-problem of the Unit Commitment (UC) problem [17]. In a specific power system with a determined load schedule, ED planning performs the optimal power generation dispatch among the existing generation units. The solution of ED problem must satisfy the constraints of the generation units, while it optimizes the generation based on the cost factor of the generation units. Equation (1) represents the total fuel cost for a power system which is the equal summation of all generation units fuel costs, in a power system.

$$Cost = \sum_{j=1}^{NG} F_j\left(P_j\right) \quad ---(1)$$

Where NG is the number of generation units and P_j is the output power of j^{th} generation unit. The cost function in eq. (1) can be approximated to a quadratic function of the power generation; therefore, the total cost function (F_T) will be changed to eq. (2).

$$F_T = \min\left(\sum_{j=1}^{NG} F_j\left(P_j\right)\right)$$

$$= \min\left(\sum_{j=1}^{NG} a_j P_j^2 + b_j P_j + c_j\right) \quad ---(2)$$

Where:

$P_j \rightarrow$ Generated power by j^{th} generation unit

$a_j, b_j, c_j \rightarrow$ Fuel cost coefficients of unit j

Two set of constraints are considered in the present study, including equality constraints and inequality constraints.

2.1. Equality Constraints

Normally, in a power system the amount of generated power has to be enough to feed the load demand plus transmission lines loss. Since the transmission lines are located between the generating units and loads, P_{loss} can occur anywhere before the power reaches load (P_d) shown in eq. (3). Any shortage in the generated power will cause shortage in feeding the load demand which may cause many problems for the system and loads.

$$\sum_{j=1}^{NG} P_j = P_d + P_{loss} \quad ---(3)$$

Where P_d is the load demand and P_{loss} is the transmission lines loss, while NG and P_j have the same definition as in eq. (2).

Here, the loss coefficient method which is developed by Kron and Kirchmayer, is used to include the effect of transmission losses [19-21]. B-matrix which is known as the transmission loss coefficients matrix is a square matrix with a dimension of NG×NG while NG is the number of generation units in the system. Applying B-matrix gives a solution with generated powers of different units as the variables. Eq. (4) shows the function of calculating P_{loss} as the transmission loss through B-matrix.

$$P_{loss} = \sum_{i=1}^{NG}\sum_{j=1}^{NG} P_j B_{ij} P_j \quad ---(4)$$

Where:

$P_{loss} \rightarrow$ Total transmission loss in the system

$P_i, P_j \rightarrow$ Generated power by i^{th} and j^{th} generating units respectively

$B_{ij} \rightarrow$ Element of the B-matrix between i^{th} and j^{th} generating units

2.2. Inequality Constraints

All generation units have some limitations in output power regardless of their type. In existing power systems, thermal units play a very important role. Thermal units can pose both maximum and minimum constraints on the generating power, so there is always a range of operating work for the generating units. Generating less power than minimum may cause the rotor to over speed whereas at maximum power, it may cause instability issues for synchronous generators [21]. So, eq. (5) has to be considered in all steps of solving the ED problem.

$$P_j^{min} \le P_j \le P_j^{max} \quad ---(5)$$

For j=1, 2… NG.

Where P_j^{min} & P_j^{max} and are the constraints of generation for j^{th} generating unit.

3. Particle Swarm Optimization

Particle swarm optimization (PSO), which is a stochastic population based, evolutionary computer algorithm for problem solving, based on social behaviour of groups like flocking of birds or schooling of fish. It is a sort of swarm intelligence that predicts everyone solution as ''particles'' which change their positions with change in time. pbest of each particle modifies its position in search space in accordance with its own experience and also gbest of neighbouring particle by remembering the best position visited by itself and its neighbours, then calculating local and global positions. The particle updates its velocity and positions with following equation (6) and (7).

$$v_i^{t+1} = w\, v_i^t + c_1 r_1 (pbest_i - x_i^t) + c_2 r_2 (gbest_i - x_i^t) \quad ---(6)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad ---(7)$$

Where, v_i is the particle velocity vector, x_i is the particle position vector. $pbest_i$ is the best position achieved by particle 'i' based on its own experience and $gbest_i$ is the best position of the particle based on overall swarm experience. r_1, r_2 is a random numbers between [0, 1]. c_1, c_2 are learning factors. Usually these are two positive constants, $c_1 = c_2 = 2$. Inertia weight is w.

The following weighting function is usually utilized:

$$w = w_{max} - \left(\frac{w_{max} - w_{min}}{Iter_{max}}\right) \times Iter \quad ---(8)$$

Where

$w_{max}, w_{min} \rightarrow$ Initial and final weights

$Iter_{max} \rightarrow$ Maximum iteration number

$Iter \rightarrow$ Current iteration number

Suitable selection of inertia weight in above equation provides a balance between global and local explorations, thus requiring less number of iterations on an average to find a sufficient optimal solution. As originally developed, inertia weight often decreases linearly from about 0.9 to 0.4 during a run. The algorithmic steps involved in particle swarm optimization technique are as follows:

1) Select the various parameters of PSO.
2) Initialize a population of particles with random positions and velocities in the problem space.
3) Evaluate the desired optimization fitness function for each particle.
4) For each individual particle, compare the particles fitness value with its pbest. If the current value is better than the pbest value, then set this value as the pbest for agent i.
5) Identify the particle that has the best fitness value. The value of its fitness function is identified as gbest.
6) Compute the new velocities and positions of the particles according to equation (6) & (7).
7) Repeat steps 3-6 until the stopping criterion of maximum generations is met.

The procedure of the particle swarm optimization technique can be summarized in the flowchart of Fig. 1.

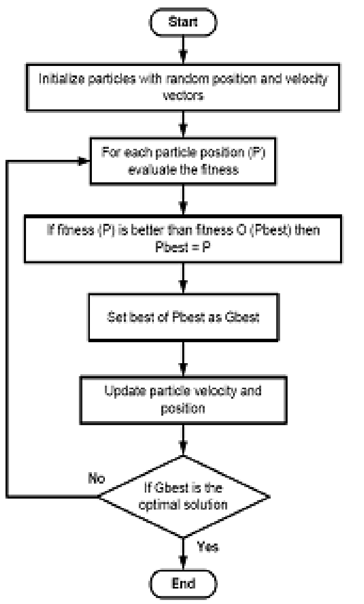

Figure 1: The flowchart of PSO technique

4. Simulation Results and Analysis of Performance

To verify the feasibility and effectiveness of the proposed PSO algorithm, two different power systems were tested one is 6 generating units and other is 9 generating units. Results of proposed particle swarm optimization (PSO) are compared with Lambda iterative method. A reasonable B-loss coefficients matrix of power system network has been employed to calculate the transmission loss. The software has been written in the MATLAB-7 language.

Case Study-1: 6-units system

In this case, a standard six-unit thermal power plant (IEEE 30 bus test system) is used to demonstrate how the work of the proposed approach. Characteristics of thermal units are given in Table 1, the following coefficient matrix B_{ij} losses.

Table 1: Generating Unit capacity and coefficients

Unit	P_j^{min} (MW)	P_j^{max} (MW)	a_j $(Rs./MW^2)$	b_j $(Rs./MW)$	c_j (Rs.)
1	100	500	0.0070	7	240
2	50	200	0.0095	10	200
3	80	300	0.0090	8.5	300
4	50	150	0.0090	11	150
5	50	200	0.0080	10.5	200
6	50	120	0.0075	12	120

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

The comparison with Lambda iterative and proposed PSO technique simulation results are shown in Table 2. Table 2 shows the optimal power output, total cost of generation, as well as active power loss for the power demands of 1000 MW, 1200 MW, 1350 MW and 1450 MW. Table 2 shows that the PSO method is better than Lambda iterative method for each loading.

Table 2: Best power output for 6-generation system

Load demand (MW)	Method	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	Power Loss (MW)	Fuel cost (Rs./Hr)
500	Lambda Iterative	216.880	50.000	85.702	50.000	50.000	50.000	1.991	6106.21
	PSO	216.106	50.000	85.880	50.000	50.000	50.000	1.991	6105.02
700	Lambda Iterative	312.282	73.420	159.487	50.000	59.140	50.000	4.164	8288.81
	PSO	312.957	77.806	160.516	50.000	52.928	50.000	4.199	8267.55
1000	Lambda Iterative	391.557	132.135	220.812	93.182	122.043	50.000	8.127	11957.2
	PSO	393.634	138.455	222.537	90.271	113.217	50.000	8.123	11930.4
1200	Lambda Iterative	434.380	163.796	254.043	128.659	15.661	76.594	11.307	14559
	PSO	438.852	172.501	257.243	125.645	146.350	70.708	11.293	14538.1
1350	Lambda Iterative	466.385	187.465	278.916	150.000	180.562	101.657	14.212	16586.1
	PSO	470.988	196.721	281.878	150.000	169.617	94.887	14.986	16575.5
1450	Lambda Iterative	497.110	200.000	300.000	150.000	200.000	120.000	16.739	17980.1
	PSO	500.000	200.000	300.000	150.000	196.687	120.000	16.688	17975.2

Case Study-2: 9-units system

In this case, a 9-unit thermal power plant is used to demonstrate how the work of the proposed approach. The simulation results with conventional method and proposed PSO technique are shown in Table 3. From the simulation results show that the generation output of each unit is obtained correction reduces the total cost of generation and transmission losses when compared with the conventional method.

Table 3: Best power output for 6-generation system

Load demand (MW)	Method	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P7 (MW)	P8 (MW)	P9 (MW)	Power Loss (MW)	Fuel cost (Rs./Hr)
700	Lambda Iterative	250.1	50	111	50	50	50	45.38	71.24	25	3.6	8527.32
	PSO	100	50.28	80	67.14	50	83.99	66.92	98.16	108.3	5.15	8526.02
1000	Lambda Iterative	328.1	85.03	171.1	50	71.45	50	124.2	100	25	6.95	11885.1
	PSO	100	104.4	80	139.7	104.9	120	138.7	100	120	7.63	11854.5
1200	Lambda Iterative	364.1	111.7	199.3	72.88	107.8	50	150	100	54.69	9.61	14338.5
	PSO	135.4	162.5	108.1	150	163.6	120	150	100	120	9.6	14137.1
1450	Lambda Iterative	410.7	146.3	235.9	114.3	155.8	56.76	150	100	9.37	13.96	17545.3
	PSO	235.5	200	187.8	150	200	120	150	100	120	13.2	17244.6
1600	Lambda Iterative	435.5	164.7	254.8	136.7	182.3	77.5	150	100	118.7	17.05	19552.1
	PSO	321	200	255.5	150	200	120	150	100	120	16.46	19251.4
1800	Lambda Iterative	487.5	200	293.4	150	200	120	150	100	120	21.63	22257.5
	PSO	481.7	200	300	150	200	120	150	100	120	21.66	22056.2

5. Conclusion

This paper presents an efficient and simple approach for solving the economic load dispatch (ELD) problem. This paper demonstrates with clarity, chronological development and successful application of PSO technique to the solution of ELD. Two test systems 6-generator and 9-generator systems have been tested and the results are compared with Lambda iteration method. The proposed approach is relatively simple, reliable and efficient and suitable for practical applications.

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