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A Crazy Particle Swarm Optimization with Time Varying Acceleration Coefficients for Economic Load Dispatch

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Abstract: ***In power generating plants, the expenses on combustible fuel is extremely costly and the concept of ELD (Economic Load Dispatch) make possible to save the considerable portion of profits. Practically generators have economic dispatch problems in terms of non-convexity. These kinds of problem cannot be resolved by conventional optimization techniques because the complication escalates due to manifold constrained that require to be fulfilled in all operating conditions. Recently a Particle Swarm Optimization (PSO) algorithm stimulated by collective conduct of swarm can be applied effectively to translate the ELD problems. The classical PSO bears the difficulty of early convergence mainly when the space of search is asymmetrical. To overcome the trouble "Crazy PSO with TVAC (Time Varying Acceleration Coefficients)" is launched which improve the search ability of the PSO by rebooting the vector of velocity whenever diffusion or saturation locate inside and to employ a scheme of parameter automation to maintain correct equilibrium between global hunt and local hunt and also circumvent the congestion. This arrangement is developed crazy PSO with TVAC and also demonstrated on two different model experimental structures of three generation units and six generation units. The result acquired from proposed method is evaluate with classical PSO and Real coded genetic algorithm (RGA) and it is found to be superior. This method is mathematically simple, gives fast convergence and robustness to resolve the rigid optimization inconvenience.***

Keywords: particle swarm optimization; time varying acceleration coefficient; ramp rate limit;

I. INTRODUCTION

Electrical system is intertwined and interdependent to attain the benefits and profit of lowest amount of production cost, highest trustworthiness with the most excellent functioning situation [1]. The Economic Load Dispatch is the most significant feature with several optimization issues in electrical power system. The prime purpose of the Economic Load Dispatch (ELD) is reduction the entire generating price of all units in order to congregate the demand while fulfilling all constraints [2].Actually the economic arrangement is the vital economic load dispatch, where it is necessary to designate the load between the all connected generating units which are essentially in parallel with the network, in such a manner to satisfy the entire system operational situation [1]. Practical generators comprise many nonlinearities in their characteristics like prohibited zones, vale point loading effect and ramp-rate limits [3].So practically ELD translated into non-smooth cost functions having heavy restrictions, having non-linear function inclusive of several minima[4],it create the dispute of attain the global minima, extremely complicated [3].

Customary schemes are failed to find this non-convex ELD problem. There is no restraint on contour of cost curve in these methods but problem is their large computational effort and many parameters are needed to adjust [5].There are many approaches such as genetic algorithm (GA)[10],evolutionary programming (EP)[6,7],tabu search(TS)[8],neural networks[9],artificial intelligence[3], and particle swarm optimization (PSO)[12-15],used for work out the non-convex economic load dispatch (NCELD) problems. Such methods are very promising and do not affects by convexity presumption and required incredibly less computing duration. This type of probable methods may not always guarantee best global results, but is usually created to intend a quick and close to global best result [3].

Among these methods, the particle swarm optimization (PSO) method is extensively used for figure out the ELD complications. Initially PSO is recommended by the Eberhart and Kennedy [16] and it is a supple, powerful, populace depended hunt algorithm with inbuilt parallelism. It exhibits the quality of simple running, less memory storage and clever to discover global resolution [15].In earlier decades many modification and hybrid of PSO method were suggested for settle down the non-convex Economic Dispatch issues such as SOH-PSO [17], fuzzy adaptive PSO[18], simulated annealing PSO(SA-PSO) [19] and an improved coordinated aggregation based PSO (ICA-PSO)[20].owing to its unfussiness, better convergence quality and high result ability, PSO acquired popularity among the researchers and power sectors.

This work presents a Crazy PSO which is implemented with TVAC and applied for NCELD to conquer the difficulty of premature convergence and for find the global optima. The proper value of inertia weight can be governed the global best solution and also enhances the global and local exploration capabilities. A big value of weight of inertia in the foremost portion of the search certifies the global investigation and at the end part the lower value of inertia weight facilitates the global convergence.

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The time varying inertia weight (TWIV) concept was introduced in [21]. The current paper suggests the method to solve the NCELD problem by using Crazy PSO with TVAC. In this work the velocity vector is also reinitialize to beat the premature convergence character of traditional PSO.

II. NONCONVEX ECONOMIC LOAD DISPATCH (NCELD)

In practice generators having much non linearity. These non-linearities are discussed in the following section one by one.

A. Valve point loading effect

Generally large turbines generators have several fuel admittances valves. In generating plant, balance of active power can control by opening and closing of fuel valves. When the demand increases valves of fuel are required to be open and vice versa. As valve is opened, the throttling losses rise quickly and the incremental heating up velocity ascends rapidly. However, it augments the ripple in the basic cost function as accustomed in figure1.[10].

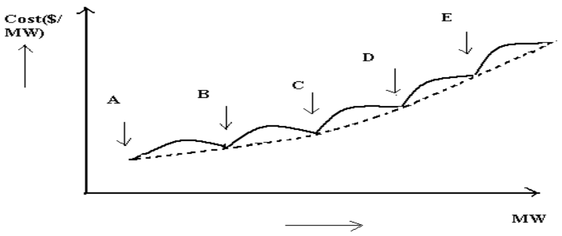

Figure 1. Valve Point loading effect in generator

In quadratic cost function additionally sine function is also included as written in below equation (1)

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + \left| e_i \times \sin\left(f_i \times \left(P_i^{\min} - P_i\right)\right)\right| \quad (1)$$

Here the fuel cost coefficients are represented by a_i, b_i and c_i of the i^{th} unit, and the cost coefficient of fuel inclusive of effects of valve point are represented by e_i and f_i.

B. Prohibited operating zone (POZ)

Each generating unit has its own highest and lowest generating limits. But the possibility of amend the unit generation output over this total array is not suitable in all circumstances. Many times, the original systems have POZ that bring in constraints to bound its function in definite series of limits in the total of probable generation.

The traditional ELD offers an issues of convex optimization trouble, with presume that the whole effective functioning array of the units sandwiched in the least and highest generation confines for proper function of the system. A thermal power plant unit suffers from POZ because of real limitations or errors of the power plant machinery e.g. steam valve process, machine vibration or fault in pumps & boilers etc. [22]

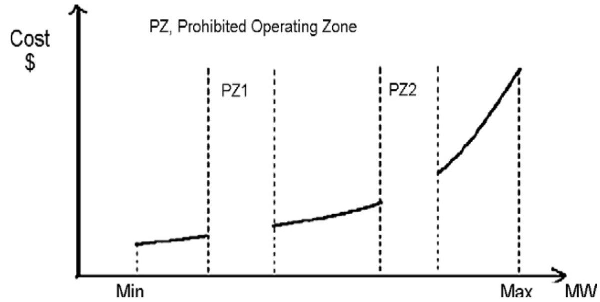

Figure.2 Prohibited operating zones of generator

As an outcome, it is observed that the entire working array of unit is not always used for load distribution. For a given prohibited zone the particular division or unit will only work for below or above the zone. This prohibited zone results in two disjoint convex regions. These two separated zones create a non-convex set as shown in figure 2. It makes the cost curve discontinuous. It is integrated with NCELD formation as given below equation (2):

$$P_i \in \begin{cases} P_i^{\min} \le P_i \le P_{i1}^L \\ P_{ik-1}^U \le P_i \le P_{ik}^L \\ P_{izi}^U \le P_i \le P_i^{\max} \end{cases} \quad (2)$$

In above condition z_i represents figure of over-all prohibited zones in i^{th} generator curve, k is the prohibited zone index of i^{th} generator, P_{ik}^L shows the lower side limit of k^{th} prohibited zone, and P_{ik}^U shows the upper side limit of k^{th} prohibited zone of i^{th} generator.

C. Generator Ramp Rate Limits

A ramp can be defined as the power alteration event at each moment of time. If the change in power is positive, it is known as a ramp-up. If the change in power is negative, it is known as ramp-down. The rate at which a ramp event is occurred called a ramp rate, which can be said that the power divergence for each minute, so its unit is [MW/minute]. Principally the ramp-up is positive ramp rate, and the ramp –down is a negative ramp rate. Hence it introduced limit between ramp-up and a ramp-down rate.

For traditional ELD difficulty it is presume that, in a particular time of period, the total power supplied by the connected set of units is constant. To keep thermal gradients up to safe limits inside the turbine, constraint of ramp rate limit is considered as the rate of swell or shrink of output given by each generating unit [23]. In practice the output of each unit cannot be accustomed directly as load varies. Let assume U_{Ri}, Up-rate limit and D_{Ri} Down-rate limit, P_i^o previous hour generation. As the generators ramp-rate limits constraint are taken into consideration, the modification of functioning limits of the i^{th} unit of generation can be done by the following condition

$$Max(P_i^{\min}, P_i^o - DR_i) \le P_i \le Min(P_i^{\max}, P_i^o + UR_i) \quad (3)$$

III. PROBLEM FORMULATION

ELD is very essential feature which should be resolved at the time of operation and controlling of the system.

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The chief worry about ELD is the reduction given objective function. Objective function is always taken on the basis of total cost of generation which satisfies all constraints. Following two equations represent the objective function.

$$MinF_T = \sum_{i=1}^{N} F_i(P_i) \qquad (4)$$

$$F_i(P_i) = \sum_{i=1}^{N} a_i P_i^2 + b_i P_i + c_i \qquad (5)$$

IV. CONSTRAINTS

Following are the constraints considered

A. *Balance Equation for Power*

The total power generated from all connected units should be equivalent to load demand and losses so that the equality constraints of power balance should be satisfied. It can be represented by the below equation (6)

$$\sum_{i=1}^{N} P_i - (P_D + P_L) = 0 \qquad (6)$$

Where, P_D is demand and PL is line loss. B-Coefficients and penalty factors-based methods are used to calculate the losses [24]. Herewith transmission losses can be expressed as

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{oi} P_i + B_{oo} \qquad (7)$$

B. *Limits of Power Generation*

For stable operation each unit power output should not exceed from its rating and also should not be below the threshold value. Hence generator unit operation should lie between the minimum and maximum limits.

$$P_i^{\min} \le P_i \le P_i^{\max} \qquad i = 1,2,\ldots,N \qquad (8)$$

here, Pi denote output power of i[th] generator, $P_i^{\min}$ and $P_i^{\max}$ are generator minimum and maximum power outputs respectively.

V. CRAZY PARTICLE SWARM OPTIMIZATION WITH TIME VARYING ACCELERATION COEFFICIENTS

James Kennedy and Russell C. Eberhart originally proposed the PSO algorithm for complex non-linear optimization problem by imitating the nature of birds' flock. PSO rapidly became a very trendy universal optimizer, essentially in objective space [25]. It is an easy and potent optimization means which disperse arbitrary particles, i.e. Results lie always in space of problem. Particles, said swarms, continuously gather and share information with each other via array which is created by its own particular positions. These particles at each moment update positions and this is known as the particle's velocity. Particle change velocity and position both from the experience of its own and also take the experience of their neighbor particle [3]. The position vector is given by $X_i = (x_{i1}, x_{i2}, \ldots\ldots x_{id})$ and velocity vectors is given by $V_i = (v_{i1}, v_{i2}, \ldots\ldots v_{id})$ of the i[th] particle in search space. According to the costing function, the most excellent prior position of a particle is traced and signifies as $pbest_i = (p_{i1}, p_{i2} \ldots\ldots p_{id})$. Suppose gth particle declared best position in group; so, this is given as $pbest_g = gbest = (p_{g1}, p_{g2}, \ldots\ldots p_{gd})$. The particle struggle to amend its location by means of the present velocity and position. Following equation (9) is used to calculate the updated velocity and position for fitness valuation for the next iteration.

$$v_{id}^{k+1} = C[w * v_{id}^{k} + c_1 * rand_1 * (pbest_{id} - x_{id}) + c_2 * rand_2 * (gbest_{gd} - x_{id})] \qquad (9)$$

$$x_{id}^{k+1} = x_{id} + v_{id}^{k+1} \qquad (10)$$

Inertia weight parameter is given by *w* it improves local & global searching competency of the particle. C represents the constriction factor, c_1, c_2 are cognitive and social coefficients, and $rand_1, rand_2$ are random numbers between 0 to1. At the time of initial search, a large inertia factor is considered and as the search progress ahead gradually its value reduces.

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

Here $iter_{\max}$ represents the number of maximum iterations.

Constant c1 drag the particles to local best position and c2 drag the particle to the global best position. The range of this parameter is from 0-4. To get convergence of PSO algorithm, can also be improved by using constriction factor [33].

$$C = \frac{2}{\left|2 - \varphi - \sqrt{\varphi^2 - 4\varphi}\right|} \qquad (12)$$

Where $4.1 \le \varphi \le 4.2$

As φ rise, the factor C decline. The classical PSO suffers the difficulty of convergence at the early stages, to tackle this problem a concept of Crazy particle was set up. This concept randomized few of the particle velocities, which are considered as 'crazy particles', these particles are elected by imagine a definite probability. In [27], function of inertia weight defined the probability of craziness ρ_{cr}, which can be given by following equation (13)

$$\rho cr = w_{min} - \exp\left(-\frac{w^k}{w_{max}}\right) \qquad (13)$$

Now following logics can be implemented to randomization of the velocities

V_j^k = rand (0, Vmax) ; if $\rho_{cr} \ge$ rand(0,1) (14)

V_j^k , otherwise

Initially if the algorithm of the PSO is moving towards saturation, a large digit of ρ_{cr} can be considered to generate the crazy particle and in later stage of search lower value is taken into consideration.

Figure 3 shows flow chart for NCELD with crazy PSO with TVAC which introduce the concept of randomize velocity to sustain the optimization procedure momentum and enhance the quality of obtained solution.

The basic concept behind the TVAC is to advance the global hunt at initial stage of the optimization process and motivate particles for converging towards global optimum at finish stage of hunt. This condition is obtained by shifting the c1 and c2 i.e. acceleration coefficients,

In such a way so cognitive factor is decreased whereas social component is increased as the hunting of particles proceed. If cognitive factor is large and social factor small, during initial period, then particles will travel near the survey space inspite of move around the *pbest* i.e. population best at the early phase. Apart from it, if social component is large with small cognitive component, then it moves the particle in the direction of global optima at the final stage of the optimization process.

$$C1 = (C1f - C1i)\frac{iter}{itermax} + C1i \qquad (15)$$

$$C2 = (C2f - C2i)\frac{iter}{itermax} + C2i \qquad (16)$$

Here C1i, and C1f, are initial and final values of cognitive factor where as C2i and C2f are initial and final values of social acceleration factors.

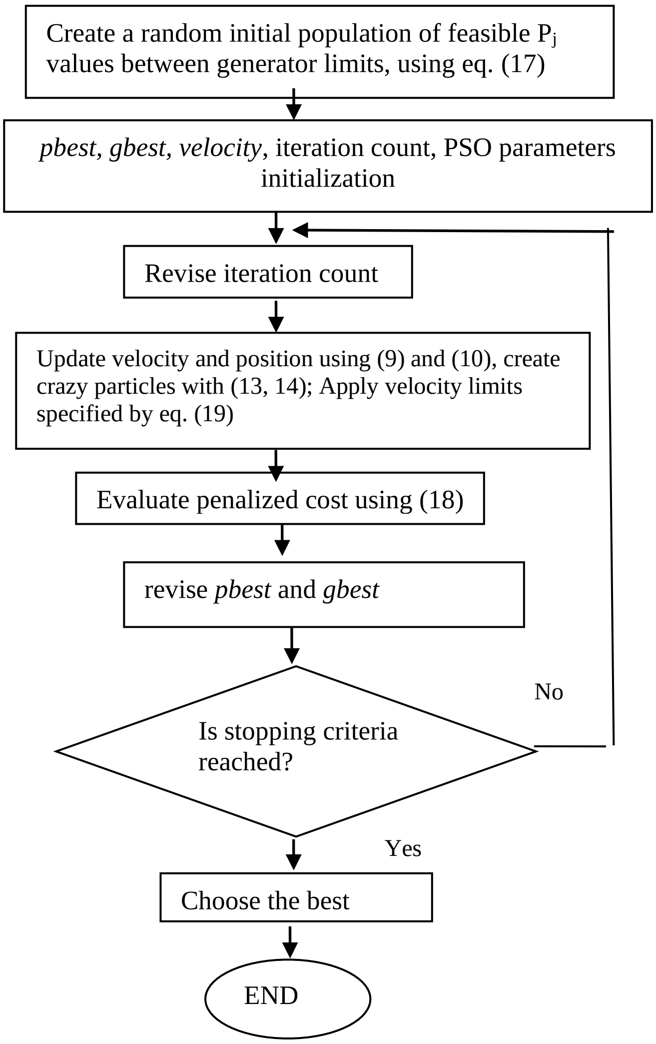

Figure.3. Flow diagram of NCELD using PSO with crazy particle method

Implementation of algorithm contains following stage: -

Stage 1*- swarm *Initialization

Particles generated randomly and adjusted between minimum and maximum limits of generator for a particular size of the population P. For N number of units, the i^{th} particle is symbolized as $P_i = (P_{i1}^n, P_{i2}^n, P_{i3}^n \ldots\ldots\ldots\ldots P_{iN}^n)$. The P_i^n can be given by below equation (17) and it fulfil the constraints given by equation (8).Here, r ∈[0, 1].

$$P_i^{\,n} = P_{j\min} - r(P_{j\max} - P_{j\min}) \qquad (17)$$

On the basis of equation (3) initialization of ramp rate limit is done for the generators and on the basis of equation (2) particles are clamped for prohibited zone as per upper and lower zone limit whatever the nearer to position of particle.

Stage 2- Evaluation function formation

Evaluation function can be define as a fitness function which value is used by the each unit particle in the swarm. The formation of evaluation functions in such a manner that if all constraints are fulfilled, the cost is reduced automatically. The penalty function scheme utilizes the functions which are formed by absolute or squared violation to trim down the strength of the particle. Abnormal condition may be created for the higher value of penalty parameters and smaller value not helpful in penalizing a particle. Hence penalty parameters should be selected cautiously to discriminate between possible and not possible solutions. This methodology helps to make constrained customization.

The evaluation function $f(P_i)$ can be given by the following equation (18)

$$f(P_i) = \sum_{i=1}^{N} F_i(P_i) + \alpha\left[\sum_{i=1}^{N} P_i - (P_D + P_L)\right]^2 + \beta\left[\sum_{k=1}^{n_i} P_i(\text{violation}_k)\right]^2 \qquad (18)$$

here α represents not satisfied load demand penalty parameter and β represents POZ penalty parameter for a unit loading.

Stage-3: *pbest and gbest Initialization*:

The *pbest* shows the values of the particle's fitness, obtained for the initial particles in the swarm and *gbest* is the finest (best) value amongst the all *pbest.*

Stage- *4: velocity valuation*:

To manage extreme travelling of particles, velocity is bounded in the limit of $-V_j^{\max}$ and $+V_j^{\max}$.Here $V_j^{\max}$ can adjust between 12 to 20%. For the j^{th} generating unit, maximum velocity limit can be calculated as follows:

$$V_j^{\max} = \frac{P_{j.\max} - P_{j\min}}{R} \qquad (19)$$

Stage-5: ***swarm updation*****:**

Equation (8) is used to modify position vector. Evaluation function updates the position of particles. Previous and new values compared if the latest new is superior than prior one *Pbest* set to the new value and optimization proceed. Similarly, if *Pbest* is superior than the prior value of *gbest* then *gbest* is also updated accordingly.

Stage- 6: ***Criteria to stop the optimization:***

A Stopping criterion of any optimization are decided by maximum iteration or decided tolerance limit. This paper adopted maximum number of iterations for stopping the process and after stopping the last stored *gbest* is the optimal solution.

VI. TEST RESULTS AND DISCUSSION

Crazy PSO with TVAC Optimization for realistic nonlinear EDL difficulty is performed and checked with two systems.

I. In the first system cost function consider valve point loading which is given by equation (6,8) having load 850 MW with 3-generating units.[10] The considered data is mentioned in the appendix section.

II. In another system constraints of POZ and ramp rate limit is considered for 6-generating units with 1263 MW [28]. B-matrix and power losses are also included for this test system as listed in Appendix section. [28]

The Performance of both the systems are compared which includes proposed method i.e. Crazy PSO with TVAC, conventional PSO and RGA. Analysis represents that Crazy PSO with TVAC creates better results as compared with other methodology.

VII. CRAZY PSO WITH TVAC FACTOR

Number of iterations run for this is 110, *w* can be changed from 0.9 to 0.4 by means of equation (11), C the constriction factor is also oscillate between 0.7 to 0.6 (for, $4.1 \le \varphi \le 4.2$) as hunt move. Rate of C1 and C2 are changes according to the equation (15) and (16).50 trials performed for all. With these values the methods i.e. PSO, Crazy PSO with TVAC and RGA are tested on 3-units and 6-units system. The comparative results are presented in fig.4 and fig.5.

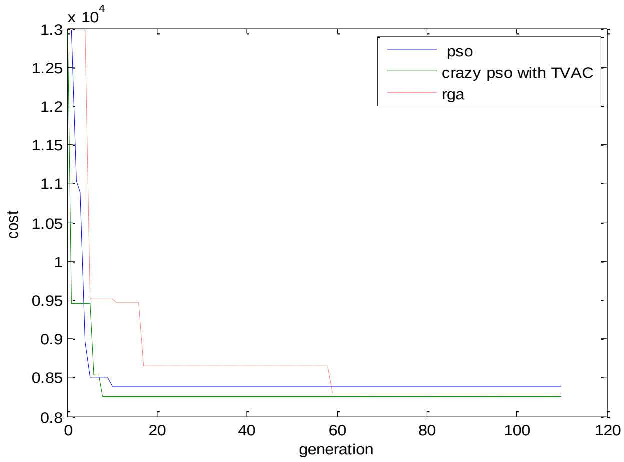

Figure. 4. Characteristics of convergence (3-unit system)

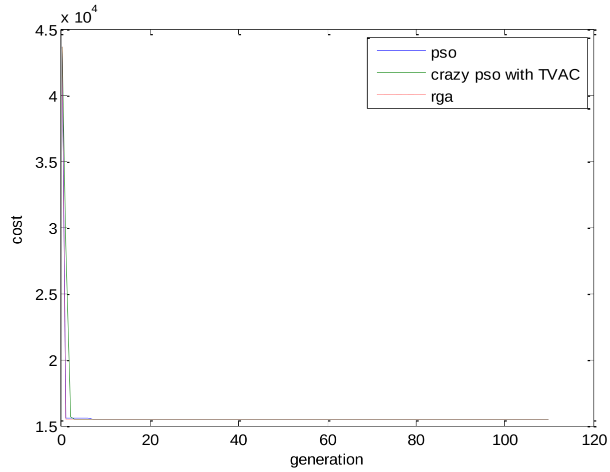

Figure.5 Characteristics of convergence (6-unit system)

Table A.1Comparitive analysis of three Generating unit

Sr.no	Technique	Lowest cost($/h)	Highest cost($/h)	Average cost($/h)
1	PSO	8234.0708	8420.9998	8330.8511
2	**Crazy PSO with TVAC**	**8234.0620**	**8380.0769**	**8276.1448**
3	RGA	8234.0725	8432.1571	8337.0334

Table A.2Comparitive analysis Of Six Generating Unit

S.no.	Technique	Lowest cost($/h)	Highest cost($/h)	Average cost($/h)
1	PSO [12]	15451.3106	15635.3768	15517.3926
2	**Crazy PSO with TVAC**	**15444.7876**	**15607.4745**	**15444.7926**
3	RGA	15461.3992	15642.5462	15527.8342
4	NPSO-LRS [5]	15450	15452	15450.5
5	SOH-PSO [17]	15446.02	15609.64	15497.25

Table A.3Output of Generator (Three units)

Power output of Units (MW)	PSO	**Crazy PSO with TVAC**	RGA
P1	400.000	**400.000**	400.000
P2	300.2667	**300.266**	300.2653
P3	149.7333	**149.733**	149.7347
Total power output	850	**850**	850
Total generation charge($/h)	8234.0718	**8234.061`**	8234.0725

Table A.4Output of Generator (Six units)

Power output of Units (MW)	PSO	**crazy PSO with TVAC**	RGA
P1	469.9415	**454.5788**	420.2342
P2	175.5558	**161.9668**	199.4412
P3	246.5108	**265.0000**	263.7234
P4	138.7732	**136.5678**	120.0030
P5	152.3809	**168.9457**	107.2319
P6	92.1599	**88.4788**	105.1250
Total power output	1263.0000	**1263**	1263
Total loss	12.6223	**12.5380**	12.7588
Total generation charge($/h)	15451.3106	**15444.7876**	15461.3992

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Table A.5Limits of generator and related coefficients (Three unit)

Variable / Generator	a_i ($)	b_i ($/MW)	c_i ($/MW^2)	ei	fi	P_i^{max}	P_i^{min}
Unit1	.00156	7.92	561	300	.031	600	100
Unit2	.00194	7.85	310	200	.042	400	100
Unit3	.00482	7.97	78	150	.063	200	50

Table A.6B-loss coefficients of Three unit

B_{ij} =	0.0000676	0.00000953	-0.0000057
	0.00000953	0.00005210	0.00000901
	-0.00000507	0.00000901	0.00029400
B_{oi} =	- 0.0007760	- 0.0000342	0.01890
B_{oo} =			0.040357

Table A.7Limits of generator and related coefficients (Six unit)

Unit	P_i^{min}	P_i^{max}	a_i ($)	b_i ($/MW)	c_i ($/MW^2)
1	100	500	0.007	7	240
2	50	200	0.0095	10	200
3	80	300	0.009	8.5	220
4	50	150	0.009	11	200
5	50	200	0.008	10.5	220
6	50	120	0.0075	12	190

Table A.8B- cofficient of six- unit

B_{ij} =	0.0017	0.0012	0.0007	-0.0001	-0.0005	-0.0002
	0.0012	0.0014	0.0009	0.0001	-0.0006	-0.0001
	0.0007	0.0009	0.0031	0	-0.001	-0.0006
	-0.0001	0.0001	0	0.0024	-0.0006	-0.0008
	-0.0005	-0.0006	-0.001	-0.0006	0.0129	-0.0002
	-0.0002	-0.0001	-0.0006	-0.0008	-0.0002	0.015
B_{oi} =	-0.00039	-0.00013	0.000705	5.91E-05	0.000216	0.000664
B_{oo} =						0.056

Table A.9 six-unit system for POZ and RRL

Unit	P_i^o	**Uri (MW/h)**	**DRi (MW/h)**	**Prohibited zone (MW)**
1	440	80	120	[210 350] [250 380]
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]

VIII. CONCLUSION

The Crazy PSO_TVAC approach is projected for resolve the composite problem of ELD which includes nonconvexity with many minima. The presentation of the method is estimate with conventional PSO and RGA. It can be concluded for Crazy PSO_TVAC tackle the difficulty of premature convergence of conventional PSO very successfully by creating 'crazy particles' with time varying acceleration coefficients as per each iteration; its velocities are reinitialized by considering the few probabilities. The supremacy of Crazy PSO with TVAC becomes more apparent for large and complicated systems. The performance of proposed method is also compared with NPSO-LRS and SOH-PSO in table A.2.It has been visibly confirmed that Crazy PSO with TVAC is capable to achieve global solutions as compared with the other methods. This method is very promising and shows the better solution, excellent computational efficiency, better convergence properties, toughness and constancy.

Appendix

From Table A.1-A.9

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