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Application of Particle Swarm Optimization for Economic Load Dispatch and Loss Reduction

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Abstract—This paper proposes a particle swarm optimization (PSO) technique to solve the economic load dispatch (ELD) problems. For the ELD problem in this work, the objective function is to minimize the total fuel cost of all generator units for a given daily load pattern while the main constraints are power balance and generation output of each units. Case study in the test system of 40-generation units with 6 load patterns is presented to demonstrate the performance of PSO in solving the ELD problem. It can be seen that the optimal solution given by PSO provides the minimum total cost of generation while satisfying all the constraints and benefiting greatly from saving in power loss reduction.

Keywords—Particle Swarm Optimization, Economic Load Dispatch, Loss Reduction.

I. Introduction

FOR electric power industry, the economic operation and planning of electric generation system is very essential. Due to the continuous rise in prices of energy, the decrease of running charge for electricity generation by running generators efficiently and economically is very important. A small percent of saving in the operation of the system represents a significant reduction in operating cost as well as in the quantities of fuel consumed [1]. The achievement in the minimum fuel costs for electric power generation involves with the classic problem in power system operation, namely, economic load dispatch (ELD) problem.

ELD is the method of determining the most efficient, low-cost and reliable operation of a power system by dispatching the available electricity generation resources to supply the load on the system. The main objective of ELD is to schedule the committed generating units output to meet the required load demand at minimum cost while satisfying all unit and system operational constraints [2]. With the proper scheduled outputs of generating units, it can lead to a significant cost saving of generating systems.

ELD is one type of an optimization problem. It has complex and nonlinear characteristics with heavy equality and inequality constraints. Many heuristics-based optimization techniques have been employed to solve the ELD problem such as simulated annealing (SA) [3], quadratic programming (QP) [4], genetic algorithms (GA) [5], tabu search algorithm (TSA) [6]. In this paper, an effective and reliable heuristics-based approach, namely, particle swarm optimization (PSO) is applied to deal with the ELD problem.

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PSO is a population based stochastic optimization technique which is originally invented in 1995. It is derived from the simulation of a simplified social model of swarms (e.g. bird flocks or fish schools) [7]-[10]. PSO uses common evolutionary computation algorithm to find the optimal regions of search space. Unlike the other evolutionary technique, PSO requires only primitive mathematical operators for the computation process. Many researches and developments in PSO have shown that it can handle difficult optimization problems which are nonlinear, non-differentiable, and multi-modal. The main merits of PSO are computationally efficient, simplicity in concept and implementation, less computation time, and inexpensive memory for computer resource [11]-[13].

In this work, the effectiveness of PSO for solving ELD problem is demonstrated by a case study in test system of 40-generation units.

II. The Economic Load Dispatch Problem

The ELD problem is to find the optimal combination of power generations that minimizes the total generation cost while satisfying an equality constraint and inequality constraints [8]. The mathematical expression for ELD problem can be written as [14]:

$$\text{Minimize} \quad Z = \sum_{i=1}^{n} F_i(P_i) \tag{1}$$

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \tag{2}$$

where

Z	=	total generation cost
F_i	=	cost function of generator *i*
P_i	=	electrical output of generator *i*
n	=	number of generation units.
a_i, b_i, c_i	=	cost coefficients of unit *i*

The first constraint of the problem is the generation output of each unit which is bounded between two limitations as:

$$P_i^{\min} \le P_i \le P_i^{\max} \tag{3}$$

where

$P_i^{\min}, P_i^{\max}$ = minimum and maximum output of power generation of unit i

The second constraint is a power balance constraint as:

$$\sum_{i=1}^{n} P_i = P_{\text{Load}} + P_{\text{Loss}} \tag{4}$$

where

P_{Load} = total real power load demand at time

P_{Loss} = total transmission loss at time

The total transmission loss can be calculated by the traditional B matrix loss formula as shown below [1].

$$P_{Loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{i0} P_i + B_{00} \tag{5}$$

where

B_{ij} = element of the loss coefficient

B_{i0} = element of loss coefficient vector

B_{00} = loss coefficient constant

III. Particle Swarm Optimization

In the last decade, many new stochastic search methods have been developed for the global optimization problems, such as genetic algorithms, evolutionary programming and particle swarm optimization. Particle swarm optimization (PSO) is one of the evolutionary computation techniques [7].

The PSO, first introduced by Kennedy and Eberhart [7], discovered through simplified social modal simulation. Its roots are in zoologist's modeling of movement of individuals (i.e., fishes, birds, and insects) with in a group. Particles are moving toward the global points through the instructions of the position and velocity of each individual.

PSO has been actively studied and applied for many academic and real world problems with promising results [15]. It has been found to be robust in solving continuous nonlinear optimization problems. It can generate high-quality solutions within shorter calculation time and have more stable convergence characteristic than other stochastic methods.

Although the PSO seems to be sensitive to the tuning of some weights or parameters, many researches are still in progress to prove its potential in solving complex power system problems [16]. The main concept of PSO can be summarized as follows:

In a physical n-dimensional search space, the position and velocity of particle i are represented as the vector $x_i = (x_{i1},...,x_{in})$ and $v_i = (v_{i1},...,v_{in})$ in the PSO algorithm. The particles explore in the search space with a velocity that is dynamically adjusted according to its own and neighbors' performances.

$$\begin{aligned} v_{id}(t+1) &= wv_{id}(t) + c_1 r_{1d}(t)[y_{id}(t) - x_{id}(t)] \\ &\quad + c_2 r_{2d}(t)[\hat{y}_d(t) - x_{id}(t)] \end{aligned} \tag{6}$$

where

w = Inertia weight factor

c_1, c_2 = Acceleration constant, in general

r_{1d}, r_{2d} = Random number in the range [0,1]

y = Position based on $Pbest$

$\hat{y}$ = Position based on $Gbest$

v_{id} = Velocity of particle i in dimension d

x_{id} = Position of particle i in dimension d

The idea for updating the velocity and position of particle is shown in Fig. 1.

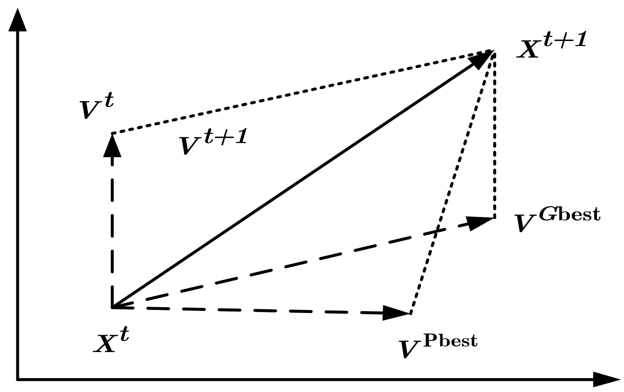

Fig. 1 Updating the velocity and position of particle in PSO

In this velocity updating process, the acceleration coefficients c_1, c_2 and the intertie weight w are predefined. In general, w is usually linear decreasing during the interaction using:

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{\text{Iter}_{\max}} \times \text{Iter} \tag{7}$$

where

$w_{\max}, w_{\min}$ = Initial and final interties parameter weights

$Iter_{\max}$ = Maximum iteration number

$Iter$ = Current iteration number

Once the velocity of particle is determined, its position is changed using the following equation.

$$x_{id}(t+1) = x_{id}(t) + v_{id}(t+1) \tag{8}$$

IV. Solution Methodology

Flowchart in Fig 2 shows the step of applying PSO algorithm to solve the ELD problem.

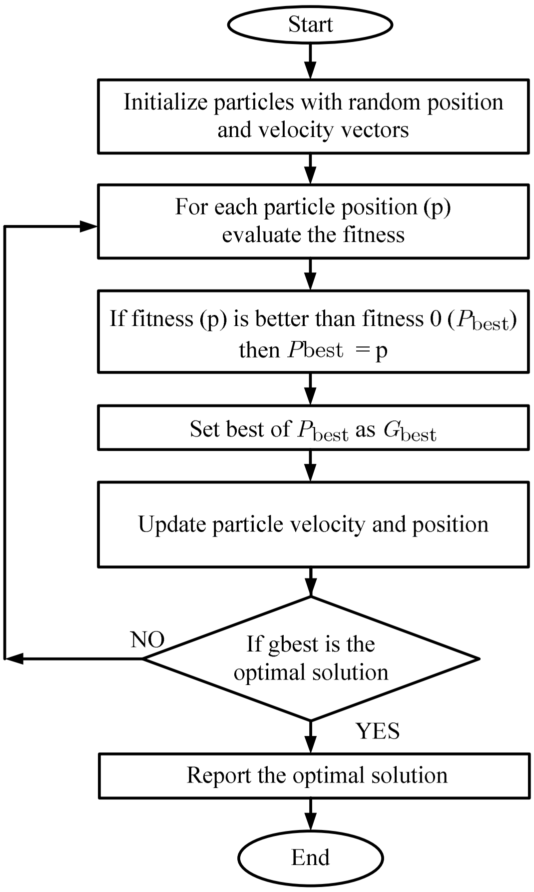

Fig. 2 Flowchart for PSO

V. Case Study

The performance of PSO for ELD problem is demonstrated by the test system of 40 generation units [17]. The load patterns and characteristics of the 40 generation units are shown in Tables I and II.

The optimal solution given by PSO, shown in Table III, is the generating power of each generation unit. Figs. 3 to 8 indicates the value of $Gbest$ (total generation cost) in each iteration of calculation for all six load patterns. When the output of each generation unit is known, the numerical results of total generation cost and total power loss can be calculated as also shown in Table III.

TABLE I
Load Patterns for Study

Load Patterns Power (MW)	Pattern 1	Pattern 2	Pattern 3
	6314	8231	9315
	Pattern 4	Pattern 5	Pattern 6
	11295	8501	7530

TABLE II
Generator 40 Units

Generator	a	b	c	P_i^{min}	P_i^{max}
1	0.0069	6.73	94.705	36	114
2	0.0069	6.73	94.705	36	114
3	0.02028	7.07	309.54	60	120
4	0.00924	8.18	369.03	80	190
5	0.0114	5.35	148.89	47	97
6	0.01142	8.05	222.33	68	140
7	0.00357	8.03	278.81	110	300
8	0.00492	6.99	391.98	135	300
9	0.00573	6.6	445.76	135	300
10	0.00605	12.9	722.82	130	300
11	0.00515	12.9	635.20	94	375
12	0.00569	12.8	654.69	94	375
13	0.00421	12.5	913.40	125	500
14	0.00752	8.84	1760.4	125	500
15	0.00708	9.15	1728.3	125	500
16	0.00708	9.15	1728.3	125	500
17	0.00313	7.97	647.85	220	500
18	0.00313	7.95	649.69	220	500
19	0.00313	7.97	647.83	242	550
20	0.00313	7.97	647.81	242	550
21	0.00298	6.63	785.96	254	550
22	0.00298	6.63	785.96	254	550
23	0.00284	6.66	794.53	254	550
24	0.00284	6.66	794.53	254	550
25	0.00277	7.10	801.32	254	550
26	0.00277	7.10	801.32	254	550
27	0.52124	3.33	1055.1	10	150
28	0.52124	3.33	1055.1	10	150
29	0.52124	3.33	1055.1	10	150
30	0.0114	5.35	148.89	47	97
31	0.0016	6.43	222.92	60	190
32	0.0016	6.43	222.92	60	[0
33	0.0016	6.43	222.92	60	190
34	0.0001	8.95	107.89	90	200
35	0.0001	8.62	116.58	90	200
36	0.0001	8.62	116.58	90	200
37	0.0161	5.88	307.45	25	110
38	0.0161	5.88	307.45	25	110
39	0.0161	5.88	307.45	25	110
40	0.00313	7.97	647.83	242	550
			Total	4817	12722

TABLE III
RESULTS OF STUDY

Generator	Pattern 1	Pattern 2	Pattern 3	Pattern 4	Pattern 5	Pattern 6
1	114	114	114	114	114	113.987
2	113.998	114	113.998	114	114	114
3	63.034	119.928	120	119.927	119.997	100.213
4	80.005	153.309	190	190	175.467	117.381
5	96.976	96.993	97	97	97	97
6	89.201	139.995	140	140	140	139.972
7	201.193	299.999	300	299.972	300	299.975
8	135.001	135.002	144.172	300	135.016	135.064
9	135.022	144.586	185.014	300	152.222	135
10	130	130.002	130	300	130.000	130
11	94	94	149.522	375	94.026	94
12	94.020	166.729	368.937	374.977	198.971	94
13	125	144.815	353.317	499.969	209.266	125.001
14	125.004	152.358	239.598	500	175.511	125
15	125.001	125.001	157.258	432.126	125.482	125
16	125.003	288.628	436.422	499.949	311.680	201.718
17	369.458	500	499.988	500	500	500
18	293.054	499.999	500	500	500	452.147
19	242	455.705	549.999	549.945	515.785	316.441
20	339.924	549.990	550	549.999	549.996	482.575
21	451.381	550	550	550	550	550
Generator	Pattern 1	Pattern 2	Pattern 3	Pattern 4	Pattern 5	Pattern 6
22	418.627	550	550	550	550	549.999
23	254	343.254	407.639	550.000	369.778	281.296
24	254	339.814	404.595	549.618	339.453	265.478
25	254.008	254.032	254	550	254.011	254.001
26	307.479	550	550	550	549.997	474.257
27	10	10.436	12.917	102.675	11.173	10.170
28	10	10	11.284	86.346	10	10
29	10	10	10.008	52.717	10.004	10
30	47.001	47.026	47	47	47	47.001
31	190	190	190	190	190	190
32	190	190	190	190	190	190
33	190	190	190	190	190	190
34	200	200	200	200	199.998	200
35	200	199.999	200	199.997	199.998	199.983
36	162.557	200.000	200	200	200.000	199.938
37	25	52.511	88.493	110	65.168	25.002
38	105.339	109.989	109.999	110	109.999	110
39	79.826	109.978	109.989	109.953	110	110
40	242	307.395	495.613	550.000	352.737	242.004
Total Power (MW)	7070.21	9447.93	10906.51	14115.07	9814.45	8485.20
Total Power Loss (MW)	378.105	608.464	795.754	1719.900	656.725	477.601
Cost	80742	102700	118580	217670	106430	93852

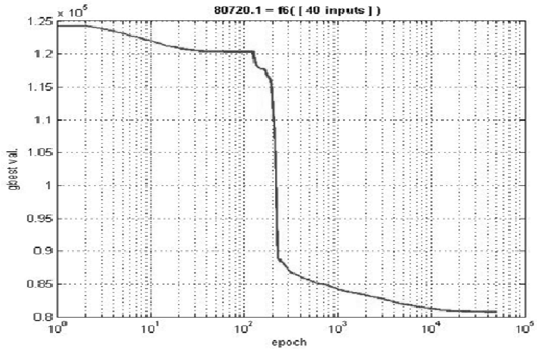

Fig. 3 Result PSO for Pattern 1

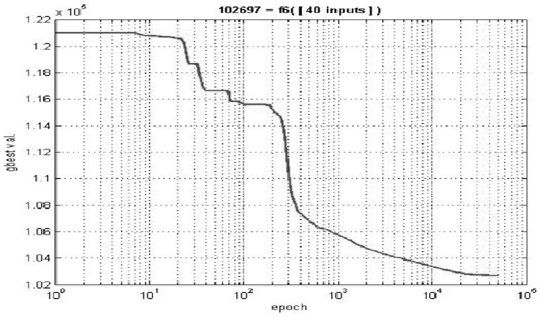

Fig. 4 Result PSO for Pattern 2

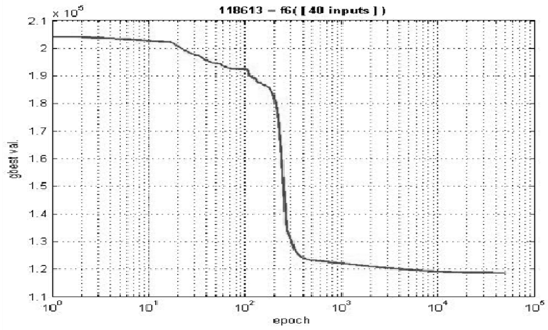

Fig. 5 Result PSO for Pattern 3

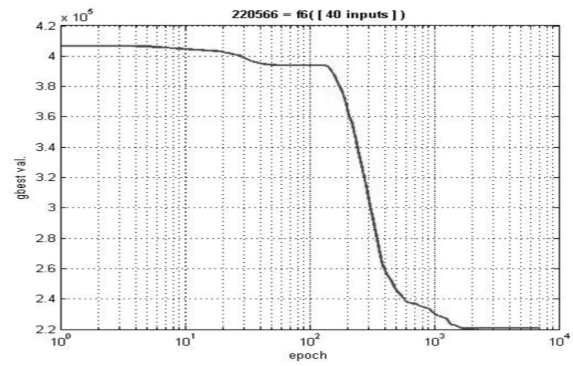

Fig. 6 Result PSO for Pattern 4

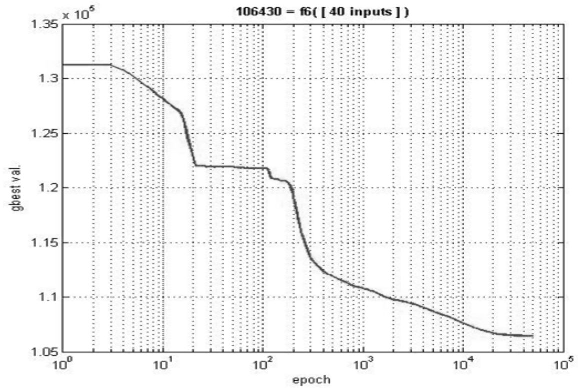

Fig. 7 Result PSO for Pattern 5

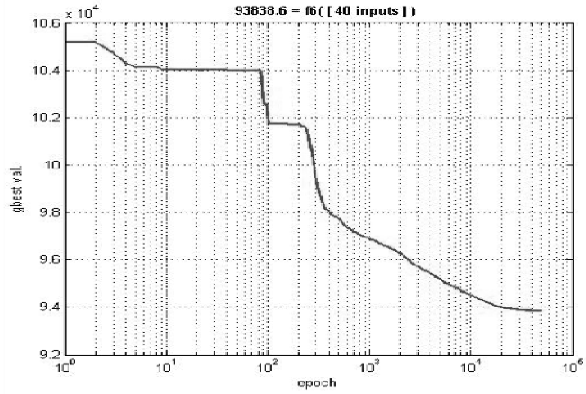

Fig. 8 Result PSO for Pattern 6

VI. Conclusion

This paper has presented a methodology based on particle swarm optimization (PSO) to solve the economic load dispatch problem concerned with daily load pattern. The objective of the problem is to minimize the total fuel cost while satisfying the load demand and retaining the active power output of all generation units within prescribed allowable limits. Case study is conducted with a test system with 40-generation units. Test results show that PSO has a capability to obtain high quality solutions efficiently.

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