Constrained Economic Load Dispatch Using Evolutionary Technique

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Abstract - **This paper proposed a new PSO with moderate random search strategy called MRPSO for the solution of economic load dispatch. The property of moderate random search strategy is to increase the convergence rate of particles and it enhances particles ability in such a way to explore in the solution space effectively. PSO is very popular optimization technique and used by various researchers to solve the economic load dispatch problem, but it is seen that, it's convergence rate very slow at last stage of iteration. The MRSPO can overcome this problem and gives global solution of economic load dispatch. Economic load dispatch is the process of allocation of power generation units such that satisfied load demand at minimal possible cost and also satisfying the various equality as well as inequality constraints. Validation of the proposed optimization algorithm tested by using test case of 3 and 10 generating unit system. The results are compared with other variants of PSO mention in this paper and it is found that the proposed approach outperforms than other PSO Variants.**

Keywords - **Economic Load Dispatch (ELD), Fuel cost, Valve point loading effect, Particle swarm optimization (PSO), Moderate random search particle swarm optimization (MRPSO).**

I. INTRODUCTION

Achieve the benefits of minimum production cost, better operating conditions and maximum reliability is the basic object of the electrical systems. The economic load is the process of on-line allocation of generating units, wherein it is required to distribute the load among the generating units, in such a way as to minimize the total operating cost of generating units

and satisfying system equality and inequality constraints [4]. Since the load demands swings continuously hence it is very difficult to satisfy the demands in the minimum cost. The fuel cost curve characteristic is nonlinear due to presence of various equality and inequality constraints. That's why it is the great challenge to get optimal solution of economic load dispatch problem.

Economic load dispatch is a nonlinear problem due to presence of valve point loading effect and various constraints. Many classical, hybrid and evolutionary technique listed in the literature were used to solve such a nonlinear ELD problem. Classical methods like Quadratic programming, Linear programming[2], Newton based techniques[4], Dynamic programming, interior point methods and Lagrange relaxation methods etc. were used to solve the ELD problem with valve point loading effects. But is it seen that classical methods have very slow convergence rate and also unable to give the global solution of the nonlinear ELD problem.

It is observed that classical methods have its own draw back such as in case of 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.

Since the classical methods are failed to give optimum solution of ELD problem so that in current scenario various modern evolutionary techniques used for solution of economic load dispatch, which is very efficient with promising performance. The heuristic methods provide a fast and reasonable solution Different modern evolutionary technique which used for the solution of nonlinear ELD model reported in literature such as Nidhul Sinha et al.[5] proposed evolutionary programming techniques for economic load dispatch, K.P. Wong et al.[6] gives simulated annealing based economic dispatch algorithm, W.M. Lin et al.[7] proposed an improved Tabu search for economic dispatch with multiple minima, J.S. Al-Sumait et al.[8] used application of pattern search method to power system valve point economic load dispatch, D.C.Walter et al.[9] used genetic algorithm for the solution of economic dispatch with valve point loading, L.L. Lai[10] proposed ANN to economic load dispatch, J.Kennedy et al.[11] proposed Particle Swarm Optimization, C.H. Chen et al[12] & K.S. Swarup[13] proposed Swarm intelligence Approach to the solution of optimal power flow, K.T. Chaturvedi et al.[14]proposed advance variantof PSO namely called Self Organizing Hierachical PSO for nonconvex economic load dispatch, Hao Gao et al.[17] proposed a A new particle swarm algorithm called MRPSO etc.

Literature shows that evolutionary technique have many advantages but also have their own disadvantages like evolutionary programming techniques rather slow converging near optimum. SA is very time consuming, and cannot be utilized easily to tune the control parameters. TS is difficult in defining effective memory structures and strategies which are problem dependent. GA lacks a strong capacity of producing better offspring and causes slow convergence near global optimum. DE greedy updating principle and intrinsic differential property usually lead the computing process to be trapped at local optima.

In comparison with among intelligent methods the PSO has superior search performance with faster and more stable convergence rates[12] but its lacks global search ability in the last stage of iterations. This problem of PSO can be solved by using moderate random search technique with PSO. In this study proposed a new approach of PSO with moderate random search strategy(MRPSO) to solve the ELD problem with valve point loading effect. MRPSO gives more opportunity of the particles to explore in the solution space and enhances the global search ability of the particles as compared to classical PSO [17].

The feasibility of the proposed method was demonstrated for 3 and 10 generator system. The results obtained through the proposed approach compared with other variants of PSO.

II. FORMULATION OF ECONOMIC LOAD DISPATCH PROBLEM

Economic load dispatch is the important task in power system. The main objective of an ELD problem is the minimization the total generation cost of generating units in such a way to meets the demand and satisfies constraints selected as the objective function.

Objective function of the ELD problem is formulated mathematically as shown in Eq. (1) and (2).

$$F_{objective} = \text{Min}\, f(FC(P_i)) \quad (1)$$

$$f(FC(P_i)) = \sum_{i=1}^{N} a_i P_i^2 + b_i P_i + c_i \quad (2)$$

Where, $FC(P_i)$ is the total fuel cost, a_i, b_i and c_i are the cost coefficients and N=number of generating units.

A. PROBLEM FORMULATION WITH VALVE POINT LOADING EFFECT

Due to presence of valve point loading effect nonlinearity and discontinuity of the ELD is increases, that why Eq.(2) can be modified as Eq.(3).

$$f'(FC(P_i) = f(FC(P_i)) + abs(e_i \sin(f_i(P_i^{min} - P_i)) \quad (3)$$

Where, e_i and f_i are constants of the valve point effect of generators.

Hence, the total fuel cost that must be minimized, according to (1), is modified to (4)

$$F_{obj\_new} = \text{Min}\, f'(FC(P_i)) \quad (4)$$

Where, f' (FC) is the cost function of i^{th} generator in ($/h).

B. CONSTRAINTS CONSIDERED

A. POWER BALANCE EQUATION

For power balance, an equality constraint should be satisfied in such a way that the total generated power should be equal to total load demand plus the total losses [7].

$$\sum_{i=1}^{n} P_i = P_D + P_L \quad (5)$$

Where, P_D is the total system demand. In this case study we disregarded the transmission losses, so that, P_L=0.

B. GENERATING UNIT OPERATING LIMITS

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 [5].

$$\mathbf{P_i^{min} \le P_i \le P_i^{max}} \quad (6)$$

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

III. EVOLUTIONARY TECHNIQUE

A. STANDARED PARTICLE SWARM OPTIMIZATION

Particle swarm optimization is a very popular optimization technique used by many researchers to solve the ELD problem. It was first introduced by Kennedy and Eberhart in the year 1995. It is a modern evolutionary approach based on the population. PSO is motivated from the behavior of social systems such as fish schooling and birds locking[12]. In the multidimensional space where the optimal solution is sought, each particle in the swarm is moved toward the optimal point by adding a velocity with its position.

The position and velocity vectors of the ith particle of a n-dimensional search space can be represented as eq.(7) & (8).

$$P_i = (p_{i1}, p_{i2}, \dots\dots\dots.. p_{id}) \quad (7)$$

$$V_i = (v_{i1}, v_{i2}, \dots\dots\dots.. v_{id}) \quad (8)$$

On the basis of the value of the evaluation function, the best previous position of a particle is recorded and represented as Eq.(9).

$$P_{best} = (p_{i1}, p_{i2}, \dots\dots\dots.. p_{in}) \quad (9)$$

If the gth particle is the best among all particles in the group so far, it is represented as

$$g_{best} = (p_{i1}, p_{i2}, \dots\dots\dots.. p_{gn}) \tag{10}$$

The particle updates its velocity and position using Eq.(11) and (12).

$$V_i^{(K+1)} = WV_i^K + c_1 Rand_1 (Pbest_i - S_i^K) + c_2 Rand_2 (gbest - S_i^K) \tag{11}$$

$$S_i^{(K+1)} = S_i^K + V_i^{K+1} \tag{12}$$

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 particle at iteration k, $Pbest_i$ is the best position of individual and gbest is the best position of the group.

The term $c_1 * rand_1(pbest, -S^k_1)$ is called particle memory influence or cognition part which represents the private thinking of the itself and the term $c_2 * Rand_2 * (gbest – S^k_1)$ is called swarm influence which represents the collaboration among the particles.

The inertia weight parameter 'W' provides a balance between global and local explorations. The following weighing function is used in (13)

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} \times iter \tag{13}$$

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. MODERATE RANDOM SEARCH PARTICLE SWARM OPTIMIZATION (MRPSO)

This is the modified version variant of classical PSO. Since classical PSO lacks with global search ability at last stage of iteration. It's have one of the major disadvantage that if once it set to local optimization than cannot gives global solution of the problem. In this study proposed moderate random search strategy with PSO. This approach not only gives better performance than classical PSO but also enhance the global search ability of particle also improving the convergence time [17]. Hao Gao and Wenbo was first introduced PSO with Moderate random search strategy in the year 2011[17]. It is initialize same as PSO when using for the solution of nonlinear economic load dispatch. In case of PSO the velocity of particles almost zero at the last stage of iteration, so [17] suggested that only update of particle position is sufficient to get optimal solution of the ELD problem with valve point loading effect.

Hence in case of MRPSO position of particles can be update by using eq. (14). The position $S_i^{(K+1)}$ of the i_{th} particle at the $(K + 1)^{th}$ iteration can be calculated using Eq. (14) & (15).

$$S_i^{K+1} = P_d + \propto \lambda (m_{besti} - S_i^K) \tag{14}$$

$$m_{besti} = \sum_{i=1}^{S} \frac{P_{best}}{S} \tag{15}$$

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.

Pd is the attractor moving direction of particles; it is given as (16).

$$P_d = rand_0 P_{best} + (1 - rand_0) g_{best} \tag{16}$$

Where, rand0 is a uniformly distributed random variable within [0, 1].

$$\lambda = (rand_1 - rand_2)/rand_3 \tag{17}$$

Where, rand1 and rand2 are two random variables within [0, 1], and $rand_3$ is a random variable within [−1, 1].

IV. ALGORITHM FOR ELD WITH VALVE POINT LOADING EFFECT PROBLEM USING MRPSO

The algorithm for ELD problem with valve point loading effect employing MRPSO for practical power system operation is given in following steps.

1. Select suitable constants.
2. 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.
3. Initialize velocity and position for all particles by randomly set to within their legal rang.
4. Set generation counter t=1.
5. Evaluate the fitness for each particle according to the objective function.
6. Compare particles fitness evaluation with its P_{best} and g_{best}.
7. Update position by using (14).
8. Apply stopping criteria.

V. CASE STUDY

A. TEST CASE 1

The first test results are obtained for 3-generator Systems with their valve point loading effect. The unit characteristics data with valve point effect are given in Table 1. The load demand in this study expected to be 850 MW.

Optimal results obtained by PSO, CPSO, WIPSO and MRPSO is shown in Table 2. Results shown in table 2 is obtain for 100 trial. Since the results are repeted for more than 100 trial so those results not considered.

TABLE I
COST COEFFICIENT, VALVE POINT LODING COEFFICIENTS AND CAPACITY LIMIT OF 3 GENERATING UNITS, DEMAND=850MW.

Unit	1	2	3
a_i	0.00482	0.00194	0.00156
b_i	7.97	7.85	7.92
c_i	78	310	561
e_i	150	200	300
f_i	0.063	0.042	0.031
P_i^{min}	50	100	100
P_i^{max}	200	400	600

TABLE II
RESULTS OF 3 GENERATOR SYSTEMS (100 TRAILS)

Unit Power Output	PSO	CPSO	WIPSO	MRPSO
P1(MW)	415.2137	327.2974	387.502	387.6287
P2(MW)	209.9597	400	327.401	324.6853
P3(MW)	143.8266	122.7026	137.601	137.38
Total Power Output(MW)	850	850	850	850
Total Cost without valve point effect($/h)	8200.713	8197.16	8200.215	8196.149
Total Cost with valve point effect ($/h)	8780.762	8802.624	8814.486	8372.777
Computation Time (sec.)	0.368939	0.356130	0.479264	0.350648

Convergence characteristic of PSO and MRPSO of 3 generating units are shown in fig.1 and fig2 respectively.

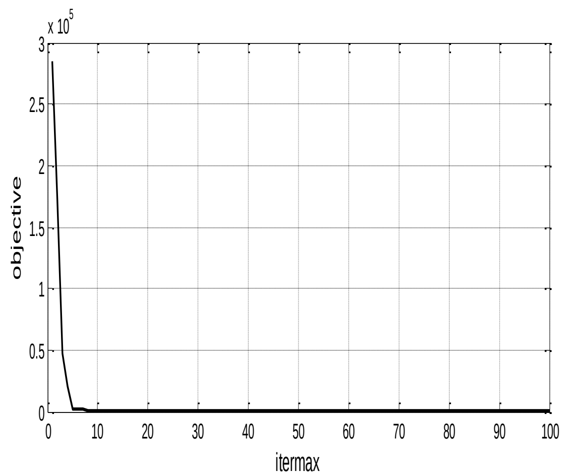

Fig.1 Convergence characteristic of PSO for 3 generating unit with valve point loading effect.

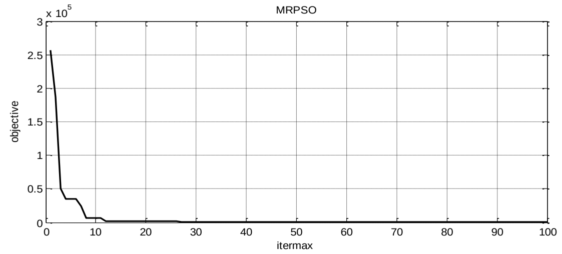

Fig.2 Convergence characteristic of MRPSO for 3 generating units with valve point loading effect.

B. TEST CASE II

The second test results are obtained for 10-generating unit system in which all units with their valve point effect. The unit characteristics data with valve point effect are given in Table 3. In this case study load demand expected to be 1036 MW.

TABLE III
COST COEFFICIENTS, CAPACITY, AND VALVE POINT LIMITS OF 10 GENERATOR SYSTEMS. DEMAND=1036MW.

Unit	c_i	b_i	a_i	e_i	f_i	P_i^{min}	P_i^{max}
1	958.2	21.60	0.00043	100	0.084	150	470
2	1313.6	21.05	0.00063	100	0.084	135	460
3	604.97	20.81	0.00039	100	0.084	73	390
4	471.6	23.90	0.00070	150	0.063	60	300
5	480.29	21.62	0.00079	120	0.077	73	243
6	601.75	17.87	0.00056	100	0.084	57	160
7	502.7	16.51	0.00211	200	0.042	20	130
8	639.4	23.23	0.00048	200	0.042	47	170
9	455.6	19.58	0.10908	200	0.042	20	80
10	492.4	22.54	0.00951	200	0.042	10	55

Convergence result of 10 generating units obtained by various PSO variants such as PSO, CPSO, WIPSO and MRPSO is shown in table 4.

TABLE IV
CONVERGENCE RESULTS OF 10 THERMAL UNITS WITH VALVE POINT LOADING EFFECT

Unit Power Output	PSO	CPSO	WIPSO	MRPSO
P1(MW)	203.0951	215.034	203.095	225.016
P2(MW)	171.213	165.032	171.213	157.09
P3(MW)	126.9716	136.0432	126.971	126.971
P4(MW)	60	75.032	59.034	71.02
P5(MW)	89.7482	112.012	89.7482	119.76
P6(MW)	89.0969	82.2217	89.0969	89.0969
P7(MW)	130	123.02	131.241	121.01
P8(MW)	101.7198	66.8902	101.719	68.032
P9(MW)	50.0356	44.8734	50.0356	39.023
P10(MW)	13.9524	16.032	13.9021	19.03
Total Power Output (MW)	1035.833	1036.191	1036.05	1036.05
Total cost without valve point($/h)	28295.02	28297.46	28291.8	28245.5
Total Cost with valve point ($/h)	29093.96	29153.2	29100.2	29047.4
Computation time (sec)	0.476176	0.539649	1.11758	0.35536

Convergence characteristic of PSO and MRPSO for 10 generating units with valve point loading effect is shown in fig.3 and fig 4 respectively.

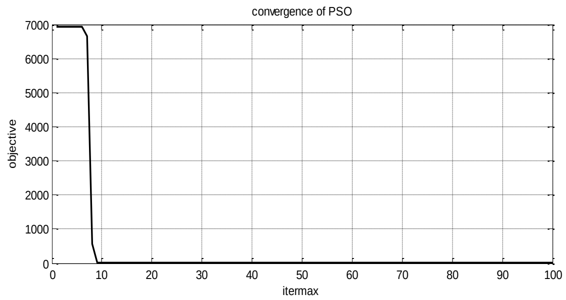

Fig.3 Convergence characteristic of PSO for 10 generating unit with valve point loading effect.

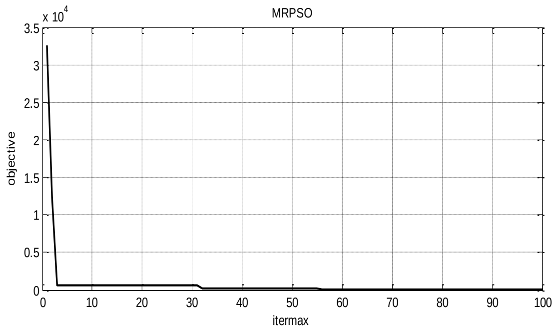

Fig.4 Convergence characteristic of MRPSO for 10 generating unit with valve point loading effect.

VI. RESULTS AND ANALYSIS

The Economic load dispatch problem solved by using various variants of PSO such as PSO CPSO WIPSO and MRPSO. Result shows that performance of MRPSO is better than other variants of PSO. Optimal result obtained by different PSO variants is shown in Table 2 for 3 generating units and Table 4 for 10 generating units were obtaine for 100 rtials.. Fuel cost obtained by MRPSO for 3 generating units without including valve point loading effect is 8196.149 \$/h and fuel cost with valve point loading effect is obtained 8372.77 \$/h. Convergence time taken by MRPSO for 3 generating units is 0.350648 sec.

Similarly MRPSO results for 10 generating units without including valve point effect is 28245.5 \$/h and total fuel cost obtained with including valve point loading effect is 29047.4 \$/h. Convergence time taken by MRPSO for 10 generating units is 0.35536 sec.

All PSO algorithm were tested on 1.4-GHz, core-2 solo processor with 2GB DDR of RAM for such ELD problem. The constants used in this study was, acceleration coefficient $c_1=c_2=2$, $W_{max}=0.9$ and $W_{min}=0.4$. The performance of MRPSO is tested in this study for the value of α taken 3.84.

VII. CONCLUSION

Economic load dispatch is a challenging task in power system. ELD model characteristic should be nonlinear due to presence of valve point loading effect and presence of various constraints. In the proposed work two case study are considered, the ELD problem with valve point loading effects is solve by using various variants of PSO.The test results obtained by MRPSO shown table 2 and table 4, the rsults demonstrated that the proposed MRPSO algorithm is capable of achieving global solution, it is computationally efficient and give better optimal results than other PSO methods. Overall, the MRPSO algorithms have been shown to be very helpful in studying optimization problems in economic load dispatch problem.

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