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Economic Load Dispatch with Daily Load Patterns and Generator Constraints by Particle Swarm Optimization

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***Abstract*—**This paper presents an optimization technique to economic load dispatch (ELD) problems with considering the daily load patterns and generator constraints using a particle swarm optimization (PSO). The objective is to minimize the fuel cost. The optimization problem is subject to system constraints consisting of power balance and generation output of each units. The application of a constriction factor into PSO is a useful strategy to ensure convergence of the particle swarm algorithm. The proposed method is able to determine, the output power generation for all of the power generation units, so that the total constraint cost function is minimized. The performance of the developed methodology is demonstrated by case studies in test system of fifteen-generation units. The results show that the proposed algorithm scan give 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, Generator Constraints.

I. Introduction

THE electric power industry, the economic operation and planning of electric power 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 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 in power system analysis. 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.

PSO, originally invented in 1995, is a population based stochastic optimization technique which derived from simulation of a simplified social model of swarms (e.g. bird flocks or fish schools) [7-10]. The interaction of particles in swarm, using common evolutionary computation algorithm, guides the direction of swarm towards 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 algorithm extend its abilities to apply with a real-world problem in science and engineering fields. PSO 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].

The effectiveness of the developed optimization technique is demonstrated by a case study in test system of fifteen-generation units. The test results indicate the applicability of the proposed method to the practical economic load dispatch problem.

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].

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the proposed method to the practical economic load dispatch problem [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

Subject to a power balance constraint

$$\sum_{i=1}^{n} P_i = P_{\text{Load}} + P_{\text{Loss}} \tag{3}$$

where P_{Load} = total real power load demand at time
P_{Loss} = total transmission loss at time

The traditional B matrix loss formula is used to calculate transmission losses as shown below [1]

$$P_{Loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{i0} P_i + B_{00} \tag{4}$$

where B_{ij} = Element of the loss coefficient
B_{i0} = Element of loss coefficient vector
B_{00} = Loss coefficient constant

The generation output of each unit is bounded between to limitations

$$P_i^{\min} \le P_i \le P_i^{\max} \tag{5}$$

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

III. Particle Swarm Optimization

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.

In a physical n-dimensional search space, the position and velocity of infidel i are represented as the vector $x_i = (x_{i1}, \dots, x_{in})$ and $v_i = (v_{i1}, \dots, v_{in})$ 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 = Velocity based on $Pbest$
$\hat{y}$ = Velocity 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 illustrated in fig 1.

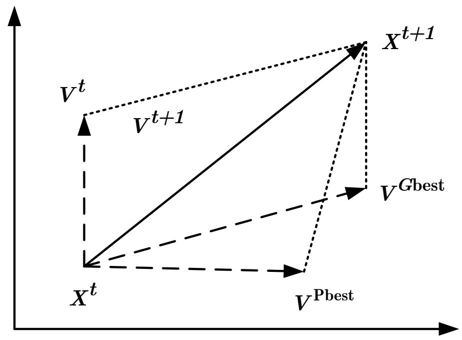

Fig. 1 Updating the velocity and position of particle in PSO

In this velocity updating process, the acceleration coefficients c_1, c_2 and the intertie weight w are predefined and r_{1d}, r_{2d} are uniformly generated random numbers in the range of [0,1] and w is an inertia term which 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 using the following equation

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

IV. Solution Methodology

The PSO algorithm is practical to solve the ELD problem by taking the PSO flowchart in Fig. 2.

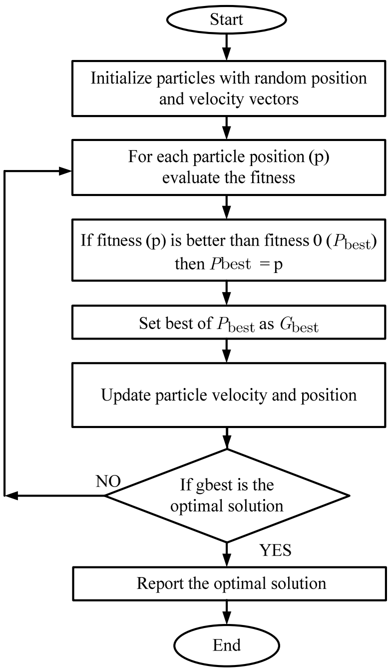

Fig. 2 Flowchart for PSO

V. Case Study

The performance of the developed PSO methodology is demonstrated by the test system of 15 generation units [9]. The characteristics of the 15 thermal units given in Table I. Load demand and duration for each level shown in Fig. 3

The two cases are examined for economic load dispatch with daily load patterns and generator constraints by particle swarm and compared with GA method. Case study as following as following:

Case 1 : Maximum of Power generation is $P\max = 100\ \%$

Case 2 : Maximum of Power generation is $P\max = 75\ \%$

The simulation results are compared case 1 and case 2 the total cost are compared in Table II. The optimal dispatch for all generation units, total power loss and cost in each load level are summarized in Table III - Table VI.

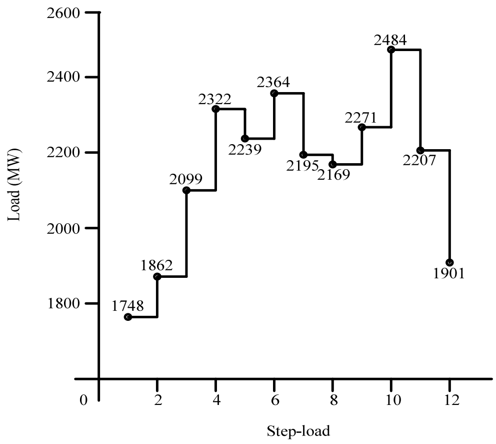

Fig. 3 Daily load patterns

TABLE I
GENERATORS 15 UNITS

unit	A	B	C	$P\min$	$P\max_{100\%}$	$P\max_{75\%}$
1	0.000229	10.1	671	150	445	334
2	0.000183	10.2	574	150	445	334
3	0.001126	08.8	374	20	130	98
4	0.001126	08.8	374	20	130	98
5	0.000205	10.4	461	150	470	353
6	0.000301	10.1	630	135	460	345
7	0.000364	9.8	548	135	465	349
8	0.000338	11.2	227	60	300	225
9	0.000807	11.2	173	25	162	122
10	0.001203	10.7	175	25	160	120
11	0.003586	10.2	186	20	80	60
12	0.005513	9.9	230	20	80	60
13	0.000371	13.1	225	25	85	64
14	0.001929	12.1	309	15	55	41
15	0.004447	12.4	323	15	55	41
			total	965	3522	2642

In this paper, we have successfully employed the PSO method to solve the ELD problem with the generator constraints. The PSO algorithm has been demonstrated to have superior features, including high-quality solution, stable convergence characteristic, and good computation efficiency. The results show that the proposed method was indeed capable of obtaining higher quality solution efficiently in ELD problems.

The total generation cost per day in table 4. PSO lower than that of GA are 2.392%, and also total power loss is 5.755%. The comparisons of result in terms of the total generation cost and loss given by the optimal dispatch schedule of PSO are slightly lower than those provided by the dispatch schedule of GA.

TABLE II
COMPARISONS OF OPTIMIZATION METHODS

	PSO-Case 1	GA –Case 2	PSO Case 2	GA Case 2
Total power (MW)	30825.49	31157.48	31717.61	32473.36
Total power loss (MW)	2482.22	2596.23	3097.566	3342.182

TABLE III
RESULTS OF CASE STUDY 1: UNIT 1-6

Unit	Step-load					
	1	2	3	4	5	6
1	279.54	340.12	307.15	445.00	420.50	445.00
2	234.48	236.48	397.71	424.89	377.45	445.00
3	130.00	130.00	130.00	130.00	130.00	130.00
4	130.00	130.00	129.99	130.00	130.00	130.00
5	150.01	150.07	150.00	157.56	150.00	171.83
6	398.68	337.32	460.00	460.00	460.00	460.00
7	256.02	383.57	393.25	464.99	457.30	465.00
8	60.01	60.00	60.00	60.00	60.00	60.00
9	25.01	25.00	25.00	25.00	25.01	25.00
10	25.05	25.05	31.29	44.66	34.37	51.44
11	55.55	60.99	71.27	80.00	79.66	80.00
12	79.73	79.94	80.00	80.00	80.00	80.00
13	25.00	25.04	25.00	30.62	25.00	41.50
14	15.00	15.00	15.01	15.00	15.00	15.02
15	15.00	15.00	15.00	15.00	15.00	15.00
Total power (MW)	2010.16	165.14	2482.34	2803.43	2679.55	2865.56
Total power loss (MW)	131.08	151.57	191.67	240.71	220.27	250.78
Cost ($/hr)	24543	25891	28759	31572	30484	32147

TABLE IV
RESULTS OF CASE STUDY 1: UNIT 7-12

Unit	Step-load					
	1	2	3	4	5	6
1	384.46	388.28	437.38	445.00	379.89	327.03
2	361.15	335.85	390.24	445.00	377.40	276.45
3	130.00	130.00	129.99	130.00	130.00	130.00
4	130.00	130.00	130.00	130.00	130.00	129.95
5	150.00	150.00	150.01	233.49	150.02	150.00
6	460.00	460.00	460.00	460.00	460.00	396.71
7	463.60	457.96	465.00	465.00	464.95	344.07
8	60.00	60.00	60.00	60.00	60.01	60.00
9	25.00	25.00	25.00	25.00	25.00	25.00
10	29.64	28.25	36.44	79.22	31.07	25.00
11	76.49	73.00	80.00	80.00	76.97	57.37
12	80.00	80.00	80.00	80.00	80.00	80.00
13	25.00	25.00	25.00	85.00	25.00	25.00
14	15.00	15.00	15.00	34.34	15.00	15.00
15	15.00	15.01	15.00	16.48	15.00	15.00
Total power (MW)	2615.68	2577.70	2727.09	3053.06	2633.61	2212.17
Total power loss (MW)	210.34	204.35	228.04	284.53	213.30	155.58
Cost ($/hr)	29923	29592	30894	33921	30079	26344

TABLE V
RESULTS OF CASE STUDY 2: UNIT 1-6

Unit	Step-load					
	1	2	3	4	5	6
1	301.12	333.75	333.75	333.75	333.75	333.75
2	261.84	333.75	333.75	333.75	333.75	333.75
3	97.50	97.50	97.50	97.50	97.50	97.50
4	97.49	97.50	97.50	97.50	97.50	97.50
5	150.00	155.79	313.95	352.50	352.50	352.50
6	344.99	345.00	345.00	345.00	345.00	345.00
7	348.75	348.75	348.75	348.75	348.75	348.75
8	60.00	60.00	60.00	225.00	98.95	225.00
9	25.00	25.00	85.64	121.50	121.50	121.50
10	25.00	41.39	85.85	120.00	115.13	120.00
11	54.89	60.00	60.00	60.00	60.00	60.00
12	60.00	60.00	60.00	60.00	60.00	60.00
13	25.00	28.12	63.75	63.75	63.75	63.75
14	15.00	15.00	41.25	41.25	41.25	41.25
15	15.00	15.00	28.55	41.25	41.25	41.25
Total power (MW)	2015.17	2171.10	2611.47	3005.86	2782.14	3005.86
Total power loss (MW)	133.58	154.55	256.23	364.36	271.57	364.36
Cost ($/hr)	24613	26021	29807	37507	31541	41707

TABLE VI
RESULTS OF CASE STUDY 2: UNIT 7-12

Unit	Step-load					
	1	2	3	4	5	6
1	333.75	333.75	333.75	333.75	333.75	333.75
2	333.75	333.75	333.75	333.75	333.75	333.75
3	97.50	97.50	97.50	97.50	97.50	97.50
4	97.50	97.50	97.50	97.50	97.50	97.50
5	352.50	335.74	352.50	352.50	352.50	174.69
6	345.00	345.00	345.00	345.00	345.00	345.00
7	348.75	348.75	348.75	348.75	348.75	348.75
8	63.79	60.00	187.99	225.00	70.36	60.00
9	102.01	87.39	121.50	121.50	112.27	25.00
10	96.95	92.79	120.00	120.00	98.06	48.73
11	60.00	60.00	60.00	60.00	60.00	60.00
12	60.00	60.00	60.00	60.00	60.00	60.00
13	63.75	63.75	63.75	63.75	63.75	44.99
14	41.25	41.25	41.25	41.25	41.25	18.37
15	32.39	28.80	41.25	41.25	34.76	15.00
Total power (MW)	2662.77	2602.95	2937.97	3005.86	2691.41	2225.05
Total power loss (MW)	233.88	216.97	333.48	364.36	242.20	162.02
Cost ($/hr)	30612	30136	32601	53707	30845	26561

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 15-generation units. Test results show that the proposed algorithm has a capability to obtain better solutions in terms of minimal fuel cost. The proposed PSO approaches are able to obtain higher quality solutions efficiently. The optimal combination of generators' output so as to minimize the total fuel cost while satisfying the constraints

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