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A Particle Swarm Optimization with Crazy Particles for Non convex and Non smooth Economic Dispatch

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Abstract

This paper presents a new approach for economic load dispatch (ELD) using particle swarm optimization (PSO) technique with crazy particles. Conventional methods assume the cost function as quadratic function but modern generation units have much nonlinearity which makes it inaccurate. Heuristic method like PSO is free from convexity and is succeed to find nearest global solution. But conventional PSO tend to converge prematurely to a local minimum solution, when search area is irregular. To solve this problem crazy particles are introduced and the velocities are randomized to find actual global minima. The performance of the crazy particles PSO tested on two test systems one 3 unit system and second 6 unit system. The comparison with classical PSO is proposed.

Keywords—*Constrained Optimization, economic load dispatch, valve point loading effect, crazy particles, particle swarm optimization, prohibited zones, ramp-rate limits.*

I. INTRODUCTION

The economic load dispatch is one of the basic and important optimization problems in power system. The cost of power generation particularly in fossil fuel plants is high [1].ELD helps to save significant amount of generation cost. The conventional methods like gradient methods, Newton method etc [2]. get rely heavily on convexity of the non-convex or piecewise quadratic function .Practical generators have many nonlinearities in their characteristics like ramp-rate limits, prohibited zones and vale point loading effect [3].So practically ELD translated into non-smooth cost functions having heavily equality and inequality constraints, having non-convex function with multiple minima.

Traditional methods are failed to find this non-convex ELD problem. There is no restriction on shape of cost curves in these methods but problem is their large computational effort and many parameters are needed to adjust [4].

The heuristic techniques like tabu search, neural network, genetic algorithm, ant colony optimization, particle swarm optimization have no restriction on convexity problem and they found the nearest and fast global solution [5].

PSO is first introduced by James Kennedy and Eberhart in 1995 which is based on swarm intelligence and population based optimization method. It works on social behavior of bird flocking and fish schooling [6]. In recent years this method is became popular in research area due to its small and simple algorithm and less parameters need to adjust. By finding local minimum and global minimum it can achieve an optimum solution. Due to its simplicity it is used in various application of power system like ELD, voltage control, reactive power compensation, state estimation etc. [7].

In this paper, a classical PSO and PSO with crazy particles for nonconvex and nonsmooth ED problem in power system are proposed. The nonlinearities of generators like ram-rate limits, valve point loading effect and prohibited zones are considered. Due to these nonlinearities the function became nonconvex or nonsmooth with multiple minima. Classical PSO can solve the problem of nonconvex function but the solution will be nearest the global solution. For achieve the actual global solution PSO should be modified or the velocities of the particles are randomized with crazy particles [8]. In crazy particles the some particles are made to excited or crazy by changing their velocities so that they can achieve a global solution. In this paper the time varying inertia weight (TVIW) is also described.

II. Problem Formulation

The ED is the part of Unit commitment (UC) problem or it can be called optimal generation scheduling. The scheduling of the generators so that the cost of the generation or transmission is minimized. The ED problem is must perform so that the system load demand is satisfied. In practically, the inequality constraints like ram-rate limits and prohibited zones are considered.

A. ED Problem With Quadratic or Smooth Cost Functions

Economic dispatch problem find the optimal power generations so that minimize the total generation cost with satisfying equality and inequality constraints. The simplest function of ED is quadratic function and described as follows [10]:

$$\text{Min } C=\sum_{i=1}^{N} F_i(P_i) \quad (1)$$

$$F_i(P_i) = a_i + b_iP_i + c_iP_i^2 \quad (2)$$

Where

C	Total generation cost;
F_i	Cost function of generator j;
a_i, b_i, c_i	Cost coefficients of generator j;
P_i	Output power of generator j;
N	Set of all generators.

Generation should be equal to the total system load demand P_D plus the transmission lossP_L. The equality constraint is:

$$\sum_{i=1}^{N} P_i - (P_D + P_L) = 0 \quad (3)$$

P_L is the transmission losses and which are assumed here by Kron's loss formula. It is also called B- loss coefficients method. The losses are function of active power generation. The transmission losses are expressed by following equation:

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{0i} P_i + B_{00} \quad (4)$$

Inequality constraints are:

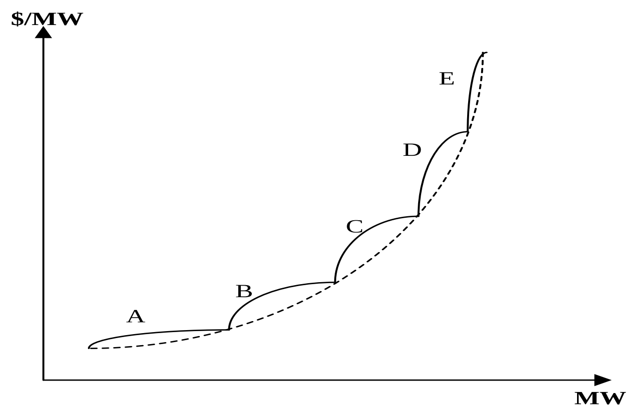
$$P_i^{min} \leq P_i \leq P_i^{max} \text{ Where j=1, 2. , N.} \quad (5)$$

B. Non-[convex Economic Load Dispatch (Valve Point Loading Effect)

Large turbine generator has number of fuel admission valves which are opened one by one as per requirements. When a valve is opened, the losses are occurred called throttling losses. In result the heat rate rises rapidly with valve open. The valve point loading effect produces the ripples on the heat rate curves and makes the objective function as a discontinuous or non-convex function. The function who is non-convex they have multiple minima. We can neglecting the valve point loading effect and assume a generation cost as a quadratic function but for accurate result it is necessary to consider it. Now there are two options, one is to consider the cost function as the pricewise quadratic function and second is the convert the eq. (1) in the sinusoidal cost function as follows:

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 + \left| e_i \times \sin(f_i \times (P_i^{min} - P_i) \right| \quad (6)$$

Where, e_i *and* f_i are the coefficients of the generator i considering valve point effect. The above eq. (6) subject to equality and inequality constraints by eq. (3) and (5).



A: Primary valve **D: Secondary valve**
B: Secondary Valve **E: Quinary valve**
C: Tertiary valve

Fig.1. An Example of cost function with five valves

C. Ramp-rate limits

There is need to scheduling of generator units at every hour or half an hour for electric utilities. Sometimes it is assumed that the generator output is smoothly and instantaneously. But in practical it is not possible so the ramp rate limits used as inequality constraints. The ramp rate limits, the up rate limits UR_i and the down rate limits $DR_i$and previous hour generation P_{i0} make the operating region of all the line units. The limits of the operating unit with considering ramp rate limits are:

$$\text{Max}\,(P_i^{min}, P_{i0} - DR_i) \leq P_i \leq \min(P_i^{max}, P_{i0} + UR_i) \quad (7)$$

D. Prohibited zones

The cost curve is not always continuous as quadratic cost curve. Sometimes due to damage of bearings of shaft or due to some faults the cost curve becomes discontinuous. So we have to disconnect that discontinuous part of the cost curve. Prohibited zones make the maximum and minimum generation limits of the units so that the unit can not generate at that discontinuous zones. By prohibited zones cost curve make discontinuous and having multiple minima. The prohibited zones can be included in the NCED as follows:

$$P_i \in \begin{cases} P_i^{min} \leq P_i \leq P_i^l \\ P_{i,j-1}^u \leq P_i \leq P_{i,j}^l \; , j = 2,3, \dots, n_i, i = l, \dots, m. \\ P_{i,n_i}^u \leq P_i \leq P_i^{max} \end{cases} \quad (8)$$

Where, n_i is the number of prohibited zone of i^{th} generator curve, $j$is the number of prohibited zones of i^{th} generator, $P_{i,j}^l$is the lower limit of j^{th} prohibited zone and $P_{i,j}^u$ is the upper limit of the j^{th} prohibited zone.

III. BASIC OF PARTICLE SWARM OPTIMIZATION

James Kennedy and Eberhart first introduced the PSO method. It is an optimization tool, provides the population based search process. Its working on behavior of bird flocking .The birds are acting here as particles. Particles change their position and velocity with time. The particles first make one search space and fly over that search space. During flying after each iteration particles adjust their position and velocity. They compare their position with own and neighborhood particle's also.

A. Classical PSO

Let x denotes the particle position and v denotes the corresponding velocity of the particle in a search space. Therefore, i^{th} particle is presented as $x_i = (x_{i1}, x_{i2}, x_{i3} \dots, x_{ik})$ in the k –dimensional space. The previous best positions are recorded of the i^{th} particle as $pbest_i = (pbest_{i1}, pbest_{i2}, \dots, pbest_{ik})$. The best particles in all particles are called $gbest_k$ in k dimension within group. The velocity of the particle i is presented as $(v_{i1}, v_{i2}, \dots, v_{ik})$.The updated velocity and position of particle i is shown in following formulas:

$$v_{ik}^{t+1} = w.v_{ik}^t + c1 * rand() * \left(pbest_{ik} - x_{ik}^t\right)$$

$$+c2 * rand() * (gbest_k - x_{ik}^t) \quad (9)$$

$$x_{ik}^{t+1} = x_{ik}^t + v_{ik}^{t+1} \quad ,i = 1,2, \dots , n, \quad k = 1,2, \dots m \quad (10)$$

Where

n	Number of particles in group;
m	Number of members in single particle;
t	Number of iteration;
w	Time varying inertia weight;
$c1, c2$	Acceleration constants;
$rand()$	Random value between [0, 1];
v_i^t	Velocity of the particle i at t iteration;
x_i^t	Position of particle i at t iteration;

The values of acceleration constants are generally taken as 2.0. The time varying inertia weight is controls the exploration of the search space, given by,

$$w = (w_{max} - w_{min}) \times \frac{(iter_{max} - iter)}{iter_{max}} + w_{min} \quad (11)$$

Where w_{max}=0.9 and $w_{min} = 0.4$ .The w is gradually decrease from 0.9 to 0.4 with iteration.

B. PSO with Crazy Particles

The concept of craziness is referred from [9].T0 randomized velocity of the some particle is called 'crazy particles'. For craziness of the particle there should be define craziness index G_{cr} where $G_{cr}$the function of inertia weight is and defined as follows:

$$G_{cr} = w_{min} - \exp(-\frac{w^t}{w_{max}}) \quad (12)$$

The velocities of the some particles are randomized by following strategy:

If $G_{cr} \geq rand(0,1)$ then, $v_i^t = rand(0, V_{max})$
Otherwise $v_i^t = v_i^t$. (13)

Here V_{max} is the parameter of PSO, which shows the maximum change can take a particle during iteration. The value of V_{max} is kept generally 10-20% of each dimension of variable.

C. Position modification constraints:

The position of each individual is modified by eq.(10).The resulting position is not always make sure to satisfy the inequality constraints due to upper and lower velocity. Therefore this can be formulated as follows:

$$P_{ik}^{t+1} = \begin{cases} P_{ik}^t + v_{ik}^{t+1} \quad if \ P_{ik}^{min} \leq P_{ik}^t + v_{ik}^{t+1} \leq P_{ik}^{max} \\ P_{ik}^{min} \ if \ P_{ik}^t + v_{ik}^{t+1} < P_{ik}^{min} \\ P_{ik}^{max} \ if \ x_{ik}^t + v_{ik}^{t+1} > P_{ik}^{max} \end{cases} \quad (14)$$

IV. ALGORITHM FOR NONCONVEX ECONOMIC DISPATCH USING PSO WITH CRAZY PARTICLES

Step 1: Create initial swarm or find random values between maximum values of generation.
Step 2: Find initial $pbest, gbest$ and give initial velocity randomly between $[V_{max}, -V_{max}]$.
Step 3: update position and velocity of the each particle using eq. (9) and (10).
Step 4: check and maintain the velocity of particle and position of particle between maximum and minimum range.
Step 5: power flow using N-R method.
Step 6: Verify the inequality constraints satisfaction of parameters generated at the end of power flow.
Step 7: Fitness function is evaluated.
Step 8: check and compare if current fitness value is better than the previous fitness value than save the better value and according to that save new updated $pbest \ and \ gbest$.
Step 9: if maximum iteration occurred then stop the program and give the latest optimal solution, else go to step 3.

V. RESULTS AND ANALYSIS

PSO with crazy particles is tested on two test systems:

A. First is 3 unit system .The total load of 850 MW and cost function including valve point loading effect. The B loss coefficients are also considered [8].
B. Second test system is 26 bus test system. The 26 bus test system contains 36 buses, 46 transmission lines. Total load of 1263 MW and the cost function is converted into non-smooth function using prohibited zones. The ramp-rate limits are also considered for this test system [9].

For both the system results are compared with the results of conventional PSO. Convergence behaviors of both methods were tested on the same evaluation function. The convergence characteristic of both methods for one trial is shown in below figure 2,3,4,5.PSO with crazy particles is superior than conventional PSO due to their crazy particles have reinitialized velocity which can find better solution.

Data of PSO parameters:

Population size=20;
Iterations =100;
$w_{max} = 0.9$;
$w_{min} = 0.4$;
$c1 = 2.0$;
$c2 = 2.0$;

$$V_{max} = \frac{P^{max} - P^{min}}{10}$$

TABLE I
Comparison of simulation results of each method for 3 unit system considering valve point loading effect

Unit Power output	Conventional PSO	PSO crazy
P_1(MW)	407.42	507.35

P_2(MW)	314.28	144.00
P_3(MW)	131.08	137.46
Total power output(MW)	850	850
Total loss(MW)	26.28	31.17
Total generation cost($/h)	8473.5015	8.0416427

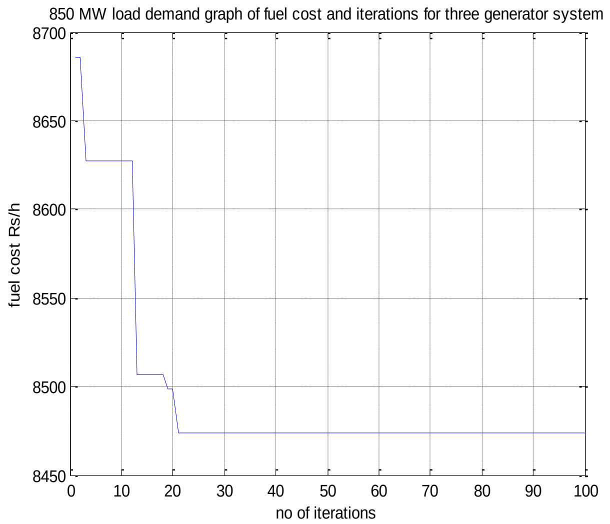


Fig. 2 Convergence characteristics of the conventional PSO for 3 unit system.

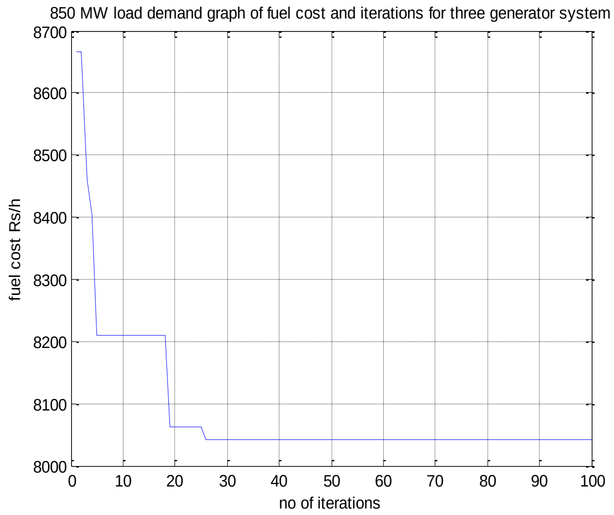


Fig. 3. Convergence characteristics of the PSO with crazy particles for 3 unit system.

TABLE II
Comparison of simulation results of each method for 6 unit system considering valve point loading effect

Unit Power output	Conventional PSO	PSO crazy
P_1(MW)	440.58	441.22
P_2(MW)	168.22	167.76
P_3(MW)	259.06	259.57
P_4(MW)	134.23	132.29
P_5(MW)	168.87	170.13
P_6(MW)	105.01	105.00
Total power output(MW)	1275.97	1275.97
Total loss(MW)	12.941	12.971
Total generation cost($/h)	15452.3468	15452.2830

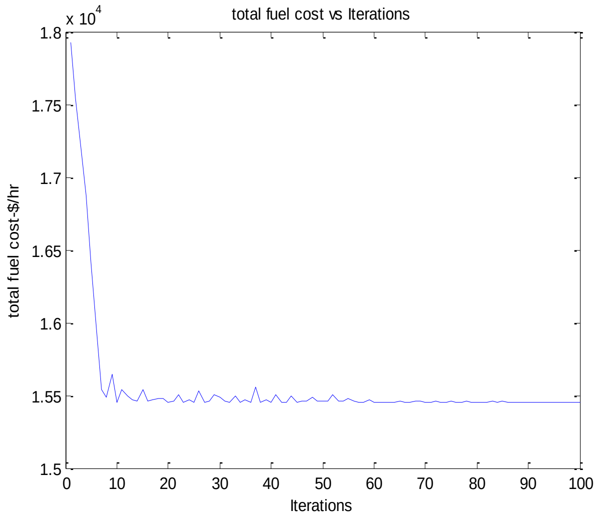


Fig. 4. Convergence characteristics of the conventional PSO for 6 unit system.

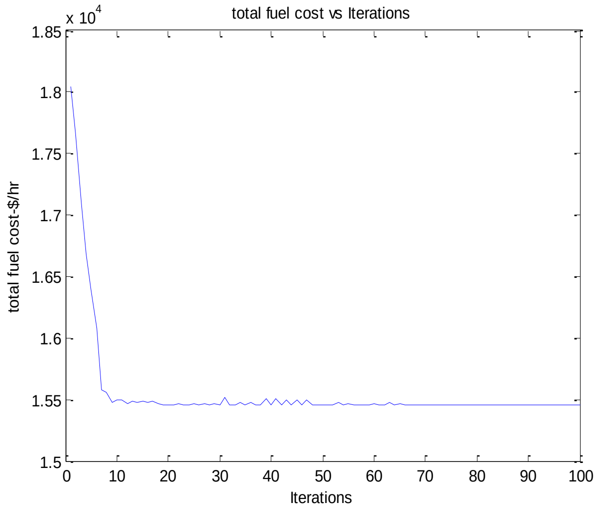


Fig. 5. Convergence characteristics of the PSO with crazy particles for 6 unit system.

VI. CONCLUSION

This paper presents a new approach for non-smooth and non-convex economic load dispatch problem on the convention PSO algorithm.PSO with crazy particles is proposed for solving the complex problems of economic load dispatch having multiple minima. It is found that PSO with crazy particles method have premature convergence behavior than conventional PSO have better results due to its crazy particles. The velocities of some particles are reinitialized due to craziness index and it takes the convergence to global solution.

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