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A Novel Inertia Weight Particle Swarm Optimizationfor Economic Load Dispatch

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***Abstract*—Economic load dispatch (ELD) is an important optimization task in power system. It is the process of allocating generation among the committed units such that the constraints imposed are satisfied and the fuel cost is minimized. Particle swarm optimization (PSO) is a population- based optimization technique that can be applied to a wide range of problems but it lacks global search ability in the last stage of iterations. This paper used a novel PSO with a inertia weight Improved (IWIPSO), which 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 IWIPSO algorithm is demonstrated through its application for six generator systems with constraints.**

Keywords-Economic Load Dispatch (ELD),Particle swarm optimization (PSO), Inertia Weight improved Particle Swarm Optimization (IWIPSO).

I. INTRODUCTION

Electric utility system is interconnected 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. ELD focuses upon coordinating the production cost at all power plants operating on the system.

Conventional as well as modern methods have been used for solving 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], [12] 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 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]. Although the heuristic methods do not always guarantee discovering globally optimal solutions in finite time, they often 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 (PSO) method is a population-based Evolutionary technique first introduced in [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 inertia weight improved to solve the power system economic load dispatch to enhance its global search ability. This new development gives particles more opportunity to explore the solution space than in a standard PSO.

The proposed method focuses on solving the economic load dispatch with Generator Ramp Rate Limits constraint. Thefeasibility of the proposed method was demonstrated forsix bus system. The results obtained through the proposed approach and compared with those reported in recent literatures.

II. ECONOMIC LOAD DISPATCH PROBLEM FORMULATION

ELD is one of the most important problems to be solved in the operation and planning of a power system the primary concern of an ED 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),

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

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

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

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

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,

$$\sum_{i=1}^{n} P_i = P_{Demand} + P_L \tag{4}$$

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

Where, P_{Demand} is the total system demand and P_{Loss} 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.
n =Number of generator.

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.

$$P_i^{min} \le P_i \le P_i^{max} \tag{6}$$

Where, Pi 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 respectively.

3). Ramp Rate Limit

According to the operating increases and operating decreases of the generators are ramp rate limit constraints described in eq. (7) & (8).

1) As generation increases

$$P_i(t) + P_i(t-1) \le UR_i \tag{7}$$

2) As generation decreases

$$P_i(\mathrm{t}-1) - P_i(t) \ge DR_i \tag{8}$$

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.

$$P_i^{min}(t) = \max(P_i^{min}, P_i(t-1) - DR_i) \quad \text{and}$$
$$P_i^{max}(t) = \min(P_i^{max}, P_i(t-1) - UR_i).$$
$$P_i^{min}(t) \le P_i(t) \le P_i^{max}(t)\ \mathrm{t} \tag{9}$$

Where, $P_i(t)$ =current output power of i_{th} generating unit,
$P_i(t-1)$ =Previous operating point of the i_{th} generator,
DR_i =Down ramp rate limit (MW/time period) and
UR_i =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.

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 swarmscollect information from each array constructed by their respective positions. The particles update their positions using the velocityof 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 $P_i=(p_{i1},p_{i2},\ldots\ldots\ldots p_{id})$ and $V_i=(v_{i1},v_{i2},\ldots\ldots\ldots v_{id},)$ 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},………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},………p_{gd}).

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

$$V_i^{(K+1)} = WV_i^K + c_1\text{Rand}_1(\ \ ) \times \left(\text{Pbest}_i - S_i^K\right) + c_2\text{Rand}_2(\ \ ) \times \left(\text{gbest} - S_i^K\right) \quad (10)$$

$$S_i^{(K+1)} = S_i^K + V_i^{K+1} \quad (11)$$

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, $\text{Rand}_1(\,)$, $\text{Rand}_2(\,)$ are the random numbers between 0 & 1,
S_i^k is the current position of individual i at iteration k,
$P^{best}{}_i$ 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_l and c_2 are often set to be 2 according to past experiences. The term $c_1\text{rand}_1$ () x (pbest, - $S^k{}_1$) is called particle memory influence or cognition part which represents the private thinking of the itself and the term $c_2\text{Rand}_2$( )×(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 (10)

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} \times iter \quad (12)$$

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

INERTIA WEIGHT IMPROVED PSO (IWIPSO)

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 IWIPSO algorithm [37] is rewritten as,

$$V_i^{(K+1)} = w_{new} V_i^K + c_1\text{Rand}_1(\ \ ) \times \left(\text{Pbest}_i - S_i^K\right) + c_2\text{Rand}_2(\ \ ) \times \left(\text{gbest} - S_i^K\right) \quad (13)$$

Where,

$$w_{new} = w_{min} + W \times rand_3 \quad (14)$$

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} \times iter \quad (15)$$

$$c_1 = c_{1max} - \frac{c_{1max} - c_{1min}}{iter_{max}} \times iter \quad (16)$$

$$c_2 = c_{2max} - \frac{c_{2max} - c_{2min}}{iter_{max}} \times iter (17)$$

Where , wmin, wmax: initial and final weight,
c1min, c1max: initial and final cognitive factors and
c2min, c2max: initial and final social factors.

IV. ALGORITHM FOR ED PROBLEM USING IWIPSO

The algorithm for ELD problem with ramp rate generation limits employing IWIPSO for practical power system operationis given in following steps:-

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:-Set generation counter t=1.

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

Step5:-Compare particles fitness evaluation with its Pbest and gbest.

Step6:-Update velocity by using (9)

Step7:- Update position by using (10)

Step8:-Apply stopping criteria.

CASE STUDY

TEST CASE I

The test results are obtained for three-generating unit system in which all units with their fuel cost coefficients. This system supplies a load demand of 150MW. The data for the individual units are given in Table 1. The best result obtained by IWIPSO for different population size is shown in Table 2 and table 3.

Table 1. Capacity limits and fuel cost coefficients for three generating units for the demand load of 150 MW

Unit	a_i	b_i	c_i	P_i^{min}	P_i^{max}
1	0.008	7	200	10	85
2	0.009	6.3	180	10	80
3	0.007	6.8	140	10	70

Table 2.Conversation results of IWIPSO for the different population size for the demand of 150 MW

Generating units	Optimal power at different pop sizes(MW)					
	10	15	20	25	30	50
P1(MW)	36.516	34.475	45.7812	36.7517	35.644	36.348
P2(MW)	68.630	78.230	59.08486	69.2945	69.051	57.0179
P3(MW)	48.453	38.524	46.369	45.954	46.305	57.6341

Table 3. Best results for 3 thermal generating units

	Population sizes					
Costs($/h)	10	15	20	25	30	50
Min cost	1580.260	1582.449	1580.853	1580.249	1579.774	1580.666
Max. cost	1623.400	1613.908	1631.879	1625.763	1621.907	1620.085
Aver. cost	1597.183	1597.283	1599.419	1596.093	1594.275	1594.991

TEST CASE II

The test results are obtained for six-generating unit system in which all units with their fuel cost coefficients. This system supplies a load demand of 1263MW. The data for the individual units are given in Table 4. The best result obtained by IWIPSO for different population size is shown in Table 5 and table 6.

Table 4. Capacity limit of generating units and fuel cost coefficients for 6 generating units

Unit	a_i	b_i	c_i	P_i^{min}	P_i^{max}
1	0.0070	7	240	100	500
2	0.0095	10	200	50	200
3	0.0090	8.5	220	80	300
4	0.0090	11	200	50	150
5	0.0080	10.5	220	50	200
6	0.0075	12.0	190	50	120

Table 5.Conversance result of IWIPSO for 6 generating unit, load demand of 1263MW

	Optimal power at different pop sizes(MW)					
Generating units	10	15	20	25	30	50
P1	452.61	445.039	451.508	429.849	436.834	425.643
P2	175.74	197.300	144.647	160.698	175.956	169.918
P3	265.51	239.499	272.58	295.324	258.374	262.574
P4	127.22	112.034	116.631	144.122	110.975	128.197
P5	145.01	185.349	169.221	138.403	192.505	175.285
P6	96.34	83.217	108.408	94.605	88.357	101.384

Table 6.Best results for the 6 thermal generating unit using IWIPSO

	Population sizes					
Costs($/h)	10	15	20	25	30	50
Min. cost	15282.976	15292.891	15290.384	15300.216	15283.757	15281.656
Max. cost	15423.231	15375.257	15357.536	15515.031	15422.025	15394.327
Aver. Cost	15348.018	15328.825	15325.591	15375.387	15357.265	15337.824

V. Result Analysis

To assess the efficiency of the proposed IWIPSO approach in this paper, tested for a case study of 3 thermal generating units and 6 thermal generating units data given in table 1 and table 3. The proposed algorithm run on a 1.4-GHz, core-2 solo processor with 2GB DDR of RAM.

The ELD data tested for different population size as shown in table 2 and table 4 and 100 iteration used for obtaining results. Constants are taken in this study are acceleration coefficients are c_1=c=2, W_{max}=0.9 and W_{min}=0.4.

The optimum result obtained by proposed approach for 3 thermal generating units is given in table2 and table 3. The minimum average cost obtained by IWIPSO is 1594.275$/h for the population size of 30. Fig.1 shows the improvementin each iteration for the six generation unit system respectively.

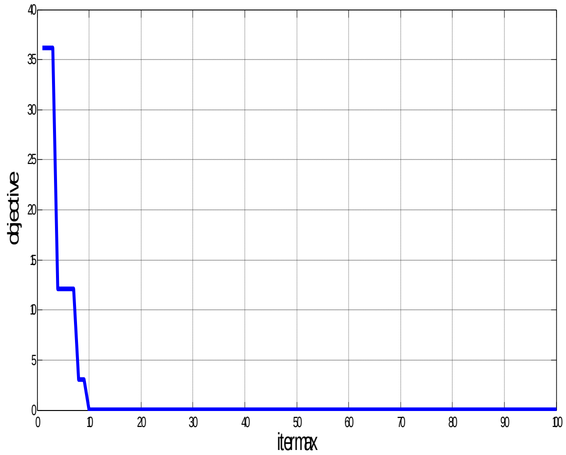

Fig.1 Convergence characteristic of IWIPSO for 3 generating units.

Similarly result obtained by IWI PSO for 6 thermal generating units shown in table 6 shows that minimum average cost is 15325.591 $/h for the population size of 20. Convergence characteristic of IWIPSO for 6 thermal generating unit is shown in figure 2.

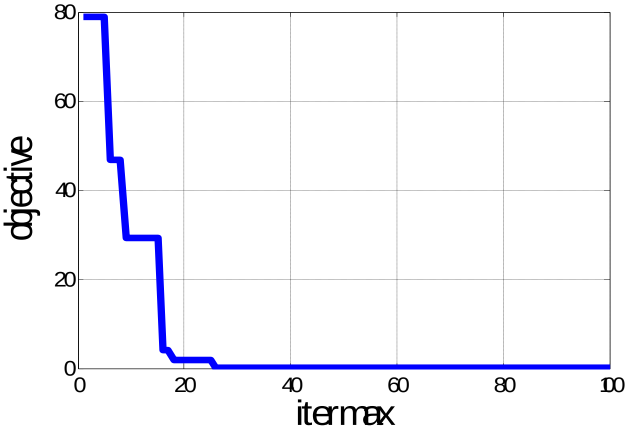

Fig.2.Convergence characteristic of IWIPSO for 6 generating units.

VI. Conclusions

This paper introduces IWIPSO optimization approach for the solution of power system economic dispatch with constraints. The proposed method hasbeen applied to different test case. The analysis results have demonstrated thatIWIPSOoutperforms the other methods in terms of a better optimal solution.. However, the much improved speed of computation allows for additional searches to be made to increase the confidence in the solution. Overall, the IWIPSO algorithms have been shown to be very helpful in studying optimization problems in power systems.

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