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Ramp Rate and Constriction Factor Based Dual Objective Economic Load Dispatch Using Particle Swarm Optimization

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***Abstract*—**Economic Load Dispatch (ELD) proves to be a vital optimization process in electric power system for allocating generation amongst various units to compute the cost of generation, the cost of emission involving global warming gases like sulphur dioxide, nitrous oxide and carbon monoxide etc. In this dissertation, we emphasize ramp rate constriction factor based particle swarm optimization (RRCPSO) for analyzing various performance objectives, namely cost of generation, cost of emission, and a dual objective function involving both these objectives through the experimental simulated results. A 6-unit 30 bus IEEE test case system has been utilized for simulating the results involving improved weight factor advanced ramp rate limit constraints for optimizing total cost of generation and emission. This method increases the tendency of particles to venture into the solution space to ameliorate their convergence rates. Earlier works through dispersed PSO (DPSO) and constriction factor based PSO (CPSO) give rise to comparatively higher computational time and less good optimal solution at par with current dissertation. This paper deals with ramp rate and constriction factor based well defined ramp rate PSO to compute various objectives namely cost, emission and total objective etc. and compares the result with DPSO and weight improved PSO (WIPSO) techniques illustrating lesser computational time and better optimal solution.

***Keywords*—**Economic load dispatch, constriction factor based particle swarm optimization, dispersed particle swarm optimization, weight improved particle swarm optimization, ramp rate and constriction factor based particle swarm optimization.

I. INTRODUCTION

INTERCONNECTED electric utility is basically meant for attaining minimum cost of generation and emission through a combined objective function satisfying the equality and inequality constraints involving well defined down ramp rate limits and up ramp rate limits with proper constriction factor nonlinear behavior of cost and emission function. The impact of valve point loading gives rise to more perturbation in cost function which can be piecewise-linearized using conventional dispatch techniques. Advanced constriction factor based well defined ramp rate particle swarm optimization (PSO) [17] approach employing heuristic principle is a population-based evolutionary programming technique employing flocks of birds. The added feature through an improved constriction factor has been used to optimize the cost of generation and environmental emission for reducing global warming to great extent. The feasibility of proposed method was demonstrated for a 6-generating unit system through 30 bus IEEE test case systems. The results obtained through the proposed method were compared with various conventional methods like Lagrange multiplier method [6], [7], mixed integer linear programming method, evolutionary programming method [8]-[10] and quadratic programming method, etc. References [1]-[5] as well with various heuristic methods like PSO, DPSO, WIPSO, etc.

II. METHODOLOGY

This section forecasts the objective function viz. cost, emission, and combined objective function satisfying equality and inequality constraints involving price penalty factor F_i. The basic ELD problem is formulated through (1) and (2),

$$Z_i = (a_i PG_i^2 + b_i PG_i + C_i) + K_i \sin(l_i(P_i - PG_i)) \quad (1)$$

$$J_i = (h_i PG_i^{\ 2} + g_i PG_i + q_i) \quad (2)$$

where Z_i and J_i are the cost and emission objective functions, and a_i, b_i, c_i, K_i, l_i and h_i, g_i, q_i are the cost and emission objective function coefficients. In this dissertation, the emission function involves global warming gases like NO_2 and SO_2. The ultimate objective function involving combined objective formulation encompassing cost as well as emission objective function through price penalty factor F_i is formulated as (3).

$$S_i = Z_i + F_i \times J_i \quad (3)$$

where

$$F_i = {Z_{i\max}}\big/{J_{i\max}} \quad (4)$$

$$Z_i = (a_i PG_i^2 + b_i PG_i + C_i) + K_i \sin(l_i(P_i - PG_i)) \quad (5)$$

$$J_i = (h_i PG_i^{\ 2} + g_i PG_i + q_i) \quad (6)$$

The constraints involved in this work are

i. Equality constraint

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$$\sum_{i=1}^{n} PGi = P_D + TL \tag{7}$$

where P_D = net power demand.

$$\text{TL}=\sum_{m=1}^{6}\sum_{n=1}^{6} PG_m \times PG_n \times B_{mn}$$

where TL is transmission loss.

ii. Inequality constraint

$$P_i \langle PG_i \langle P_j \tag{8}$$

where PG_i represents the output power of i^{th} generating unit, P_i and P_j are the minimum and maximum output power of i^{th} generating unit, respectively.

III. OVERVIEW OF RAMP RATE CONSTRICTION FACTOR BASED PSO

PSO [11], [12] first propounded by Kennedy and Ebert formed the behavior of evolutionary techniques for ELD optimization. Intersecting the valve point strategy employed in the multi objective generation dispatch the nonlinear characteristics of cost objective function and that of emission objective function as well become a challenging issue for ELD optimization. So, in order to obtain optimistic results of nonlinear optimization technique, we incorporate here a ramp rate limit that outsmarts the ordinary inequality constraints through advanced constriction factor based well defined ramp rate PSO technique. This method involves dispersed particles, i.e. swarms [13], [14] in search space randomly updating their position using their velocity heuristically resembling their neighbors so as to obtain position and velocity vectors viz. P_{best} and g_{best}, i.e. $(P_{1best}, P_{2best} \ldots.. P_{ibest})$ and $(g_{1best}, g_{2best} \ldots.. g_{ibest})$ respectively. The updated values of position and velocity are computed using (9) and (10).

$$Y_{n2}{}^{(k+1)} = [WY_{n1}^{k} + C_1 Rand_1(L_0 - S_i{}^{k}) + C_2 Rand_2(g_{best} - S_i{}^{k})] \tag{9}$$

$$S_{n1}^{k+1} = S_i^{k} + V_i^{k+1} \tag{10}$$

where C_1, C_2 are acceleration coefficients, W = Inertia weight, V_i^{k+1}= Updated velocity of the k+1 iteration, L_0 = P_{best} function, S_i^k = Initial i^{th} particle after k^{th} iteration, C_1R and 1 $(P_{best} - S_i^k)$ = Particle's Private thinking, C_2R and 2 $(g_{best} - S_i^k)$ = Collaboration amongst particles

$$W = W_{\max} - \frac{W_{\max} - W_{\min}}{k} \times n \tag{11}$$

K = Maximum number of iterations, n = Iteration number, $W_{\max}$ = Initial Weight in per unit = 0.85, $W_{\min}$= Final Weight in per unit = 0.35. To optimize the valve point loading effect, the ramp rate constraints are imposed upon the iteration inequality constraints as under.

$$Max(PG_{i\min}, P_{i0} - DR_i) \le PG_{inew} \le Min(PG_{i\max}, P_{i1} + UR_i) \tag{12}$$

Subject to condition that $P_{gi} - P_{i0} \le UR_i$ (Generation increases)

$$P_{i0} - P_{i1} \le DR_i \text{ (Generation decreases)} \tag{13}$$

where P_{i1} = Power generation of i^{th} unit in the current interval and P_{i0} = Power generation of i^{th} unit just before the interval

Looking into the valve point loading, a constriction factor finds use in advanced constriction factor-based well defined ramp rate PSO algorithm given by,

$$\text{CF}=\frac{4}{\left|4 - \Psi - \sqrt{\Psi^3} - \Psi^2 - 3\Psi - 2.2\right|} \tag{14}$$

where Ψ lies between 2.1 and 3.1.

As Ψ rises, CF decreases giving rise to slower convergence because of diminished population velocity up-gradation using (14)

$$Y_{n2}{}^{(k+1)} = CF[WY_{n1}^{k} + C_1 Rand_1(L_0 - S_i{}^{k}) + C_2 Rand_2(g_{best} - S_i{}^{k})] \tag{15}$$

A. RRCPSO Algorithm

Step 1) Initialize parameters like:

$$PG_1, PG_2, PG_3, PG_4, PG_5, PG_6$$

Step 2) If L_i is better than L_0, then

$$L_i = L_{0new} \qquad \text{Else} \qquad L_i = L_{0old}$$

Step 3) Initialize g_{best} values for generating units PG_1 to PG_6

Step 4) Assign best of L_{inew} and L_{0old} to g_{best}

Step 5) Current position $S_i = Z_i + F_i \times J_i$ and current velocity

$$Y_{n1} = U_{i\min} + Randi()(U_{i\max} - U_{i\min})$$

Step 6) Update position for each particle

$$S_{n1}(k+1) = S_i^{k} + Y_{n2}^{(k+1)}$$

where Y_{n2}^{k+1} is the update velocity for each particle

Step 7) If particle position is greater than or equal to bounds in (12) then stop otherwise go to step 2.

IV. RESULT ANALYSIS

The results obtained for the proposed RRCPSO method (Fig. 1) for various objectives viz. cost, emission [16] and combined objective for the IEEE 30 bus test case system through Fig. 1 suggest that beyond 200 MW cost as well as emission objective yields better performance over the classical methods like lambda iteration, mixed integer with linear programming method, and quadratic method, etc. It also outperforms heuristic methods like PSO [15], WIPSO, and DPSO, etc. as illustrated through results obtained in Table III The Simulink model (Fig. 2) and simulated results (over 30 sec) for these objectives (Figs. 3-5) for a thermal power plant yield better performance over other heuristic method.

TABLE I
COST COEFFICIENTS, UNIT CAPACITY AND EMISSION COEFFICIENTS FOR IEEE 30 BUS TEST CASE SYSTEM WITH 6 GENERATING UNIT

Unit	a_i	b_i	c_i	$P_{i\max} = P_i$
1	0.1424	37.439	755.80	125
2	0.0958	45.144	455.325	170
3	0.0180	39.385	1048.88	225
4	0.0025	37.304	1235.55	235
5	0.0111	35.326	1656.56	320
6	0.0169	37.250	1355.65	390
Unit	$P_{i\min} = P_i$	h_i	g_i	q_i
1	15	0.0039	0.3266	13.84932
2	10	0.0040	0.32667	13.84932
3	30	0.00673	-0.54771	40.2709
4	30	0.00103	-0.54.651	40.2709
5	135	0.00501	-0.5119	42.88553
6	130	0.00501	-0.5119	42.88553

TABLE II
RESULT OF 6-UNIT SYSTEM FOR A LOAD DEMAND OF 1200 MW INCORPORATING TRANSMISSION LOSS

Unit Power Output	PSO	WIPSO	DPSO	ACWRRPSO
PG_1 (MW)	49.22	50.02	93.02	120
PG_2 (MW)	18.84	20.88	100.02	130
PG_3 (MW)	108.85	110.09	95.00	150
PG_4 (MW)	58.88	60.34	150.47	200
PG_5 (MW)	208.81	210.62	200.05	250
PG_6 (MW)	307.13	308.58	270.55	350
Loss (MW)	55.78	58.89	62.57	46.69
Total Power output	807.51	819.42	971.68	1200
Fuel cost($/h)	61115.0	62120.09	63629.22	59626
Emission(T/h)	1026.23	1033.477	1043.458	1020.307
Total cost($/h)	100702	100719	100922	100611

TABLE III
PARAMETERS OF A 6-UNIT TEST CASE THERMAL SYSTEM

Frequency (f) = 60 HZ
$T_g1 = T_g2 = 0.8$ s
$P_{\text{tie max}} = 350$ MW
$T_r1 = T_r2 = 10$ s
$K_r1 = K_r2 = 0.5$
$T_t1 = T_t2 = 0.3$
$K_p1 = K_p2 = 120$ Hz/ PU MW
$T_p1 = T_p2 = 1$ S, a = -0.5; a12 = -0.5

TABLE IV
OPTIMAL SYSTEM PARAMETERS INCORPORATING RRCPSO TECHNIQUE

Areas under interconnections	Optimal Parameters	Optimal System Parameters using ACWRRPSO technique
Thermal Power system-1	K_p1	120
	K_i1	0.02
	B1	1
	R1	1
Thermal Power system-2	K_p2	120
	K_i2	0.02
	B2	1
	R2	1
Thermal Power system- 3	K_p3	120
	K_i3	0.02
	B3	1
	R3	1
Thermal Power system- 4	K_p4	120
	K_i4	0.02
	B4	1
	R4	1
Thermal Power system- 5	K_p5	120
	K_i5	0.02
	B5	1
	R5	1
Thermal Power system- 6	K_p6	120
	K_i6	0.02
	B6	1
	R6	1

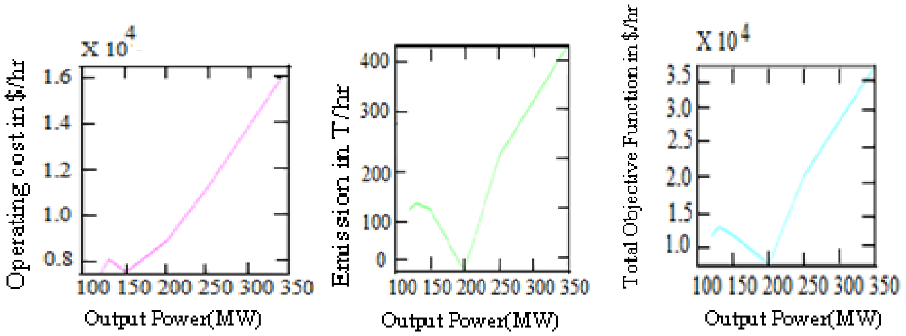
TABLE V
OPTIMAL PARAMETERS FOR RRCPSO TECHNIQUE FOR 6 UNIT TEST CASE THERMAL SYSTEM

Sl. No.	Description of parameters	Symbol used	Optimal value of parameters
1	Constriction factor	CF	2.9
2	Acceleration coefficients	C1,C2	2.1
3	Minimum Inertia weight	$W_{\min}$	0.35
4	Maximum Inertia weight	$W_{\max}$	0.85
5	Number of iterations	K	100
6	Random values	R_1,R_2,R_i	0.3,0.7,0.5
7	Power Demands	PD	1200 MW
8	Power generation of i^{th} unit just before the current interval	Pi0	80
9	Down Ramp rate limit of i^{th} unit	DR_i	44
10	UP Ramp rate limit of i^{th} unit	UR_i	1244

TABLE VI
TRANSMISSION LOSS COEFFICIENTS FOR 6-UNIT TEST CASE THERMAL SYSTEM

Unit	B coefficients (B_{ij})					
	1	2	3	4	5	6
1	1.39	0.16	0.14	0.18	0.25	0.21
2	0.16	0.59	0.12	0.15	0.14	0.19
3	0.141	0.12	0.64	0.16	0.23	0.18
4	0.18	0.15	0.16	0.61	0.29	0.24
5	0.25	0.14	0.23	0.29	0.68	0.31
6	0.21	0.19	0.18	0.24	0.31	0.84

A. Various Objective Functions



(a) (b) (c)

Fig. 1 (a) Operating cost function vs Output Power, (b) Emission level vs Output Power, (c) Total objective function vs. Output power for 30 number of iterations

B. Simulink Model

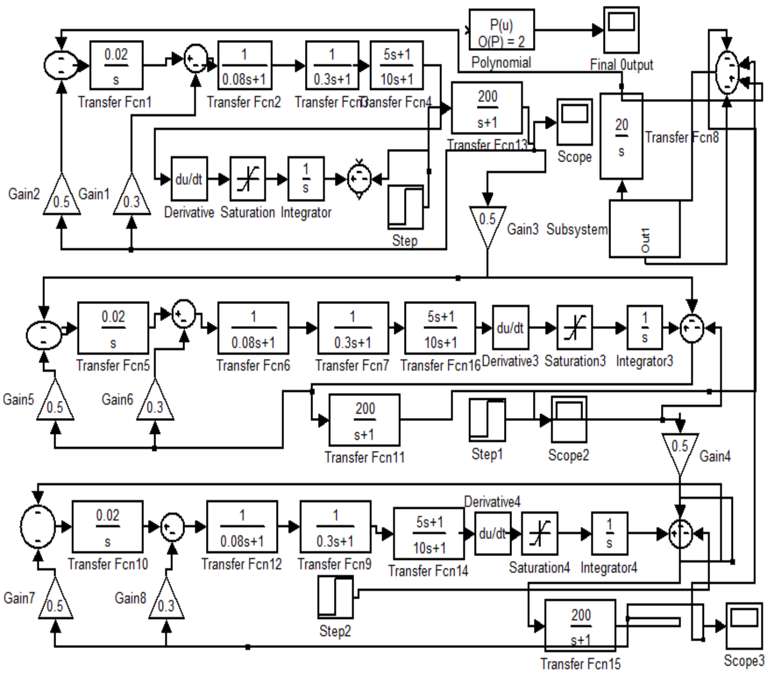


Fig. 2 Simulink Model of various objectives for a thermal power plant

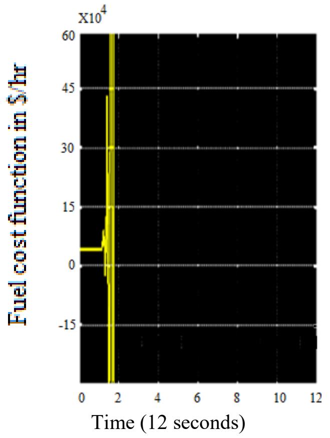


Fig. 3 Fuel cost function of the RRCPSO for 6-generator 30 bus IEEE test case system for demand of 1200 MW

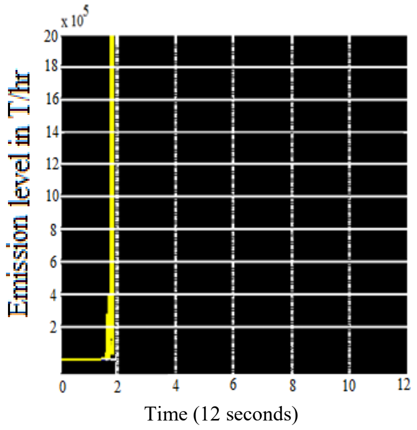


Fig. 4 Emission function for 6-unit 30 bus IEEE test case system

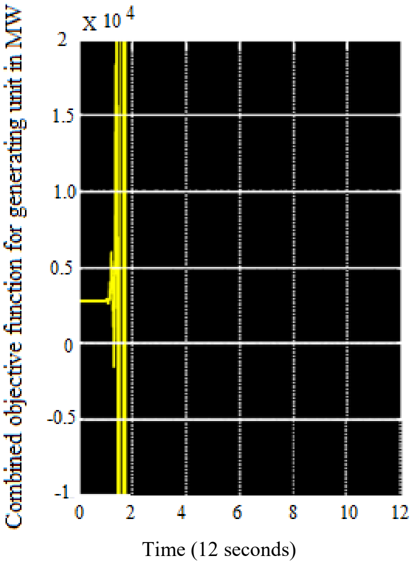


Fig. 5 Combined objective function for 6-unit 30 bus IEEE test case system

V. CONCLUSION

The proposed method RRCPSO presented advanced PSO technique involving valve point loading, ramp rate constraints, constriction factor based swarm optimization tool box for analyzing the economic dispatch problem. The results of this analysis (Tables I-VI) outperform classical methods like lambda iteration method, mixed integer linear programming method (MILP), quadratic programming method, etc., and heuristic methods like PSO, WIPSO, DPSO, etc. in terms of computational time for better optimal solution.

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