A New modified particle swarm Optimization (PSO) Technique for Non-Convex Economic Dispatch

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Abstract: *This paper gives a new modified technique for evaluating non-convex economic dispatch (NCED) problem having non-linear, discontinuous cost function. This new particle swarm optimization technique incorporates time varying acceleration coefficients (NPSOTVAC). The highly non-linear cost function due to ramp rate limit, prohibited operating zones and valve point loading effect is considered in the proposed method. The effectiveness of proposed NPSOTVAC algorithm is proved through test on 6 and 15 unit test systems.*
Keywords: *Nonconvex economic dispatch (NCED), Particle swarm optimization (PSO), Time varying acceleration coefficients (TVAC), New PSO with Time-Varying Acceleration Coefficients (NPSOTVAC).*

I.   Introduction

The economic load dispatch (ELD) is about minimizing the total generation cost of generating units in order to meet the power demand while satisfying equality and inequality constraints. Traditionally, the cost function of the generator is assumed to be piecewise linear and represented by a quadratic function. However, in practical, this assumption is no longer valid due to the valve point effect and prohibited operating zones (POZ) of generating units. This makes the ELD problem highly non linear and nonconvex optimization problem, which is difficult to be solved by mathematical approach. Moreover, the ELD problem becomes more complicated when ramp-rate limits and transmission losses are taken into account.

Many optimization methods have been used for solving classical ELD problem, such as lambda iteration, gradient method, linear programming and quadratic programming [1]. Most of these methods might be unable to solve nonconvex and discontinuous ELD problem efficiently. This is because these methods require monotonically increasing incremental cost function, where the derivative information of the cost function exists. In order to solve nonconvex ELD problem, heuristic methods such as evolutionary programming (EP), genetic algorithm, artificial immune system, tabu search, ant colony optimization and particle swarm optimization (PSO) have been implemented to solve nonconvex and discontinuous ELD problems [2,3]. These methods do not require the derivative information of the cost function. Thus, it can be used to solve nonconvex ELD problem due to valve point effects, prohibited operating zones, multi fuels options and nonlinear power flow constraints that cannot be solve by classical methods. However, these methods not always guarantee the global optimal solution.

Among these methods, the particle swarm optimization (PSO) method is widely used for solving ELD problem due to its simple implementation, less memory storage and able to find global solution. Many modifications and hybrid of PSO methods were proposed for solving the nonconvex ELD problem such as IPSO [8], fuzzy adaptive PSO [12], simulated annealing PSO (SA- PSO) [14], SOH-PSO [15],adaptive PSO (APSO) [16] and an improved coordinated aggregation based PSO (ICA-PSO) [17]. Nevertheless, the classical PSO can be further improved to obtain a good solution.

The PSO, first introduced by Kennedy and Eberhart [9] is a flexible, robust, population based stochastic search/optimization algorithm with inherent parallelism. In recent years this method has gained popularity over its competitors and is increasingly gaining acceptance for solving economic dispatch [6-8] and a variety of power system problems [13], due to its simplicity, superior convergence characteristics and high solution quality. The convergence towards the global best solution is governed by the proper control of global and local exploration capability. The concept of inertia weight was introduced to balance the local and global search. A high inertia weight during initial part of the search ensured global exploration while a lower value at the end facilitates global convergence. With this in view, the concept of time varying inertia weight (TVIW) was introduced in [10,11].

A novel PSO based strategy based on time varying acceleration is applied in this paper for the NCED to overcome the problem of premature convergence and for finding the global optima. A relatively high value of the cognitive component results in excessive wandering of particles while a higher value of the social component causes premature convergence of particles [6]. Hence, time-varying acceleration coefficients

(TVAC) [18] are employed to strike a proper balance between the cognitive and social component during the search. This paper proposes a new modified PSO based algorithm, Integration of this approach with time varying penalty helps in exploring the search space very effectively to identity the promising solution region. The NPSOTVAC method is illustrated through two systems with 6 and 15 generating units.

II.Objective Function Formulation

II.1Economic cost function: The primary objective of any ED problem is to reduce the operational cost of system fulfilling the load demand within limit of constraints. Simplified economic dispatch problem can be represented as a quadratic fuel cost objective function as described in Eq. (1)

$$MinF_T = \sum_{i=1}^{N} F_i(P_i)$$

$$F_i(P_i) = \sum_{i=1}^{N} (a_i P^2 + b_i P + c_i)Rs/h \qquad (1)$$

Where F_T: total generating cost; F_i: cost function of ith generating unit; a_i, b_i, c_i: cost coefficients of generator i; P_i: power of generator i; N: number of generators.

II.2.Economic cost function with valve point loading effect.

The generating units with multiple valves in steam turbines are available. The opening and closing of these valves are helpful to maintain the active power balance. However it adds the ripples in the cost function as shown in Fig. 1 which makes the objective function highly nonlinear. The sinusoidal functions are added to the quadratic cost function as given in (2)
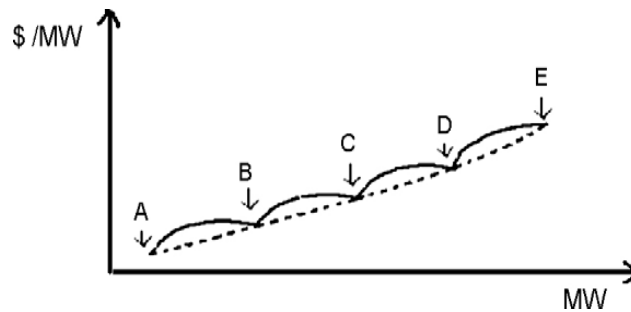

Figure 1. Incremental fuel cost curve for 5 valve steam turbine unit

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + \left| k_i \times \sin\left(l_i \times \left(P_i^{\min} - P_i \right) \right) \right| \qquad (2)$$

Where k_i and l_i are the coefficients of generator i considering valve point loading effect.

Equality constraint and Inequality constraints:

(**1**) *System power balance equation*: It is an equality constraint which should be satisfied for power plant system.

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

Where L_D and P_L are load demand and power losses respectively. To calculate system losses, methods based on penalty factors and constant loss formula coefficients or B-coefficients [1] are in use. The latter is adopted in this paper as per which transmission losses are expressed as

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{oi} P_i + B_{oo}$$

(2)Power generation capacity limits:

$$P_i^{\min} \le P_i \le P_i^{\max} \qquad i = 1, 2, ..., N \qquad (4)$$

where $P_i^{\min}$ and $P_i^{\max}$ are minimum and maximum power generation capacity limit of ith generator

3.Prohibited operating zone:

The generators may have certain range where operation is restricted due to the physical limitation of machine component, steam valve, vibration in shaft bearing etc as shown in Fig. 2. The consideration of prohibited operating zone creates discontinuities in cost curve and converts the constraint as below.

$$P_i \in \begin{cases} P_i^{\min} \le P_i \le P_{i1}^L \\ P_{ik-1}^U \le P_i \le P_{ik}^L \\ P_{ik}^U \le P_i \le P_i^{\max} \end{cases} \qquad (6)$$

Here k are the number of prohibited zones in ith generator curve, P_{ik}^L is the lower limit of kth prohibited zone, and P_{ik}^U is the upper limit of kth prohibited zone of ith generator.
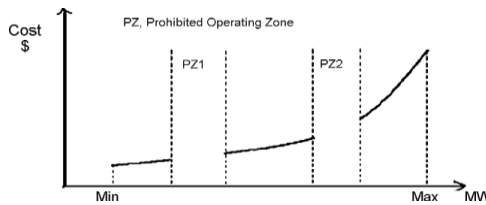

Figure 2. Cost function with prohibited operating zone.

4. Generator ramp-rate limits

The operating range of on-line generating units is restricted by ramp-rate limits. In practice, the unit output can not be adjusted instantaneously whenever load changes. Ramp rate limits, i.e. up-rate limit UR_i, down-rate limit DR_i and previous hour generation P_i^o restrict the operating region of all the on-line units. When the generator ramp-rate limits are considered, the operating limits of the ith generating unit are modified as follows:

$$Max(P_i^{\min}, P_i^o - DR_i) \le P_i \le Min(P_i^{\max}, P_i^o + UR_i) \qquad (7)$$

III. Particle Swarm Optimization (PSO)

A. Classical PSO

A PSO is a population based modern heuristic search method that traces its evolution to the emergent motion of a flock of birds searching for food. 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 other through an array constructed by their respective positions. The particles update their positions by comparing their relative convergence towards the global optimum. The update mode is termed as the *velocity* of particles. 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 $X_i = (x_{i1}, x_{i2}, \ldots \ldots x_{id})$ 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 $pbest_i = (p_{i1}, p_{i2} \ldots \ldots p_{id})$. If the gth particle is the best among all particles in the group so far, it is represented as $pbest_g = gbest = (p_{g1}, p_{g2}, \ldots \ldots p_{gd})$. The particle tries to modify its position using the current velocity and the distance from $pbest$ and $gbest$. The modified velocity and position of each particle for fitness evaluation in the next iteration are calculated using the following equations:

$$v_{id}^{k+1} = C[w * v_{id}^k + c_1 * rand_1 * (pbest_{id} - x_{id}) + c_2 * rand_2 * (gbest_{gd} - x_{id})] \qquad (8)$$

$$x_{id}^{k+1} = x_{id} + v_{id}^{k+1} \qquad (9)$$

Here C is constriction factor, w is the inertia weight parameter, c_1, c_2 are cognitive and social coefficients, and $rand_1, rand_2$ are random numbers between 0 and 1. The inertia weight w regulates the tradeoff between the global and local exploration capabilities of the particle. A large inertia weight helps in good global search, while a smaller value facilitates local exploration. Therefore, the practice is to use larger inertia weight factor during initial exploration and gradual reduction of its value as the search proceeds in further iterations.

B. New PSO with Time-Varying Acceleration Coefficients (NPSOTVAC)

In PSO, tuning of parameters with time plays an important role in finding the optimum solution accurately and efficiently [4-6]. A new PSO technique where acceleration coefficients are varied with time are used in this paper to solve the complex problem of ED with valve point loading effects.

Kennedy and Eberhart [9] stated that a relatively higher value of the cognitive component, compared with the social component, results in roaming of individuals through a wide search space. On the other hand, a relatively high value of the social component leads particles to a local optimum prematurely.

In population-based optimization methods, the policy should be to encourage the individuals to roam through the entire search space, during the initial part of the search, without clustering around local optima. During the latter stages, however convergence towards the global optima should be encouraged, to find the optimum solution efficiently.

The idea behind TVAC is to enhance the global search in the early part of the optimization and to encourage the particles to converge towards the global optima at the end of the search. This is achieved by changing the acceleration coefficients c_1 and c_2 with time in such a manner that the cognitive component is reduced while the social component is increased as the search proceeds.

The acceleration coefficients are expressed as:

$$c_1 = \left(c_{1F} - c_{1I}\right)\frac{iter}{iter_{max}} + c_{1I} \tag{10}$$

$$c_2 = \left(c_{2F} - c_{2I}\right)\frac{iter}{iter_{max}} + c_{2I} \tag{11}$$

Where c_{1I}, c_{1F}, c_{2I} and c_{2F} are initial and final values of cognitive and social acceleration factors respectively.
The flowchart of proposed NPSOTVAC algorithm is depicted in Fig 3.
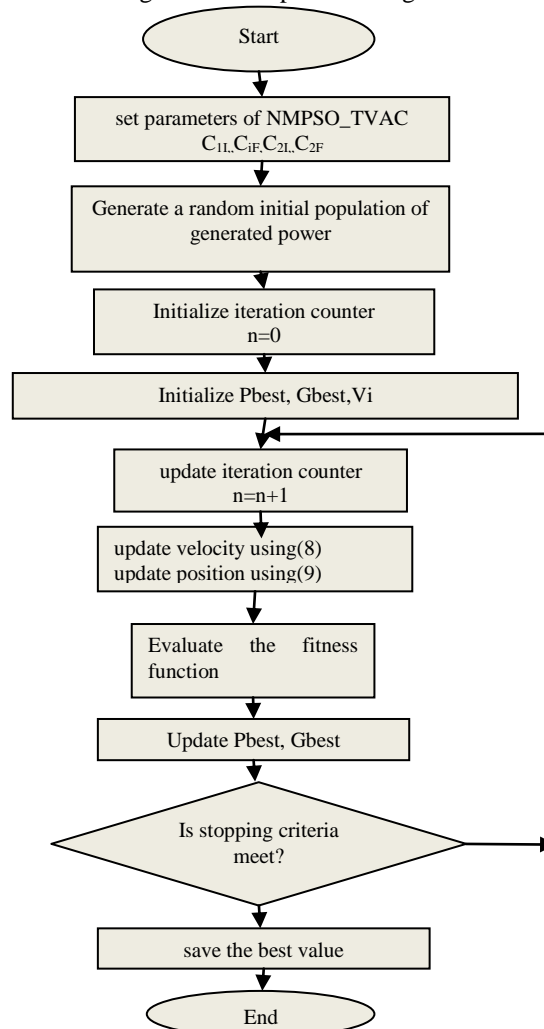

Figure 3. Flowchart of NPSOTVAC

IV. Numerical Results and Analysis

In order to show how to use the NPSOTVAC to solve NCED problems and to verify the effectiveness, two practical systems were employed to test the algorithm. The ramp rate limit, prohibited operating zones and valve point loading effects are considered for practical application.

A. The two power systems

Test system 1: The system consists of 6 generating units, 26 buses and 46 transmission lines [19-20].The load demand is 1263 MW.The generating capacity and cost coefficients, loss coefficients B, ramp rate limit and prohibited zones for six unit system are given in table I, II and III respectively.

Test system 2: This is a system with 15 generating units whose characteristics are given in Tables IV and V [21]. The load demand of the system is 2630 MW.

TABLE I. GENERATING UNIT CAPACITY AND COEFFICIENTS OF THE 6-UNIT SYSTEM

Unit	P_i^{min}	P_i^{max}	a_i	b_i	c_i
1	100	500	240	7.0	0.0070
2	50	200	200	10.0	0.0095
3	80	300	220	8.5	0.0090
4	50	150	200	11.0	0.0090
5	50	220	220	10.5	0.0080
6	50	120	190	12.0	0.0075

TABLE II. LOSS COEFFICIENTS B OF THE 6-UNIT SYSTEM

B_{ij}	1	2	3	4	5	6
1	0.0017	0.0012	0.0007	-0.0001	-0.0005	-0.0002
2	0.0012	0.0014	0.0009	0.0001	-0.0006	-0.0001
3	0.0007	0.0009	0.0031	0	-0.001	-0.0006
4	-0.0001	0.0001	0	0.0024	-0.0006	-0.0008
5	-0.0005	-0.0006	-0.001	-0.0006	0.0129	-0.0002
6	-0.0002	-0.0001	-0.0006	-0.0008	-0.0002	0.0150
B_{0i}	-0.0004	-0.0001	0.0007	0.0001	0.0002	-0.0007
B_{00}	0.056					

TABLE III. GENERATING UNIT RAMP RATE LIMITS AND PROHIBITED ZONES OF THE 6-UNIT SYSTEM

Unit	P_i^0	UR_i	DR_i	Prohibited Zones
1	440	80	120	[210,240] [350,380]
2	170	**50**	90	[90,110] [140,160]
3	200	65	100	[150,170] [210,240]
4	150	50	90	[80,90] [110,120]
5	190	50	90	[90,110] [140,150]
6	110	50	90	[75,85] [100,105]

TABLE IV.GENERATING UNIT CAPACITY AND COEFFICIENTS OF THE 15-UNIT SYSTEM

Unit	P_i^{min}	P_i^{max}	a_i	b_i	c_i
1	150	455	671	10.1	0.000299
2	150	455	574	10.2	0.000183
3	20	130	374	8.8	0.001126
4	20	130	374	8.8	0.001126
5	150	470	461	10.4	0.000205
6	135	460	630	10.1	0.000301
7	135	465	548	9.8	0.000364
8	60	300	227	11.2	0.000338
9	25	162	173	11.2	0.000807
10	25	160	175	10.7	0.001203
11	20	80	186	10.2	0.003586
12	20	80	230	9.9	0.005513
13	25	85	225	13.1	0.000371
14	15	55	309	12.1	0.001929
15	15	55	323	12.4	0.004447

TABLE V. GENERATING UNIT RAMP RATE LIMITS AND PROHIBITED ZONES OF THE 15-UNIT SYSTEM

Unit	P_i^0	UR_i	DR_i	Prohibited Zones
1	400	80	120	
2	300	80	120	[185,225] [305,335] [420,450]
3	105	130	130	
4	100	130	130	
5	90	80	120	[180,200] [305,335] [390,420]
6	400	80	120	[230,255] [365,395] [430,455]
7	350	80	120	
8	95	65	100	
9	105	60	100	
10	110	60	100	
11	60	80	80	
12	40	80	80	[30,40] [55,65]
13	30	80	80	
14	20	55	55	
15	20	55	55	

B. Results and discussion:

NCED problem was solved using the NPSOTVAC. Optimum population size for 6 and 15 unit systems have been found 50 and 100. The performance of each system has been judged out of 50 trials. The acceleration coefficients c_1(cognitive component) is initially set with high value and decreases as the search advances to explore the problem space in the first half of the search. In the later half, social component c_2 increases to exploit the search space and reach global optimal solution.

The results for 6 and 15 unit system are given in Table VI and Table VII. The minimum cost of operation obtained for 6-unit system is 15447.028($/h) and for 15 unit system is 32450.39($/h).

TABLE VI. GENERATOR OUTPUT FOR MINIMUM OPERATING COST (6-GENERATING UNIT SYSTEM)

Unit Power Output	NPSOTVAC ($/h)
P1(MW)	450.01
P2(MW)	171.18
P3(MW)	266.543
P4(MW)	131.916
P5(MW)	165.58
P6(MW)	89.62
Total power output(MW)	1274.849
Total loss(MW)	12.44
Total generation cost($/h)	15445.028

TABLE VII. GENERATOR OUTPUT FOR MINIMUM OPERATING COST (15- GENERATING UNIT SYSTEM)

Unit Power Output	NPSOTVAC ($/h)
P1(MW)	455
P2(MW)	375
P3(MW)	130
P4(MW)	135.28
P5(MW)	165.77
P6(MW)	460
P7(MW)	424.52
P8(MW)	65
P9(MW)	25
P10(MW)	157
P11(MW)	84.23
P12(MW)	74.68
P13(MW)	25
P14(MW)	24.98

P15(MW)	34
Total power output(MW)	2635.46
Total generation cost($/h)	32450.39

C. Convergence characteristics

The convergence characteristics of NPSOTVAC for 6 and 15 unit system is given in Fig 4 and Fig 5.The two figures show that the characteristics of NPSOTVAC, are continuously decreasing and tending to converge to find global optimal solution.
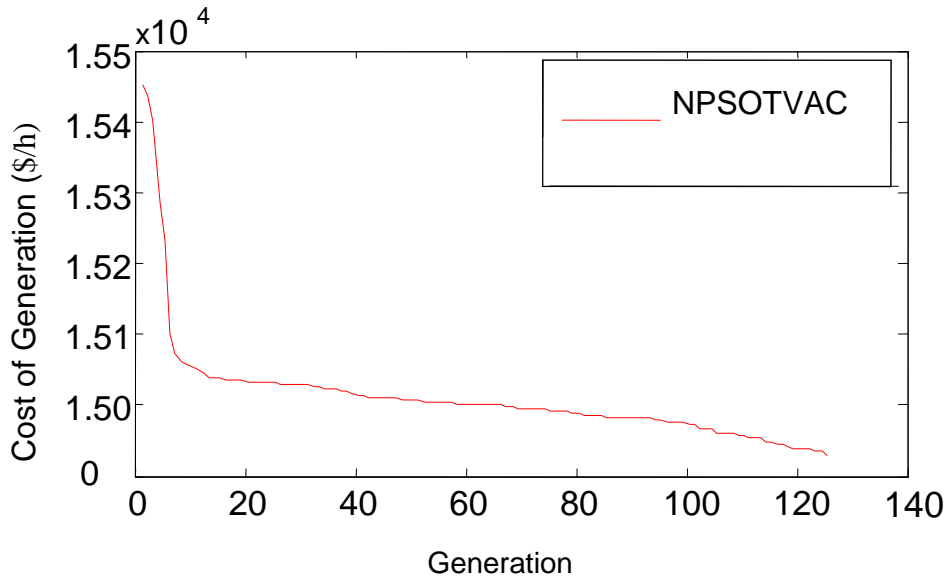

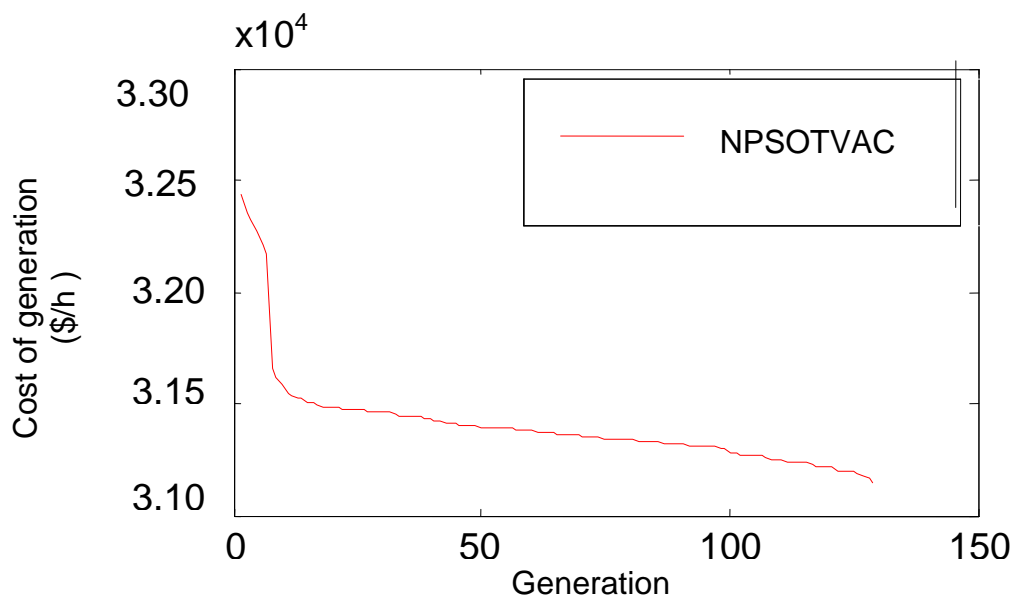Fig 4.Convergence properties of 6-unit generating system using NPSOTVAC

Fig 5.Convergence properties of 15-unit generating system using NPSOTVAC

V.   Conclusion

The complex and nonconvex economic load dispatch is solved by using new modified PSO technique. By proper tuning of parameters a balance between local and global parameters are set which helps in addressing problem of premature convergence. The results reflect the efficiency of this method. It is simple, less time consuming and gives better solution.

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