Economic Power Dispatch using Hybrid Particle Swarm Optimization with Simplex Search Method

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ABSTRACT

This paper presents the solution of economic power dispatch (EPD) in thermal power plants using the hybridization of particle swarm optimization (PSO) and simplex search method (SSM). EPD is obtaining the best generating schedule to supply the power demand and cover the transmission losses with minimum overall fuel cost. Physical constraints like valve point loading effects, ramp rate limits and prohibited operating zones are also included with basic EPD problem to increase the practicability in the problem. As PSO performs well in finding the global best solution and SSM in finding the local best solution, combination of both these improves the overall minimum results obtained for the generation of the fuel cost objective function. The performance of the proposed methodology is tested on different test systems having categories of small-scale, medium-scale and large-scale power system problems. The results obtained are then compared with other reported methods to show the superiority of the proposed algorithm.

Keywords: Economic Power Dispatch, Particle Swarm Optimization, Simplex Search Method, Valve Point Loading, Ramp Rate Limits, Prohibited Operating Zones

1. INTRODUCTION

Today's modern daily life is totally dependent on the electrical supply from the generating units. The increase in power demand has led to the increase in the number of generating stations and their capacities, resulting in the consequent increase in the consumption of resources like coal, water, diesel, etc. So the problem of economic power dispatch is considered, in which, with the optimal allocation of load, the overall fuel consumption and cost is minimized. Economic load dispatch determines the reliable, low cost and efficient power system operation by available power generation to supply the system demand. Thus the objective of economic load dispatch problem is to minimize the overall fuel cost of power generation while satisfying the various operational constraints on the system [1]. To include the more practical aspect in the problem considered, transmission losses are included in the objective of minimizing the fuel cost.

A large number of optimization methods had been proposed for economic power dispatch problem like Particle Swarm Optimization (PSO) [2–3], Genetic Algorithm (GA) [4–5] , Lagrangian Method (LM) [6], Evolutionary Programming (EP) [7–8], Harmony Search Algorithm (HS) [9], Teaching Learning Based Optimization (TLBO) [10], Artificial Bee Colony (ABC) [11–12] etc. Classical methods such as Lambda iteration method, Newton's method, Linear programming method and Gradient method were used previously for solving EPD problem [13]. These classical methods requires monotonically increasing incremental cost curves. But generally due to the nonlinear behaviour of input output characteristics, multiple minima points exist in the fuel cost function. Thus, classical methods were not able to provide an optimal solution and were unable to handle the variation in power demand. Modified optimization methods as individual or in hybrid nature prove to be effective in finding the solution. Various optimization methods are hybridized in order to take the advantage of one method with the another. This type of integration between two or more methods helps in eliminating the drawbacks of the methods used. Santra et al. [14] presents the detailed survey of comparison of various optimization methods like Artificial Bee Colony, Particle Swarm Optimization, Clonal Selection Algorithm, Ant Colony Optimization, Simulated Annealing, Genetic Algorithm, Firefly Algorithm and Gravitational Search Algorithm with regard to the economic dispatch problem. Roy et al. [15] suggested the modified Shuffled Frog Leaping Algorithm (SFLA) hybridized with Genetic Algorithm for economic dispatch problem with valve point load-

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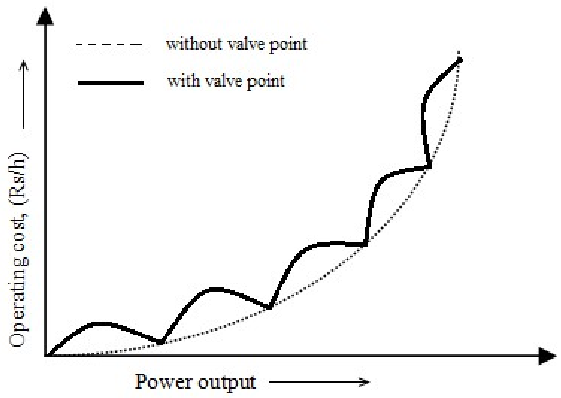

Fig. 1: *Input–output characteristics with and without valve point loading effect.*

ing effect. In this paper the shortcomings like slow search speed and getting trapped in the local minima of SFLA method are overcomed by hybridizing it with GA crossover operation.

In Cuckoo Search Algorithm (CSA), the natural phenomena of cuckoo species and Levy flights has been considered and is widely applied on the various optimization problems. Tran et al. [16] in its work modifies CSA by using two distributions including Gaussian distribution and Cauchy's distribution to solve the economic dispatch problem with multi fuel options and valve point loading effects. Direct search methods like simplex search method, pattern search method, Powell's method and others are also integrated with the optimization methods to improve the results at local minima [17].

In this paper, a novel hybrid method is proposed which includes the integration of PSO with simplex search method (SSM). As PSO performs well in finding the global best solution and SSM in finding the local best solution, thus, using the advantages of PSO and SSM, an optimal best solution is achieved for the problem of economic load dispatch. Also, for including the practical aspect in the problem, valve point loading effect, ramp rate limits and prohibited operating zones are considered along with the basic EPD problem.

2. EPD PROBLEM FORMULATION

2.1 Minimizing fuel cost function

In the basic economic power dispatch problem, fuel cost for generating units is represented as a quadratic function with the supposition that the incremental cost curves of the units are monotonically growing as linear functions. Mathematically, the fuel cost equation can be given as,

$$\text{Minimize } F_C(P_i) = \sum_{i=1}^{gu} \left(a_i P_i^2 + b_i P_i + c_i\right) \quad \text{Rs/h} \quad (1)$$

where, $i = 1, 2, ..., gu$, F_C represents final fuel cost, P_i represents the real power generated by i^{th} generator, a_i , b_i , c_i , d_i and e_i are the fuel cost coefficients and gu is the total number of generator units. But in the case of real fossil fuel burning plants, multiple-valve steam turbine produces variations in the total fuel cost functions. Due to this, real input-output characteristics (Fig. 1) display higher order nonlinearities and discontinuities, and introduce ripples in the heat rate curves [2, 4, 18–20]. Thus, for including the valve point loading effect, the fuel cost and pollutants' emission equations are given as,

$$F_C(P_i) = \sum_{i=1}^{gu} \left(a_i P_i^2 + b_i P_i + c_i + \left|d_i \sin\left\{e_i\left(P_i^{min} - P_i\right)\right\}\right|\right) \quad (2)$$

2.2 Generator's constraint handling

2.2.1 Equality constraint

To make certain of the real power stability in the system, equality constraint is applied as,

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

where, P_D is the total power demand and P_L represents the total transmission loss of the generating station.

The losses in transmission line can be expressed by Kron's loss formula as,

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

where, P_i, P_j are the real power generation of generating units i and j and B_{ij}, B_{0i}, B_{00} are the loss coefficients.

2.2.2 Inequality constraint

The inequality constraint imposed on the outputs of the generator units can be given as,

$$P_{i,min} \le P_i \le P_{i,max}, \quad (i = 1, 2, ..., gu) \quad (5)$$

where, $P_{i,min}$ represents the minimum real power assigned at unit i and $P_{i,max}$ represents the maximum real power assigned at unit i.

2.2.3 Ramp rate limit constraints

The unit ramp limits constraints (Fig. 2) are given as:

i) With the increase in power generated,

$$P_i - P_i^o \le UR_i, \quad (i = 1, 2, ..., gu)$$

ii) With the decrease in power generated,

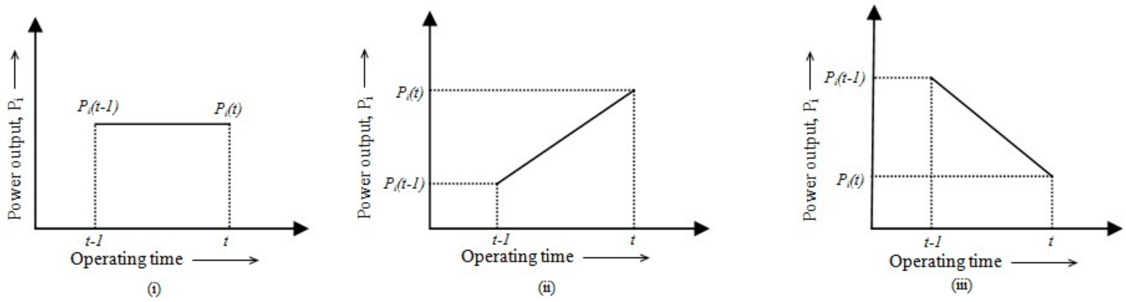

Fig.2: *Ramp rate limits for the committed generating units.*

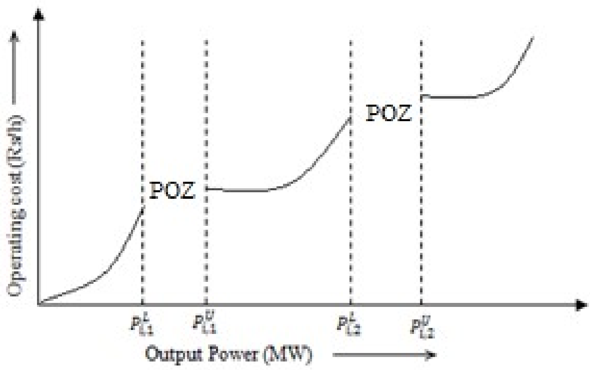

Fig.3: *Input–output characteristics with prohibited operating zones.*

$$P_i^o - P_i \leq DR_i, \quad (i = 1, 2, ..., gu)$$

Hence, generator ramp rate inequality constraint on the outputs of the generator units is given as,

$$\max(P_i^{min}, P_i^o - DR_i) \leq P_i \leq \min(P_i^{max}, P_i^o + UR_i) \tag{6}$$

where, UR_i represents up ramp limit of i^{th} unit in MW/h, DR_i represents the down ramp limit of i^{th} unit in MW/h, P_i^o represents the previous output power of i^{th} unit in MW.

2.2.4 Prohibited operating zones (POZ)

For the units having prohibited operating zones, operating ranges are,

$$P_i = \begin{cases} P_i^{min} \leq P_i \leq P_{i,1}^L \\ P_{i,j-1}^U \leq P_i \leq P_{i,j}^L, \ (j = 2, ..., N_{Zi}) \\ P_{i,N_{Zi}}^U \leq P_i \leq P_i^{max} \end{cases} \tag{7}$$

where, N_{Zi} is the total prohibited operating zones of i^{th} generator, $P_{i,j}^L$ and $P_{i,j}^U$ are the lower and upper bound of j^{th} prohibited operating zones of i^{th} generator [21] (Fig. 3).

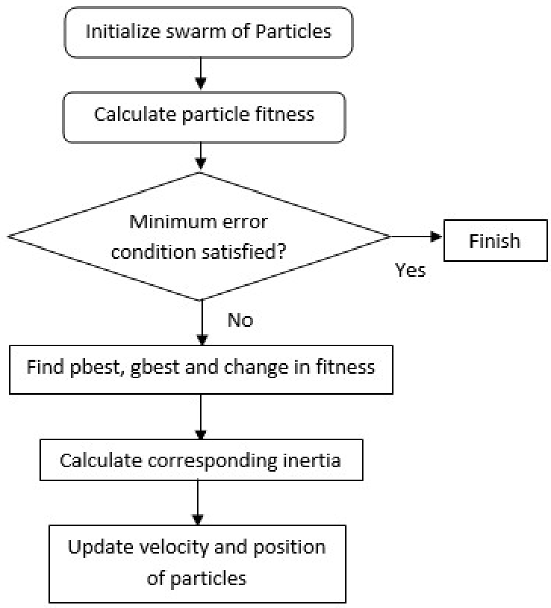

Fig.4: *Basic flowchart of PSO.*

3. IMPLEMENTATION OF PROPOSED PSOSSM

In the proposed method, particle swarm optimization (Fig. 4) is used as the base level search which is engaged in global exploration and simplex search method is then used for local exploitation that can escape the local minima and accelerate the converging process by further improving the solutions to reach the global optimum or near global optimum point.

3.1 Classical Particle Swarm Optimization

Classical Particle Swarm Optimization is a population based nature inspired stochastic meta heuristic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, which is inspired by the social behavior of bird or fishes in the swarm. A set of random particles is required to start this optimization technique and then it searches for optima by upgrading each generation. Each particle is upgraded by the two best values, pbest and gbest with individual iteration. pbest is the best solution that has been

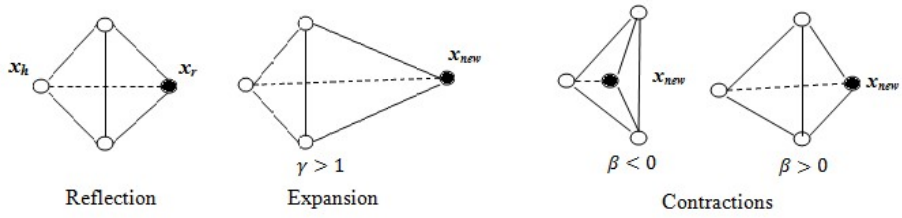

Fig.5: *Different steps in simplex algorithm.*

achieved so far between all particles in each iteration. Another best value that is followed by the PSO algorithm is the one which is obtained so far by any particle in the whole population. This best value is a global best and is called gbest. Thus, with each iteration or forward step obtained so far, the particle changes its position and follows the best particle to obtain the best solution or to get near to the solution. Each particle modifies its position and velocity in every step movement during the iterations [2, 22–24].

Initialization of swarms

The number of swarms p_i, taken is equal to the total number of generating units, gu

$$p_i = [P_1, P_2, ..., P_{gu}] \tag{8}$$

Initial velocity of particles is given as

$$v_{pi}(0) = v_{pi}^{min} + r\left(v_{pi}^{max} - v_{pi}^{min}\right); (i = 1, 2, \dots, gu) \tag{9}$$

where, $v_{pi}^{min} = -0.5P_{i,min}$ and $v_{pi}^{max} = -0.5P_{i,max}$.

Initial position of particles is given as

$$P_{pi}(0) = P_{i,min} + r(P_{i,max} - P_{i,min}) \tag{10}$$

Updating of velocity and position of swarms

After getting these best values, velocity and position of individual particles is updated as,

$$v_{pi}(k+1) = wv_{pi}(k) + c_1r_1(k)\left(pbest_{pi}(k) - P_{pi}(k)\right) + c_2r_2(k)\left(gbest_i(k) - P_{pi}(k)\right) \tag{11}$$

$$P_{pi}(k+1) = P_{pi}(k) + v_{pi}(k+1) \tag{12}$$

$$w = w^{max} - \left(\frac{w^{max} - w^{min}}{iter^{max}}\right) iter \tag{13}$$

with $w^{min} = 0.4$ and $w^{max} = 0.9$, where, N_P: number of swarm particles, gu: number of members in one particle, $v_{pi}(k)$: velocity of p^{th} particle during k^{th} movement, w: inertia weight, P_{pi}: position of p^{th} particle during k^{th} movement, $pbest_{pi}(k)$: best solution of the particle at each iteration, $gbest_i(k)$: best solution out of all the best particle solutions, $r_1(k)$, $r_2(k)$: random numbers distributed in (0,1), c_1, c_2: acceleration constants usually equal to 2, $iter$: current iteration number, and $iter^{max}$: maximum number of iterations.

3.2 Simplex Search Method

This technique was originally suggested by Spendley in 1962 and after that improved by Nelder and Mead for finding local minima from a function of several variables.

In n dimensions, only $n + 1$ points are used in the initial simplex, which means that $n + 1$ best results of objective function are taken as initial simplex. It then extrapolates the behavior of the objective function measured at each test point, in order to find a new test point and to replace one of the old test points with the new one, and so the technique progresses. This technique iteratively improves the inferior point by different operational calculations as reflection, expansion and contraction [17, 25–26] (Fig. 5).

The Stepwise procedure for SSM is

1. Determine the worst variable (x_h), the best variable (x_l) and the next to worst variable (x_g) from the initial set of simplex variables.
2. Calculate centroid (x_{cj}) of all the initial variables except the worst variable using Eq. (14)

$$\text{Centroid,} \quad x_{cj} = \frac{1}{n} \sum_{i=1, i \neq h}^{n+1} x_{ij}; (j = 1, 2, ..., n) \tag{14}$$

3. Calculate the new reflected variable (x_{rj}) as,

$$\text{Reflected point,} \quad x_{rj} = 2x_{cj} - x_{hj} \tag{15}$$

4. If $F_T(x_{rj}) < F_T(x_{lj})$, perform expansion operation as,

$$x_{new,j} = (1 + \gamma)x_{cj} - \gamma x_{hj} \tag{16}$$

where, γ is the factor to control the amount of expansion.

5. If $F_T(x_{rj}) \geq F_T(x_{hj})$, perform the inside contraction as,

$$x_{new,j} = (1 - \beta)x_{cj} + \beta x_{hj} \tag{17}$$

6. If $F_T(x_{gj}) < F_T(x_{rj}) < F_T(x_{hj})$, perform the outside contraction as,

$$x_{new,j} = (1+\beta)x_{cj} - \beta x_{hj} \tag{18}$$

where, β is the factor to control the amount of contraction.
7. Replace x_{hj} by $x_{new,j}$ and repeat steps 2-6 with new simplex.
8. Continue the iterations to find the optimal solution until the stopping criteria given by Eq. (19) is satisfied.

$$\left[\sum_{i=1}^{N+1} \frac{(F_T(x_i) - F_T(x_{ci}))^2}{N+1}\right]^{1/2} \leq \varepsilon \tag{19}$$

where, ε is the termination parameter. The recommended values for the parameters are $\gamma \approx 2.0$, $\beta \approx 0.5$ and $\varepsilon \approx 0.001$.

3.3 Overall PSOSSM procedure for EPD problem

The proposed algorithm presents the integration of deterministic method, SSM with the stochastic method, PSO. In this, PSO is used as a base level search whereas SSM is then used to further improve the solutions to reach the global optimum or near global optimum point. The EPD problem based on the proposed PSOSSM algorithm is described as follows:

Step 1. Initialize the system data and PSO parameters.

Step 2. Generate randomly the initial particles which are equal to the number of generators considered in particular case.

Step 3. Calculate minimum and maximum velocity using Eq. (9).

Step 4. Set the movement counter $k = 0$.

Step 5. Calculate initial velocity and positions of particles using Eqs. (9) and (10).

Step 6. Check equality and inequality constraints using Eqs. (3–7).

Step 7. Calculate of the objective function using Eq. (1–2).

Step 8. Increment the movement counter, $k = k + 1$.

Step 9. Update the velocity and position of particles using Eqs. (11–12) and check the corresponding constraints again.

Step 10. If $(k \leq iter^{max})$, repeat from step 8 for the overall best results of objective function.

Step 11. Input the individual particle's best solution obtained from the PSO steps to the SSM algorithm. Also, initialize the simplex parameters γ, β, ε, tolerance limits and iteration counter, itr.

Step 12. The total number of best solutions taken must be one greater than the number of generators and this is considered as the initial simplex.

Step 13. Set the iteration counter $itr = 1$.

Step 14. Set the worst point (x_h), the best point (x_l) and the next to worst point (x_g) from the initial simplex.

Step 15. Calculate centroid, reflected, expansion and contraction operations using Eqs. (14–18).

Step 16. Check constraints for the new points obtained.

Step 17. If (convergence criterion using Eq. (19) is not satisfied), replace the worst point (x_h) of the initial simplex with the new points obtained and increment the counter $itr = itr + 1$.

Step 18. Repeat from step 15 for the overall best solution.

Step 19. Stop.

Table 1: *Test systems undertaken for the validation of proposed algorithm.*

Test System	Type of system	Case	Number of generators	Power demand (MW)	VPL	RRL	POZ	Transmission losses
1	Small-scale	1	10	2000	✓	×	×	✓
		2	15	2630	×	✓	✓	✓
2	Medium-scale	1	80	21000	✓	×	×	✓
3	Large-scale	1	140	49342	✓	×	×	×

Table 2: *EPD at various power demands (small-scale test system 1, case 1).*

Unit power output (MW)	Power Demand (MW)				
	1800	1900	2000	2100	2200
P1	25.00	32.34	54.80	55.00	55.00
P2	60.00	60.00	62.40	75.89	80.00
P3	80.00	80.00	81.94	95.43	111.10
P4	80.00	80.00	81.94	95.43	111.10
P5	110.00	110.00	111.94	125.43	141.10
P6	180.00	180.00	181.94	195.43	211.10
P7	250.00	253.49	275.94	289.43	300.00
P8	300.00	300.00	310.65	324.14	339.81
P9	383.70	432.85	455.31	468.80	484.46
P10	400.34	449.48	470.00	470.00	470.00
Total Power	1869.04	1978.16	2086.85	2194.99	2303.66
P_L	69.03	78.15	86.86	95.00	103.67
Total Fuel cost (Rs/h)	101212.07	107088.25	113207.65	120108.43	127437.33

Table 3: *Comparison of results with other methods (small-scale test system 1, case 1).*

Unit power output (MW)	PSOSSM	ABC_PSO [19]	NSGA-II [27]	SPEA-2 [27]	DE [27]
P1	54.80	55.00	51.95	52.98	54.95
P2	62.40	80.00	67.26	72.81	74.58
P3	81.94	81.14	73.69	78.11	79.43
P4	81.94	84.22	91.36	83.61	80.69
P5	111.94	138.34	134.05	137.24	136.86
P6	181.94	167.51	174.95	172.92	172.64
P7	275.94	296.83	289.44	287.20	283.82
P8	310.65	311.58	314.06	326.40	316.34
P9	455.31	420.34	455.70	448.88	448.59
P10	470.00	449.16	431.81	423.90	436.43
P_L	86.86	84.17	–	–	–
Total Fuel cost (Rs/h)	113207.65	113420.0	113540.0	113520	113480

4. RESULT ANALYSIS AND DISCUSSION

For solving the economic power dispatch problem, the proposed algorithm is coded in MATLAB R2014b on a system with Intel core *i3* processor and 3GB RAM. Initialization of PSO and SSM parameters are undertaken as: total particles in each swarm = 10, total members in one particle = number of generators taken in each case, $w^{min} = 0.4$, $w^{max} = 0.9$, $c_1 = c_2 = 2$, $\gamma = 2.0$, $\beta = 0.5$ and $\varepsilon = 0.001$. Effectiveness of the proposed method is tested on various test systems demonstrated in Table 1 including the physical constraints like valve point loading effect, ramp rate limits and prohibited operating zones.

Table 4: *EPD at various power demands (small-scale test system 1, case 2).*

Unit power output (MW)	Power Demand (MW)				
	2580	2610	2630	2650	2700
P1	455.01	455.01	455.01	455.02	455.02
P2	184.93	184.99	184.98	184.91	185.00
P3	130.01	130.01	130.01	130.02	130.02
P4	130.01	130.01	130.01	130.02	130.02
P5	179.98	179.97	179.97	180.00	180.00
P6	429.97	429.96	430.01	429.99	429.98
P7	430.01	430.01	430.01	430.02	430.02
P8	160.01	160.01	160.01	160.02	160.02
P9	95.80	108.31	116.73	125.19	146.46
P10	106.16	118.68	127.10	135.56	156.83
P11	80.01	80.01	80.01	80.02	80.02
P12	29.98	29.99	29.80	29.90	29.88
P13	85	85	85	85	85
P14	55	55	55	55	55
P15	55	55	55	55	55
Total Power	2606.77	2631.85	2648.51	2665.45	2708.01
P_L	27.34	22.83	19.95	17.05	10.21
Total Fuel cost (Rs/h)	32310.66	32591.31	32778.61	32968.7	33447.84

Table 5: *Comparison of results with other methods (small-scale test system 1, case 2).*

Unit power output (MW)	PSOSSM	GA [3]	PSO [3]
P1	455.01	415.31	439.12
P2	184.98	359.72	407.97
P3	130.01	104.42	119.63
P4	130.01	74.98	129.99
P5	179.97	380.28	151.07
P6	430.01	426.79	459.99
P7	430.01	341.32	425.56
P8	160.01	124.79	98.56
P9	116.73	133.14	113.49
P10	127.10	89.26	101.11
P11	80.01	60.06	33.91
P12	29.80	50.00	79.96
P13	85.01	38.77	25.00
P14	55.01	41.94	41.41
P15	55.01	22.64	35.61
Total Power	2648.51	2668.44	2662.41
P_L	19.95	38.28	32.42
Total Fuel cost (Rs/h)	32778.61	33113.00	32858.00

4.1 Small-scale test system

In small scale test system 1, the input data for case 1 is taken from [19]. Economic power dispatch with valve point loading effect is solved for different power demands shown in Table 2.

Table 6: *EPD at power demand of 21000 MW (medium-scale test system 2).*

Generating Unit	Power Output (MW)	Generating Unit	Power Output (MW)	Generating Unit	Power Output (MW)	Generating Unit	Power Output (MW)
P1	595.74	P21	422	P41	408.39	P61	510.00
P2	88.72	P22	492.84	P42	36	P62	476.56
P3	64.76	P23	520.90	P43	60.01	P63	433.13
P4	60	P24	523.60	P44	60	P64	422
P5	136.53	P25	477.86	P45	120	P65	422
P6	60	P26	422	P46	75.17	P66	422
P7	68	P27	478.41	P47	77.80	P67	486.61
P8	229.73	P28	145.47	P48	248.57	P68	110
P9	253.68	P29	136.63	P49	264.71	P69	110
P10	201.03	P30	125.20	P50	200	P70	110
P11	213.15	P31	69.57	P51	271.37	P71	67
P12	274.41	P32	155.82	P52	356.04	P72	170.91
P13	220.08	P33	168.51	P53	340.49	P73	168.46
P14	443.40	P34	159.73	P54	474.92	P74	185.74
P15	441.42	P35	168.60	P55	484.40	P75	168.51
P16	412.04	P36	195.74	P56	402.62	P76	138.99
P17	401.82	P37	195.74	P57	422.75	P77	130
P18	484.77	P38	74.25	P58	490.66	P78	81.17
P19	409.50	P39	97.53	P59	485.85	P79	55.16
P20	422	P40	75.62	P60	477.06	P80	65.75
Total Power (MW)		21077.61	P_L (MW)	77.61	Total Fuel cost (Rs/h)		242859.59

Table 7: *Comparison of results with other methods (medium-scale test system 2).*

Method	SCA [30]	FAPSO [29]	SSA-II [30]	CSO [30]	THS [30]	SSA-I [30]	MSSA[30]	PSOSSM
Total Fuel cost (Rs/h)	250864.05	244273.54	243398.17	243195.38	243192.69	243173.59	242909.25	242859.59

The comparison of the results obtained by PSOSSM at 2000 MW with other methods (ABC_PSO [19], DE [27], NSGA-II [27] and SPEA [27]) is shown in Table 3. It is observed that the proposed method shows minimum fuel cost even with the transmission losses also taken into account. However the other methods like DE, NSGA-II and SPEA-2 do not consider the losses in their calculations which shows the limitation of other systems on the practical grounds.

In case 2, the physical constraints like ramp rate limits and prohibited operating zones are also considered with fifteen generator EPD problem and the input data is taken from [3, 28]. Results obtained at different power demands are given in Table 4. The comparison of the results obtained at 2630 MW is done with other methods (PSO [3] and GA [3]). From Table 5, it is observed that the generation fuel cost obtained by PSOSSM is much better than the reported algorithms.

Thus, the reported proposed algorithm shows its effectiveness in the small scale test systems with different practical constraints like valve point loading effect, ramp rate limits and prohibited operating zones. The comparison Tables 3 and 5 prove the effective performance of the proposed algorithm as compared to other cited literature.

4.2 Medium-scale test system

In this case, expanded data of a forty unit system from [7] is examined as a medium-scale eighty generator system. This system consists of valve point loading along with the transmission losses having total demand of 21000 MW. The best results obtained are reported in Table 6 and are then compared with other available reported methods (SCA [30], SSA-II [30], CSO [30], THS [30], SSA-I [30], MSSA [30] and FAPSO [29]) in Table 7. It is observed that PSOSSM shows better results as compared to other methods. The best fuel cost reported by the proposed algorithm is lowered by 8004.46 Rs/h from the highest reported by SCA [30], whereas it is lowered by 49.66 Rs/h in comparison to MSSA [30], which otherwise was lowered.

Thus, with the increasing complexity in the expanded system, the proposed algorithm shows its effectiveness for medium-scale systems also, in the presence of physical constraints like valve point loading effect.

Table 8: *EPD at power demand of 49342 MW (large-scale test system 3).*

Unit	Power Output (MW)	Unit	Power Output (MW)	Unit	Power Output (MW)	Unit	Power Output (MW)	Unit	Power Output (MW)
P1	111.48	P31	433.13	P61	293.39	P91	293.42	P121	261.34
P2	181.48	P32	422.67	P62	190.62	P92	522.61	P122	11.48
P3	182.48	P33	411.82	P63	293.92	P93	532.15	P123	51.48
P4	182.48	P34	385.93	P64	296.54	P94	917.50	P124	75.48
P5	168.65	P35	395.13	P65	318.48	P95	914.84	P125	45.48
P6	159.41	P36	407.90	P66	318.81	P96	674.48	P126	29.48
P7	428.16	P37	213.89	P67	273.16	P97	705.52	P127	26.48
P8	421.93	P38	226.60	P68	355.09	P98	686.20	P128	193.51
P9	416.21	P39	629.61	P69	245.64	P99	712.48	P129	12.48
P10	420.32	P40	714.22	P70	317.62	P100	891.64	P130	30.48
P11	430.79	P41	11.48	P71	339.20	P101	898.96	P131	11.48
P12	395.60	P42	20.48	P72	211.06	P102	855.38	P132	90.48
P13	356.07	P43	237.12	P73	277.77	P103	934.96	P133	7.95
P14	432.74	P44	233.85	P74	325.40	P104	875.21	P134	66.48
P15	417.78	P45	242.48	P75	425.96	P105	854.28	P135	66.48
P16	402.28	P46	224.69	P76	280.45	P106	906.49	P136	97.48
P17	435.65	P47	242.48	P77	323.74	P107	928.30	P137	43.48
P18	384.26	P48	242.48	P78	466.13	P108	961.90	P138	11.48
P19	427.57	P49	225.67	P79	333.36	P109	989.10	P139	11.48
P20	433.70	P50	220.41	P80	360.87	P110	933.34	P140	32.48
P21	417.97	P51	263.63	P81	316.49	P111	941.10	Total Power (MW)	49341.99
P22	351.27	P52	301.04	P82	124.48	P112	195.48		
P23	410.20	P53	314.52	P83	165.42	P113	189.62		
P24	438.87	P54	308.34	P84	224.42	P114	183.43	Total Fuel cost (Rs/h)	1559800.23
P25	448.50	P55	338.42	P85	205.50	P115	338.68		
P26	436.08	P56	307.38	P86	295.97	P116	371.48		
P27	440.52	P57	241.81	P87	299.48	P117	364.05		
P28	478.78	P58	387.83	P88	279.41	P118	175.66		
P29	418.80	P59	304.48	P89	307.00	P119	164.65		
P30	379.47	P60	345.61	P90	335.62	P120	186.48		

Table 9: *Comparison of results with other methods (large-scale test system 3).*

Method	CCPSO [24]	CSA [30]	IDE [30]	GWO [30]	SSA-II [30]	PSOSSM
Best fuel cost (Rs/h)	1657962.7	1655746.1	1564648.7	1559953.2	1559841.2	1559800.2

4.3 Large-scale test system

To study the performance of the proposed algorithm on the large-scale systems, a Korean power system [24], [31] with 140 generator power units is investigated. This system consists of 40 thermal units, 51 gas units, 20 nuclear units and 29 oil units with total power demand of 49342 MW. Out of these, 12 units have valve point loading effect. Transmission losses are ignored in this case. Due to complexity of the system considered, it is a challenging task to solve this system. The best results obtained using the proposed method at 49342 MW are reported in Table 8. Table 9 shows the comparison of best fuel cost obtained with the proposed method and other available methods (CCPSO [24], CSA [30], IDE [30], GWO [30] and SSA-II [30]). It is observed that the proposed method shows the overall minimum fuel cost in comparison to the reported methods for the large scale systems, which shows the effectiveness of the proposed method in large scale systems also.

5. CONCLUSION

This paper presents a novel hybrid method combining the particle swarm optimization and simplex search method and applied on the problem of economic power dispatch in thermal power plants. Various physical constraints like valve point loading effect, ramp rate limits and prohibited operating zones are also included along with the transmission line losses to increase the practicability in the economic power dispatch problem. The robustness of the proposed method is examined by considering the test systems with categories small, medium and large scale power systems. The results obtained in each case show that the proposed method works well in each category as compared to other reported methods. Thus the combination of stochastic algorithm with deterministic methods proves its superiority in order to achieve the objective of minimum generation fuel cost with respect to other cited methods.

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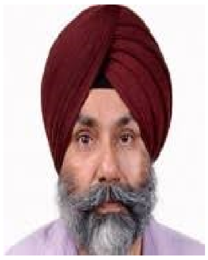

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