ISSN: 2278 – 1323
International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)
Volume 2, Issue 4, April 2013

Economic Load Dispatch with Valve Point Loading Effect and Generator Ramp Rate Limits Constraint using MRPSO

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Abstract— **Economic load dispatch is the process of allocating generation among the committed units such that the constraints imposed are satisfied and the fuel cost is minimized. In this work proposed a new Particle swarm optimization with moderate random search. Particle swarm optimization is a population based optimization technique that can be applied to a wide range of engineering problems. Particle swarm optimization with a moderate-random-search strategy called MRPSO, enhances the ability of particles to explore the solution spaces more effectively and increases their convergence rates. In this paper the power and usefulness of the MRPSO algorithm is demonstrated through its application to three and six generator systems with valve point loading effect and ramp rate limit constraints.**

Index Terms— Economic **load dispatch , Generator ramp rate limits, moderate random particle (MRPSO), New weight improved particle swarm optimization (NWIPSO), Particle swarm optimization (PSO), Particle swarm optimization with constriction factor (CPSO).**

I. Introduction

Electric utility systems are interconnected in such a way to achieve the benefits of minimum production cost, maximum reliability and better operating conditions. The economic scheduling is the on-line economic load dispatch, wherein it is required to distribute the load among the generating units which are actually paralleled with the system, in such a way as to minimize the total operating cost of generating units while satisfying system equality and inequality constraints. For any specified load condition, ELD determines the power output of each plant (and each generating unit within the plant) which will minimize the overall cost of fuel needed to serve the system load [1]. ELD is used in real-time energy management power system control by most programs to allocate the total generation among the available units.

Conventional classical as well as modern evolutionary techniques have been used for the solution of economic load dispatch problem employing different objective functions. Various conventional methods like lambda iteration method, gradient-based method, Bundle method [2], nonlinear programming [3], mixed integer linear programming [4], [5], dynamic programming [8], linear programming [7], quadratic programming [9], Lagrange relaxation method [10], direct search method [12], Newton-based techniques [11], and interior point methods [6], [13] reported in the literature are used to solve such problems.

Conventional methods have many draw back such as nonlinear programming has algorithmic complexity. Linear programming methods are fast and reliable but require linearization of objective function as well as constraints with non-negative variables. Quadratic programming is a special form of nonlinear programming which has some disadvantages associated with piecewise quadratic cost approximation. Newton-based method has a drawback of the convergence characteristics that are sensitive to initial conditions. The interior point method is computationally efficient but suffers from bad initial termination and optimality criteria.

Recently, different modern heuristic approaches have been proved to be effective with promising performance, such as evolutionary programming (EP) [16], [17], simulated annealing (SA) [18], Tabu search (TS) [19], pattern search (PS) [20], Genetic algorithm (GA) [21], [22], Differential evolution (DE) [23], Ant colony optimization [24], Neural network [25] and particle swarm optimization (PSO) [26], [29], [30], [32]. The heuristic methods do not always guarantee discovering globally optimal solutions in finite time, but they provide a fast and reasonable solution. EP is rather slow converging to a near optimum for some problems. SA is very time consuming, and cannot be utilized easily to tune the control parameters of the annealing schedule. TS is difficult in defining effective memory structures and strategies which are problem dependent. GA sometimes lacks a strong capacity of producing better offspring and causes slow convergence near global optimum, sometimes may be trapped into local optimum. DE greedy updating principle and intrinsic differential property usually lead the computing process to be trapped at local optima.

Particle-swarm-optimization method is a population-based evolutionary technique first introduced [26], and it is inspired by the emergent motion of a flock of birds searching for food. In comparison with other EAs such as GAs and evolutionary programming, the PSO has comparable or even superior search performance with faster and more stable convergence rates. Now, the PSO has been extended to power systems, artificial neural network training, fuzzy system control, image processing and so on.

The main objective of this study is to use of PSO with moderate random search technique [36] to solve the

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economic load dispatch problem with valve point loading effect and generator ramp rate limits to enhance its global search ability. The proposed algorithm has the ability to explore the solution space than in a standard PSO. The proposed method focuses on solving the economic load dispatch with valve point loading effect and generator ramp rate limits constraint. The feasibility of the proposed method demonstrated for the test data of three and six generator system. The results obtained through the proposed approach and compared with other PSO techniques reported in recent literatures.

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II. ECONOMIC DISPATCH PROBLEM FORMULATION

A. *Basic Economic Dispatch Formulation*

Economic load dispatch is one of the most important problems to be solved in the operation and planning of a power system the primary concern of an ELD problem is the minimization of its objective function. The total cost generated that meets the demand and satisfies all other constraints associated is selected as the objective function.

The ED problem objective function is formulated mathematically in (1) and (2),

$$F_T = \mathrm{Min}\ f(FC) \tag{1}$$

$$f(FC) = \sum_{i=1}^{n} (a_i \times P_i^2 + b_i \times P_i + c_i) \tag{2}$$

$$P_i = \sum_{i=1}^{n} P_D + P_L \tag{3}$$

Due to presence of valve point loading effect nonlinearity and discontinuity of the ELD is increases, that why (2) can be modified as (4) and (5).

$$f'(FC) = f(FC) + \mathrm{abs}(e_i \sin(f_i(P_i^{min} - P_i))) \tag{4}$$

$$f'(FC) = (a_i P_i^2 + b_i P_i + c_i) + \mathrm{abs}(e_i \sin(f_i(P_i^{min} - P_i))) \tag{5}$$

Where, F_T is the objective function, a_i, b_i and c_i are the cost coefficients and e_i & f_i are the valve point loading effect coefficients of the i^{th} generator, P_D and P_L represent total demand power and the total transmission loss of the transmission lines respectively.

B. *CONSTRAINTS*

This model is subjected to the following constraints,

1) Real Power Balance Equation

For power balance, an equality constraint should be satisfied. The total generated power should be equal to total load demand plus the total losses,

$$\sum_{i=1}^{n} P_i = P_D + P_L \tag{6}$$

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{i0} P_i + B_{00} \tag{7}$$

Where, P_D is the total system demand and P_L is the total line loss.

B_{ij} =ijth element of loss coefficient symmetric matrix B,

B_{i0} =ith element of the loss coefficient vector and

B_{00} =loss coefficient constant.

2). Unit Operating Limits

There is a limit on the amount of power which a unit can deliver. The power output of any unit should not exceed its rating nor should it be below that necessary for stable operation. Generation output of each unit should lie between maximum and minimum limits.

$$P_i^{min} \le P_i \le P_i^{max} \tag{8}$$

Where, P_i is the output power of i^{th} generator, $P_{i,min}$ and $P_{i,max}$ are the minimum and maximum power outputs of generator i^{th} respectively.

3). Ramp Rate Limit

According to the operating increases and operating decreases of the generators are ramp rate limit constraints described in eq. (9) & (10).

1) As generation increases

$$P_i(t) + P_i(t-1) \le UR_i \tag{9}$$

2) As generation decreases

$$P_i(t-1) - P_i(t) \ge DR_i \tag{10}$$

When the generator ramp rate limits are considered, the operating limits for each unit, output is limited by time dependent ramp up/down rate at each hour as given below.

$$P_i^{min}(t) = \max(P_i^{min}, P_i(t-1) - DR_i) \tag{11}$$

$$P_i^{max}(t) = \min(P_i^{max}, P_i(t-1) - UR_i) \tag{12}$$

$$P_i^{min}(t) \le P_i(t) \le P_i^{max}(t)\ t) \tag{13}$$

Where, $P_i(t)$ is current output power of i^{th} generating unit, $P_i(t-1)$is previous operating point of the i^{th} generator, DR_i is the down ramp rate limit (MW/time period) and UR_i is up ramp rate limit (MW/time period).

III. OVERVIEW OF SOME PSO STRATEGIES

A number of different PSO strategies are being applied by researchers for solving the economic load dispatch problem and other power system problems. Here, a short review of the significant developments is presented which will serve as a performance measure for the MRPSO technique [36] applied in this paper.

A. Standard particle swarm optimization (PSO)

Particle swarm optimization was first introduced by Kennedy and Eberhart in the year 1995 [26]. It is an exciting new methodology in evolutionary computation and a population-based optimization tool. PSO is motivated from the simulation of the behavior of social systems such as fish schooling and birds flocking. It is a simple and powerful optimization tool which scatters random particles, i.e., solutions into the problem space. These particles, called swarms collect information from each array constructed by their respective positions. The particles update their positions using the velocity of articles. Position and velocity are both updated in a heuristic manner using guidance from particles' own experience and the experience of its neighbors.

The position and velocity vectors of the ith particle of a d-dimensional search space can be represented as

$P_i=(p_{i1},p_{i2},\ldots\ldots p_{id})$ and $V_i=(v_{i1},v_{i2},\ldots\ldots v_{id})$ respectively. On the basis of the value of the evaluation function, the best previous position of a particle is recorded and represented as $P_{besti}=(p_{i1},p_{i2},\ldots\ldots p_{id})$, If the gth particle is the best among all particles in the group so far, it is represented as $P_{gbest}=g_{best}=(p_{g1},p_{g2},\ldots\ldots p_{gd})$.

The particle updates its velocity and position using (10) and (11).

$$V_i^{(K+1)} = WV_i^K + c_1 Rand_1(\,) \times \left(Pbest_i - S_i^K\right) + c_2 Rand_2(\,) \times \left(gbest - S_i^K\right) \tag{14}$$

$$S_i^{(K+1)} = S_i^K + V_i^{K+1} \tag{15}$$

Where, V_i^k is velocity of individual i at iteration k, k is pointer of iteration, W is the weighing factor, c_1, c_2 are the acceleration coefficients, $Rand_1(\,)$, $Rand_2(\,)$ are the random numbers between 0 & 1, S_i^k is the current position of individual i at iteration k, P_{besti} is the best position of individual i and g_{best} is the best position of the group.

The coefficients c_1 and c_2 pull each particle towards pbest and gbest positions. Low values of acceleration coefficients allow particles to roam far from the target regions, before being tugged back. on the other hand, high values result in abrupt movement towards or past the target regions. Hence, the acceleration coefficients c_1 and c_2 are often set to be 2 according to past experiences. The term $c_1 rand_1$ () x (pbest, $-S^k{}_1$) is called particle memory influence or cognition part which represents the private thinking of the itself and the term $c_2 Rand_2(\,)\times(gbest - S^k{}_1)$ is called swarm influence or the social part which represents the collaboration among the particles.

In the procedure of the particle swarm paradigm, the value of maximum allowed particle velocity V_{max} determines the resolution, or fitness, with which regions are to be searched between the present position and the target position. If V_{max} is too high, particles may fly past good solutions. If V_{max} is too small, particles may not explore sufficiently beyond local solutions. Thus, the system parameter V_{max} has the beneficial effect of preventing explosion and scales the exploration of the particle search. The choice of a value for V_{max} is often set at 10-20% of the dynamic range of the variable for each problem.

W is the inertia weight parameter which provides a balance between global and local explorations, thus requiring less iteration on an average to find a sufficiently optimal solution. Since W decreases linearly from about 0.9 to 0.4 quite often during a run, the following weighing function is used in (16)

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} \times iter \tag{16}$$

Where, W_{max} is the initial weight, W_{min} is the final weight, $Iter_{max}$ is the maximum iteration number and iter is the current iteration position.

B. CLASSICAL PSO

In this section, for getting better solution the standard PSO algorithm, used classical PSO [11] [28][35],The constriction factor is used in this algorithm given as(17).

$$C = \frac{2}{\left|2-\emptyset-\sqrt{\emptyset^2-4\emptyset}\right|} \tag{17}$$

Where, Ø is define as 4.1≤Ø≤4.2

As ∅ increases, the factor c decreases and convergence becomes slower because population diversity is reduced.

Now the update its velocity using (14).

$$V_i^{(K+1)} = C[WV_i^K + c_1 Rand_1(\,) \times \left(Pbest_i - S_i^K\right) + c_2 Rand_2(\,) \times \left(gbest - S_i^K\right)] \tag{18}$$

C. WEIGHT IMPROVED PSO (WIPSO)

In this section, for getting the better global solution, the traditional PSO algorithm is improved by adjusting the weight parameter, cognitive and social factors. Based on [15], the velocity of individual I of WIPSO algorithm [37] is rewritten as,

$$V_i^{(K+1)} = w_{new} V_i^K + c_1 Rand_1(\,) \times \left(Pbest_i - S_i^K\right) + c_2 Rand_2(\,) \times \left(gbest - S_i^K\right) \tag{19}$$

Where,

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} \times iter \tag{20}$$

$$w_{new} = w_{min} + w \times rand_3 \tag{21}$$

$$c_1 = c_{1max} - \frac{c_{1max} - c_{1min}}{iter_{max}} \times iter \tag{22}$$

$$c_2 = c_{2max} - \frac{c_{2max} - c_{2min}}{iter_{max}} \times iter \tag{23}$$

Where , wmin, wmax: initial and final weight, c_{1min}, c_{1max}: initial and final cognitive factors and c_{2min}, c_{2max}: initial and final social factors.

D. Moderate random search particle swarm optimization (MRPSO)

MRPSO was first introduced by Hao Gao and Wenbo in the year 2011[35], In order to enhance the global search ability of the PSO but not slow down its convergence rate, we used a new PSO algorithm with an MRS strategy. In this algorithm used only position update and no need of velocity updating .

The position $S_i^{(K+1)}$ of the i_{th} particle at the (K + 1)th iteration can be calculated using the following formula

$$S_i^{K+1} = P_d + \propto \lambda(m_{besti} - S_i^K) \tag{24}$$

$$m_{besti} = \sum_{i=1}^{S} \frac{P_{best}}{S} \tag{25}$$

Where, S denotes the population size in the MRPSO.

The parameter α is obtained by changing α from 0.45 to 0.35 with the linear-decreasing method during iteration, P_d is the attractor moving direction of particles, it is given as

$$P_d = rand_0 P_{best} + (1 - rand_0) g_{best} \tag{26}$$

Where, $rand_0$ is a uniformly distributed random variable within [0, 1].

$$\lambda = (rand_1 - rand_2)/rand_3 \quad (27)$$

Where, $rand_1$ and $rand_2$ are two random variables within [0, 1] and $rand_3$ is a random variable within [−1, 1].

IV. ALGORITHM FOR ED PROBLEM USING MRPSO

In this work a new PSO with moderate random search techniques is used to solve the proposed ELD problem with valve point loading effect and generator ramp rate limits as constraints. The following steps were taken when solving the proposed problem by MRPSO.

Step1:- Initialization of the swarm: For a population size the particles are randomly generated in the range 0–1 and located between the maximum and the minimum operating limits of the generators.

Step2:-Initialize velocity and position for all particles by randomly set to within their legal rang.

Step3:-Now set generation counter t=1.

Step4:- Evaluate the fitness for each particle according to the objective function.

Step5:-Compare particles fitness evaluation with its P_{best} and g_{best}.

Step6:-Update position by using eq.(24).

Step7:-Apply stopping criteria.

V. CASE STUDY

A. *Test Case I*

The first test results are obtained for 3-generator systems in which all units with their ramp-rate limits. The unit characteristics data are given in Table I The load demand is 850 MW. The line loss coefficients for 3 generating units are given in Table-II. The best solutions of the proposed MRPSO, PSO, PSO with constriction factor (CPSO) & WIPSO methods are shown in Table V.

Table I

Capacity, cost coefficients valve point loading constant and ramp- rate limits of 3 generator systems.

units	1	2	3
a_i	0.00482	0.00194	0.001562
b_i	7.97	7.85	7.92
c_i	78	310	562
e_i	150	200	300
f_i	0.063	0.042	0.0315
P_i^{max}	200	400	600
P_i^{min}	50	100	100
P_i	170	350	440
UR_i	50	80	80
DR_i	90	120	120

Table II

B coefficient (in MW^{-1}) for 3 generator system

Bij	0.0006760	0.0000953	-0.0000507
	0.0000953	0.0005210	0.0000901
	-0.0000507	0.0000901	0.0002940
Bio	-0.007660	-0.00342	0.01890
Boo	0.40357		

B. *Test Case II*

The second test results are obtained for six-generating unit system in which all units with their valve point and ramp-rate limits constraints. This system supplies a 1263MW load demand. The data for the individual units are given in Table III. The line loss coefficients are given in table IV. The best solutions of the proposed MRPSO, PSO, PSO with constriction factor (CPSO) and WIPSO methods are shown in Table VI.

Table III

Capacity, cost coefficients, valve point loading effect and ramp- rate limits of 6 generator systems.

units	1	2	3	4	5	6
a_i	.007	0.0095	0.009	.009	.0080	.0075
b_i	7	10	8.5	11	10.5	12
c_i	240	200	220	200	220	190
e_i	300	150	200	100	150	100
f_i	.031	0.063	0.042	0.08	0.063	0.084
P_i^{max}	500	200	300	150	200	120
P_i^{min}	100	50	80	50	50	50
P_i	440	170	200	150	190	110
UR_i	80	50	65	50	50	50
DR_i	120	90	100	90	90	90

Table IV

Line loss coefficients (in MW^{-1}) for six bus systems

Bij	.000 017	0.00 0012	.000 07	-0.00 001	-.000 005	.000 002
	.000 012	.000 014	.0000 09	.000 001	-.000 006	.000 001
	.000 007	.000 009	.000 031	.000	-.000 010	.000 006
	-.000 001	.000 001	0.00	.00 024	-.000 006	.000 008
	-.000 005	-.000 006	-.000 010	-.000 006	.000 129	.000 002
	-.000 002	-.000 001	-.000 006	-.00 008	-.000 002	.000 150
Bio	-0.39 08	-1.29	7.047	0.5910	2.161	-6.63
Boo	0.0056					

TABLE V

Results of three generating unit system, load 850MW (100 trails)

Unit Power Output	*PSO*	*CPSO*	*WIPSO*	*MRPSO*
P1(MW)	189.94	189.542	198.2	172.972
P2(MW)	314.05	304.45	318.034	330.62
P3(MW)	470.82	480.14	458.034	471.0324
Power loss(MW)	124.89	126.277	128.3423	126.8917
Total Power Output	974.80	974.132	974.268	974.6244
Total Cost($/h)	11548.2	11459.1	11414.39	11412.60
CPU Time(sec)	0.5204	0.4815	0.4802	0.47901

ISSN: 2278 – 1323
International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)
Volume 2, Issue 4, April 2013

TABLE VI
Generator output for six bus system (100 trails)

Unit Power Output	*PSO*	*CPSO*	*WIPSO*	*MRPSO*
P1(MW)	443.034	467.550	437.82	442.07
P2(MW)	169.03	163.05	173.28	167.23
P3(MW)	262.02	253.415	271.97	267.09
P4(MW)	134.78	115.07	138.7	132.81
P5(MW)	147.47	169.45	146.98	155.02
P6(MW)	125.35	113.24	103.632	107.023
Loss	18.68	18.70	18.08	18.03
Total Power Output	1281.68	1281.77	1281.082	1281.033
Total Cost($/h)	16372.9	16329.2	16327	16310.76
CPU Time(sec)	0.6034	0.6109	0.592	0.5835

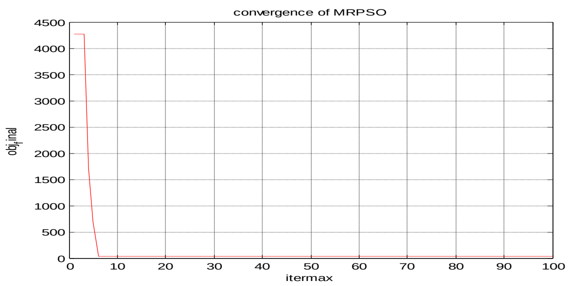

Fig.1. Fitness function of the conversion system for three generator system.

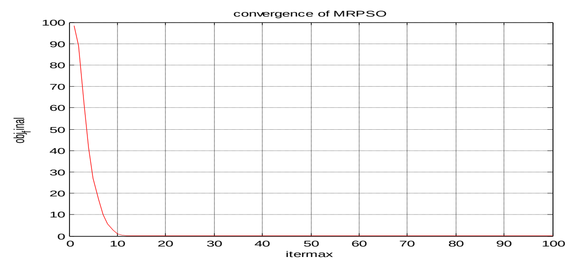

Fig.2. Fitness function of the conversion system for six generator system.

VI. RESULTS AND ANALYSIS

To assess the efficiency of the proposed MRPSO approaches in this work, two case studies (3 and 6 thermal units or generators) of ELD with their valve point loading effect and ramp rate limit constraints were taken into account. All the test data is taken from the literature. Different variants of PSO techniques used to solve the proposed ELD problem given in table I and table III were run on a 1.4-GHz, core-2 solo processor with 2GB DDR of RAM.

In each case study, 100 iterations were taken for obtaining optimum results from different PSO variants mentioned in this work. The constant used in this study was, acceleration coefficient used in this study are c1=c2=2 , α=3.1-4.5, W_{max}=0.9 and W_{min}=0.4. the optimal result obtained by MRPSO for the 3 generating units with line loss and load of 850MW shown in table V, it shows fuel cost of 11412.60 $/h and optimal line loss of 126.8917 MW and total computational time taken of 0.47901sec.

The optimal result obtained by MRPSO for the 6 generating units with line loss and load of 1263 MW shown in table VI, it shows fuel cost of 16310.76 $/h and optimal line loss of 18.03 MW and total computational time taken of 0.5835 sec. the optimal result obtained by MRPSO in both test case is shows that, it give better result means lowest fuel cost value than other PSO variants mentioned in this work and it also taken less computational time

Fig.1& fig.2 shows the improvement in each iteration for the three and six generation unit system for the load of 850 MW and 1263 MW with valve point loading effect and generator ramp rate limit constraints respectively.

VII. CONCLUSIONS

This paper introduces PSO with moderate random search optimization techniques called MRPSO for the solution of proposed ELD problem. proposed method has been applied to test case for the given data in table I. The optimal result obtained shows in table V and table VI demonstrated that MRPSO outperforms the other methods in terms of a better optimal solution and significant reduction of computing times. However, the much improved speed of computation allows for additional searches to be made to increase the confidence in the solution. Overall, the MRPSO algorithms have been shown to be very helpful in studying optimization problems in power systems.

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