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Economic load dispatch with valvepoint effects and Ramp rates using New Approach in PSO

V.Mahidhar[1] G.Sreenivasulu reddy[2]

***Abstract*—This paper proposes a newly improved method of particle swarm optimization for solving economic dispatch problem with valve point effects and with ramp rates included .The new method of pso uses time varying acceleration coefficients .The proposed method is tested on a 13 unit system and 19 unit Indian systems. The result is compared with the traditional methods. This gave a good result for the observed systems.** *(Abstract)*

***Index terms*—economic dispatch,valve point effects,Particle swarm optimization,time varying acceleration coefficient,ramp rates**

NOMENCLATURE

a,b,c	cost coeffiecients for quadratic cost function of unit i
e,f	cost coefficients of generator i reflecting valve point
B,B0,B00	loss coefficents of transmission lines
Pd	Demand of the system
Pl	transmission losses
Iwt	inertia weight
Pmin,Pmax	generator limits of operation

I. Introduction

The economic load dispatch problem has been extensively studied due to its importance in power system operation .This is a real time problem for properly allocating the real power output among the online generating units so as the cost on the production of thermal power will get is minimized while satisfying the unit and unit constraints .Many papers have been proposed for the efficient method of finding the least cost method for the economic load dispatch problem. At the early ages economic load dispatch was considered a quadratic objective function and the mathematical methods were used for it. The simplified model has been used since the mathematical methods require the fuel costs function to be differential. However, the input-output characteristics of the thermal generating units are actually more complicated due to the effect of valve point effects which includes a sine function in it. Therefore the practical ED problem is a non-convex optimization problem subject to the constraints, which cannot be directly solved by the mathematical programming techniques. Hence more advanced techniques have to be incorporated in solving with the problem with multiple minima. Recently the problem was extremely studied due to the advent of advanced programming techniques like genetic algorithm, ant colony optimization, Macluarein series based lagrangian technique[13] and in PSO itself there are a variety of improvements which lead to the enhancement of the solution.

There are plenty of methods that have enhanced the result of the operation of economic load dispatch and there are several advantages and disadvantages in each and every method. In this paper a newly improved particle swarm optimization based on the time varying acceleration coefficients have been proposed. With the new method, the search ability of the PSO has been considerably enhanced in comparison with the previous methods like MSL. The proposed method has been tested with 13 unit system and the 19 unit Indian system and the results have been checked with the previous methods.

The remaining organization of the paper is as follows, section II addresses the formulation of the economic dispatch problem with valve point effects .The proposed method has been described in the section III .Numerical results are followed in section IV. Finally, the conclusion is given

II **Problem formulation**

The ED problem with the valve point effects is a non-convex and non smooth problem with multiple minima due to taking into consideration of the ripples in the heat curve of the boilers. The model of the valve point effects have been proposed early by introducing sinusoidal function added to the quadratic fuel cost function[5] .The objective of the problem is to minimize the total cost of the thermal units while satisfying the power balance and generator limits including the ramp rates.

Mathematically, the problem is formulated as follows:

$$F(P_{gi}) = \left(\mathrm{a_i}\,\mathrm{P_{g_i}^2} + \mathrm{b_i P_{g_i}} + \mathrm{c_i}\right) + \mathrm{abs}(\mathrm{e_i}\ \sin\left(\mathrm{f_i}\left(\mathrm{P_{min\,g_i}} - \mathrm{P_{g_i}}\right)\right) \quad (1a)$$

$$\mathrm{Min\ F} = \Sigma_{\mathrm{i=1}}^{\mathrm{n}}\left(\mathrm{a_i}\,\mathrm{P_{g_i}^2} + \mathrm{b_i P_{g_i}} + \mathrm{c_i}\right) + \mathrm{abs}(\mathrm{e_i}\ \sin\left(\mathrm{f_i}\left(\mathrm{P_{min\,g_i}} - \mathrm{P_{g_i}}\right)\right) \quad (1b)$$

Subject to

A. Power Balance

The total power generation from the online generating units must satisfy the load demand plus power loss.

$$\Sigma_{i=1}^{n} P_{g_i} = P_D + P_L \quad (2)$$

Where the power loss P_L is calculated based on the power flows coefficients of B-matrix as follows:

$$P_L = \Sigma_{i=1}^{n}\Sigma_{j=1}^{n} P_{gi} B_{ij} P_{gj} + \Sigma_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{B_{0i} P_{gi}} + \mathrm{B_{00}} \quad (3)$$

B. Generaotor Limits

The real power output P_{gi} of unit i should be limited between its upper and lower bounds for safety operation represented by

$$P_{gi\ min} \leq P_{gi} \leq P_{gimax} \tag{4}$$

Where $P_{gi\ min}$ is lower bound and P_{gimax} is the upper bound of operation of the generator

C. Ramp rate limits

In some of the previous approaches of ELD strategy, generators outputs were assumed to be handled instantaneously. Although in the practical case the output are constrained by the ramp up and down limits depending upon the nature of the generators power orientation, this scenario is described mathematically as

$$P_i(t) - P_i(t-1) \leq UR_i \ \ if\ power\ increases$$

$$P_i(t-1) - P_i(t) \leq DR_i \ \ if\ power\ decreases \tag{5}$$

Where UR_i and DR_i are the up and down ramp limits for generator i, respectively .Merging them with above equation (4), the power limits of the i[th] generator can be redefined as

$$\max(P_{i,min}, P_i(t-1) - DR_i) \leq P_i(t) \leq \min(P_{i,min}, P_i(t-1) + UR_i) \tag{6}$$

III Particle swarm optimization

A.Particle swarm otimization

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Kennedy and Elberhart in 1995[10], discovered through simplified social model simulation. It stimulates the behaviors of bird flocking involving the scenario of a group of birds randomly looking for food in an area. PSO is motivated from this scenario and is developed to solve complex optimization problems.

In the conventional PSO, suppose that the target problem has *n* dimensions and a population of particles, which encode solutions to the problem, move in the search space in an attempt to uncover better solutions. Each particle has a position vector of Xi and a velocity vector *Vi*. The position vector *Xi* and the velocity vector *V I* of the *i* th particle in the *n*-dimensional search space can be represented as $X_i = (x_{i1}, x_{i2} ... x_{in})$ and $V_i = (v_{i1}, v_{i2}, ..., v_{in})$,respectively. Each particle has a memory of the best position in the search space that it has found so far $(Pbest_i)$, and knows the best location found to date by all the particles in the swarm $(Gbest)$. Let $Pbest = (x_{i1}^{pbest}, x_{i2}^{pbest}, x_{i3}^{pbest} \dots\dots, x_{in}^{pbest})$ and $Gbest = (x_{i1}^{gbest}, x_{i2}^{gbest}, \dots\dots x_{in}^{gbest})$, be the best position of the individual *i* and all the individuals so far, respectively. At each step, the velocity of the *I* th particle will be updated according to the following equation in the PSO algorithm:

$$v_i^{k+1} = w^k \times v_i^k + c1 \times rand_1 \times (pbest_i^k - x_i^k) + c2 \times rand_2 \times (gbest_i^k - x_i^k) \tag{7}$$

Where,

v_i^k	Velocity of individual *i* at iteration *k*,
w	inertia weight parameter,
c_1, c_2	acceleration coefficients,
$rand_1$, $rand2$	random numbers between 0 and 1
x_i^k	Position of individual *i* at iteration *k*,
$pbest_i^k$	Best position of individual *i* at iteration *k*,
$gbest_i^k$	Best position of the group until iteration *k*

In this velocity updating process the acceleration coefficients c1and c2 and the inertia parameters are predefined. The random numbers $rand_1$ and $rand_2$ are uniformly generated in the range of [0,1].In general the inertia weight w is set according to the equation as follows:

$$\omega^k = \omega_{max} - (\omega_{max} - \omega_{min}) \times (\frac{k}{IT_{max}}) \tag{8}$$

$\omega_{max}, \omega_{min}$	are the inertia weight parameters,
K	the iteration value,
IT_{max}	the max. no. of iterations.

This approach is called the inertia weight acceleration approach .Using the above equations the values will shift from pbest to gbest .Each particle is moved from current position to the nest position by the use of the modified velocity and the modified position as shown below

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{9}$$

B.Proposed Particle swarm optimization with Time varying acceleration coefficients

In this paper the proposed method is based on the improvements in PSO if operated with the time varying acceleration coefficients i.e PSO-TVAC .In the implementation of the PSO-TVAC for the n-dimensional optimization problem ,the position and velocity of the particles are represented by $X_i = [x_{i1}, x_{i2}, \dots\dots\dots\dots x_{in}]$ and $V_i = [v_{i1}, v_{i2} \dots\dots\dots . v_{i3}]$ respectively. The best previous particle is based on the evaluation of the fitness function Pbest,and the best among the all the particles is given by Gbest.The velocity and position of each particle in the next iteration for fitness evaluation is given as follows

$$v_i^{k+1} = \omega^{k+1} \times v_i^k + c_1^k \times r_1 \times (pbest_i^k - x_i^k) + c_2^k \times r_2 \times (gbest_i^k - x_i^k) \tag{10}$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{11}$$

Where

$$c_1^k = (c_{1f} - c_{1i}) \times {}^{k}/_{IT_{max}} + c_{1i} \tag{12}$$

$$c_2^k = (c_{2f} - c_{2i}) \times {}^{k}/_{IT_{max}} + c_{2i} \tag{13}$$

$$\omega^k = \omega_{max} - (\omega_{max} - \omega_{min}) \times {}^{k - IT_{max}}/_{IT_{max}} \tag{14}$$

The upper and lower bounds for each particle x_i are limited by the maximum and minimum limits of variable represented by the particle ,respectively. The velocity of each particle is limited in $[-v_{imax}, v_{imax}]$ for i=1, 2,3…….n, where the velocity of the particle for each element in the search space is determined by:

$$v_{imax} = R \times (x_{imax} - x_{imin}) \quad (15)$$

In this paper the value of the R is in the range from 0.01 to 0.05.

IV Algorithm steps

step 1. Choose the parameters of the PSO-TVAC including the number of particles Np, maximum no. of iterations IT_{max}, initial value of social and cognitive acceleration factors c_{1i} and c_{2i} and the final value of social and cognitive acceleration factors c_{1f} and c_{2f}.

step 2. Generate particles for all generators defined in the data including the position and velocity .For each particle calculate the fuel cost using (1a) and determine the F_{Pbest} which is the minimum value of the particles and also determine the value of the Gbest which is the min of the total determined Pbest (i.e)F_{gbest}=min(F_{pbest})

step 3. Set Pbest to x_i for each and Gbest to the position of the particle corresponding to the F_{Pbest} .Set number of iterations to 1.

step 4. Calculate the velocity (v_i^k)and position (x_i^k)for each particle (10) and (11) respectively.Note that the obtained position and velocity of the particle should lie in their lower limits and upper limits which are determined after ramp rates are considered .

step 5. Evaluate the fitness with the updated position of the paticle using (1a).Compare the $F^{(k)}$ to the F_{pbest}^{k-1} to obtain the best fitness function up to the current iteration F_{pbest}^{k} for each particle .Pick up the position $Pbest_i^k$ corresponding to F_{pbest}^{k} for each particle. Determine the global best fitness function F_{pbest}^{k} and corresponding position $Gbest^k$.

step 6. If $k<IT_{max}$,k=k+1 and return to step5. Otherwise, stop.

V Numerical results

The proposed method has been measured on a 13-unit system, data taken from [14]with the load demand of 1800 Mw and an Indian system in the southern power grid that consist of 19 generating stations in the state of tamilnadu where theare are a large number of thermal power plants.The algorithm is coded in matlab platform and run for 100 trials for each test case on a 2.1GHz PC with 1.5GB of RAM. In all cases the parameter are selected as ω_{max}=0.9,ω_{min}=o.4,c_{1i}=c_{2f}=2.5,c_{2i}=c_{1f}=0.2.The other parameters for the test are R=1,and Np=200 and 400.

A.13-unit system

Table-1

S.No	A_i	B_i	C_i	E_i	F_i	P_{min}	P_{max}
1	0.00028	8.1	550	300	0.035	0	680
2	0.00056	8.1	309	200	0.042	0	360
3	0.00056	8.1	307	150	0.042	0	360
4	0.00324	7.74	240	150	0.063	60	180
5	0.00324	7.74	240	150	0.063	60	180
6	0.00324	7.74	240	150	0.063	60	180
7	0.00324	7.74	240	150	0.063	60	180
8	0.00324	7.74	240	150	0.063	60	180
9	0.00324	7.74	240	150	0.063	60	180
10	0.00284	8.6	126	100	0.084	40	120
11	0.00284	8.6	126	100	0.084	40	120
12	0.00284	8.6	126	100	0.084	55	120
13	0.00284	8.6	126	100	0.084	55	120

Table-II

P_i^0	UR_i	DR_i
420	335	360
280	250	290
280	250	290
120	80	130
150	80	130
130	80	130
160	80	130
140	80	130
140	80	130
100	120	120
80	120	120
80	120	120
75	120	120

Table-III

Solution for the 13-unit system for Load demand of 1800Mw

The problem is solved for taking into account of 100 trails are considered and the best and worst cases are studied for the 100 trials for different population size and the values are found as in the table.

Population size	Best case	Worst case
400	17989.84$/h	18333.45$/h
200	17994.32$/h	18645.37$/h

B.19-unit Indian system

Data of the 19 unit Indian system is as follows:

Table-I

A_i	B_i	C_i	E_i	F_i
0.0097	6.8	119	90	0.72
0.0055	4	90	79	0.05
0.0055	4	45	0	0
0.0025	0.85	0	0	0
0	5.28	0.891	0	0
0.008	3.5	110	0	0
0.006	5.439	21	0	0
0.0075	6	88	50	0.52
0.0085	6	55	0	0
0.009	5.2	90	0	0
0.0045	1.6	65	0	0
0.0025	0.85	78	58	0.02
0	2.55	49	0	0
0.0045	1.6	85	0	0
0.0065	4.7	80	92	0.75
0.0045	1.4	90	0	0
0.0025	0.85	10	0	0
0.0045	1.6	25	0	0
0.008	5.5	90	0	0

Table-II

Ramp rates of the generators

P_i^0	UR_i	DR_i
250	95	150
300	138	180
300	100	200
20	5	12
120	80	90
300	100	150
130	70	100
600	400	500
500	200	300
30	10	15
100	55	85
50	25	25
120	80	90
50	40	45
125	95	105
55	25	40
55	25	40
150	80	100
550	100	150

Table-III

Solution for the Pd=3750Mw is tested for 100 trials independently and the value of the best and the worst costs are found and are here tabulated below.

Population size	Best case	Worst case
200	26110.33$/h	27639.57$/h
400	26075.20$/h	27216.36$/h

The results of the both systems are tabulated as below for plant wise power output and also the best and worst performance are also given care of.

C.SIMULATION RESULTS

A. Results for 13 unit System Unit wise at two different populations

Table-I

Population of 400		Population of 200		Ramp rate considered	
Best	Worst	Best	Worst	Pmin	Pmax
419.045	419.0423	419.064	329.3065	60	680
234.4629	84.80964	234.4393	84.95515	10	360
160.0968	159.5928	159.6177	360	10	360
159.7404	159.7355	109.934	87.24056	60	180
109.8664	109.8687	109.9668	60.06077	60	180
109.8649	131.8278	109.8705	118.8122	60	180
109.8792	109.8732	159.7877	159.5289	60	180
159.7388	159.7366	159.7507	159.6766	60	180
109.8986	109.867	109.8772	60.28229	60	180
77.39096	93.44354	40.0948	90.2643	40	120
40.01582	114.8019	40.08994	77.36856	40	120
55.00009	55.00204	92.47863	92.51869	55	120
55	92.39894	55.027	119.9939	55	120
Best cost=17989.84$/h		Best Cost=17994.32$/h			

From the above table it can be cleared that at high population levels we will get good results.

B.Results for 19- unit System Unit wise at two different populations

Table-I

From the table below on the right side it is cleared that at high population we will have good results.

Population of 200		Population of 400		Ramp rate considered	
Best	Worst	Best	Worst	Pmin	Pmax
239.6204	291.961	278.8884	265.7837	100	300
434.0161	382.2182	434.4727	371.2344	120	438
225.5227	217.7803	239.768	187.9166	100	250
24.9674	24.83847	24.92365	24.54044	8	25
63.67815	63.72809	63.56116	63.73158	50	63.75
299.5455	280.499	293.6119	290.7806	150	300
63.75	63.11671	63.40492	63.75	50	63.75
438.3529	498.7605	438.3957	486.6361	100	500
447.101	564.4981	461.921	561.6225	200	600
39.96066	38.46988	39.44294	39.47403	15	40
149.9579	109.1706	142.992	149.8819	50	150
74.91513	74.75709	74.97589	75	25	75
63.74556	63.36901	63.75	63.60993	50	63.75
89.96228	89.97188	89.98735	89.83108	5	90
219.9863	154.043	212.6942	149.8625	20	220
79.95427	79.967	79.36067	79.91894	15	80
80	79.9947	79.9828	80	15	80
229.9124	206.9454	230	228.1075	50	230
485.0501	465.9277	437.8501	478.371	400	500
Best cost=26110.33$/h		Best cost=26075.20$/h			

C.Results of other methods

Method	Cost obtained for 13-unit system
MSL[4]	18158$/h
CPSO	18006$/h

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VI CONCLUSIONS

In this paper, the PSO-TVAC method has been very efficiently implemented for a 13 unit system for solving economic load dispatch with valve point load effects and ramp rates included. With the improvements the search ability a solution quality has been considered improved in comparisons with other methods. The results comparisons' from the test cases have shown the efficiency of the system in finding the solution for the non-convex problem. Therefore the proposed method could be favorable for solving the complicated ED problems with non-convex objective function.

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V.Mahidhar—M.tech student of electrical power Engineering in Narayana Engineering College, received his B.E in Electrical and electronics from Arunai engineering college, Anna university

G.Sreenivasulu Reddy-Presently working as a associate professor in Narayana Engineering college ,Nellore.Presently pursuing his PhD .