Asian Journal of Electrical Sciences
ISSN: 2249-6297 (P) Vol.7, No.1, 2018, pp.29-36

DOI: https://doi.org/10.51983/ajes-2018.7.1.2058

Multiarea Economic-Emission Dispatch Using Simplex Based Particle Swarm Optimization Method

Namarta Chopra[1], Y.S. Brar[2] and J. S. Dhillon[3]
[1&2]Research Scholar, Department of Electrical Engineering,
I.K.Gujral Punjab Technical University, Punjab, India
[3]Department of Electrical and Instrumentation Engineering,
Sant Longowal Institute of Engineering and Technology, Punjab, India
E-Mail: namartachopra@yahoo.co.in

(Received 23 January 2018; Revised 18 February 2018; Accepted 10 March 2018; Available online 19 March 2018)

***Abstract* - This paper introduces the hybridization of Particle Swarm Optimization (PSO) with Simplex Search Method (SSM) in the field of Multi Area Power Dispatch (MAPD) problem. The proposed simplex based particle swarm optimization (SPSO) helps in refining the global solution obtained using PSO, with local search through SSM. As in today's power industry, the energy flow between the areas and fossil fuel emissions from the generating units are of major concern. So, the objective of MAPD is to reduce the overall generation cost of the areas along with the reduction of pollutants' emissions also. The comparison with Single Area Power Dispatch (SAPD) system is done to understand the benefit of resolving the whole region into small areas. Due to the conflicting nature of both the objectives, Price Penalty Factor (PPF) method is used to convert the multiobjective problem into single objective optimization problem while satisfying its various equality and inequality constraints. The effectiveness of the proposed method is tested on a test system consisting four areas, twelve generator system under both MAPD and SAPD cases. These cases are compared with each other and with the available literature to show the robustness of the proposed method.**

***Keywords*: Economic-Emission Dispatch (EED), Particle Swarm Optimization (PSO), Simplex Search Method (SSM), Price Penalty Factors (PPF)**

I. INTRODUCTION

The electrical power industry moves towards development with saving in energy and reducing emissions due to the impact of the global environmental awareness. The power plants in the country are distributed nationwide to compete with the reliability and the optimal dispatch of the power throughout. The concentration of dangerous gaseous emissions was stabilized with proper distribution of generating stations throughout the region by making small area zones in between. Different areas in the electrical power systems are interconnected to improve their operating efficiency, reliability and reducing the overall operating cost. The areas are connected to each other through tie lines. This whole system consisting of various areas as well as tie lines comes under the problem of multi area power dispatch (MAPD) [12]. In MAPD, each area has its own generator characteristics and load demand which co-ordinate through tie lines. If the load changes in any area, it is collectively covered by all the generators with change in the power flow on the tie lines. This whole process of power flow is taken care by the electrical power industry of the particular country, so that each and every operation is performed with maximum possible efficiency.

The objective of MAPD problem is to determine the power produced by each generator in different areas as well as the power flow between the areas so as to reduce the total overall generating cost and emissions of the entire system. The demand requirement is distributed evenly among different areas to reduce the harmful effect pollutants emissions. The power dispatch between the areas must not violate the power balance constraint in the whole system as well as generator and tie line limit constraints. In MAPD, the individual power generation is not balanced within its own area only because of the presence of the power export and import to other areas also [17]. Hence, the MAPD is considered as the large scale optimization problem.

Limited work has been carried to deal with the problem of multi area economic dispatch, to reduce the overall fuel cost only [1,7,8,13,14]. Nowadays, the work is also carried out for emission dispatch, so as to regulate the environmental issues. Due to the complexity of the problem, conventional methods [20] which use derivatives and gradients alone like lambda iteration method, Newton method, gradient method and linear programming method are not able to locate the global solution in MAPD. There are many papers which solve the combined economic emission dispatch problem for thermal units in single area system using nature inspired algorithms [2,6,10,15,16,18]. In [3,4,19] classical PSO was applied to solve the multi area problem with economic emission dispatch.

In this paper, the problem of MAPD is formulated which includes both economic and emission dispatch between different connected areas through tie lines while satisfying equality and inequality constraints of the generated power and power flow on transmission lines. This optimization problem is solved using Particle swarm optimization hybridized with the simplex search method (SPSO) so as to reach the overall improved Pareto-optimal solution. Price penalty factor method (PPF) [11] is further used to convert the conflicting multi objective problem into scalar optimization problem. The price penalty factor is defined as the proportion of fuel cost to emission values with different approaches as Min-Min, Max-Max, Max-Min and Min-Max. These various approaches are then used as decision making to get the best overall result. The proposed hybridized method is effectively tested on four areas twelve generator system connected with six tie lines for the cases of both multi area as well as for single area system.

II. FORMULATION OF MAPD PROBLEM

The multi area power dispatch is solved to fulfill the objectives of reducing the overall fuel cost from all the areas as well as reducing the pollutants emissions. These objectives are conflicting and non-commensurable in nature which must satisfy the system constraints to get the optimal solution. Each area has its own set of generators, which are connected to each other through tie lines.

A. Minimization of objective function

Mathematically, the objective function consist equation for both fuel cost and pollutant's emissions. These conflicting multi-objective equations are converted into single objective using price penalty factors (h) as,

$$Minimize\ objective\ function, F_{Tk} = FC + h_k(PE) \quad (k = 1,2,3,4) \tag{1}$$

In 'A' areas, they are represented as,

$$FC = \sum_{i=1}^{A}\sum_{j=1}^{G}(a_{ij}P_{ij}^2 + b_{ij}P_{ij} + c_{ij}) \tag{2}$$

$$TC = \sum_{m=1}^{A}\sum_{n=1}^{A} f_{mn}P_{Tmn}$$

$$Total\ operational\ cost, TOC = FC + TC$$

$$PE = \sum_{i=1}^{A}\sum_{j=1}^{G}\left(\alpha_{ij}P_{ij}^2 + \beta_{ij}P_{ij} + \gamma_{ij}\right) \tag{5}$$

$$h_1 = \frac{FC(P_{min})}{PE(P_{max})} \tag{6}$$

$$h_2 = \frac{FC(P_{min})}{PE(P_{min})} \tag{7}$$

$$h_3 = \frac{FC(P_{max})}{PE(P_{max})} \tag{8}$$

$$h_4 = \frac{FC(P_{max})}{PE(P_{min})} \tag{9}$$

where A is the number of areas, G is the number of generators committed to the operating system. FC is the fuel cost, h is the price penalty factor and PE is the pollutant's emissions. a_{ij} , b_{ij} , c_{ij} are the fuel cost coefficients and α_{ij} , β_{ij} , γ_{ij} represents the pollutant's emission coefficients of the j^{th} generator in i^{th} area. P_{ij} represents the real power produced by j^{th} generator of i^{th} area. TC is the transmission cost in which f_{mn} represents the transmission cost coefficient and P_{Tmn} is the power flow on tielines from area m to area n if its value is positive and power flow from area n to area m if its value is negative.

The optimization problem is to minimize (1) by using different values of price penalty factors as given in (6-9).

$$F_{Tk} = min\{F_{T1}, F_{T2}, F_{T3}, F_{T4}\} \tag{10}$$

Here, the value of (10) will become the optimal solution for the MAPD problem.

B. Constraints on objective function

The objective function defined in (1) has subjected to power balance constraint throughout the region, generator limits constraints and tie line limits constraint. In the multi area system, the individual area generation is not balanced with its own generation because of the presence of the power export and import to other areas also. Hence, the overall real power generated in the region must be balanced with the overall power demand, total losses and net power flow on transmission lines. Equation (11) gives the power balance constraint whereas (13) and (14) represents the limits imposed on the generated power and tie line power.

$$\sum_{j=1}^{G} P_j = PD + PL + \sum_{m=1}^{L} P_{Tm} \tag{11}$$

where, PD represents total power demand in all areas, PL is the total power loss in the region as given in (12) and P_T is the power transfer on 'L' tie lines between the areas. The loss in transmission line can be expressed by Kron's loss formula as,

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j + \sum_{i=1}^{n} B_{0i}P_i + B_{00} \tag{12}$$

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 transmission loss coefficients.

$$Generator\ limits, \quad P_{j,min} \le P_j \le P_{j,max}\ ;\ (j = 1,2,\dots,G) \tag{13}$$

$$Tie\ line\ limits, \quad P_{Tm,min} \le P_{Tm} \le P_{Tm,max}\ ; (m = 1,2,\dots,L) \tag{14}$$

$P_{j,min}$ and $P_{j,max}$ are the minimum and maximum powers that can be produced by the j^{th} generator in the particular area. $P_{Tm,min}$ and $P_{Tm,max}$ are the minimum and maximum power flow on the 'L' transmission lines.

III. IMPLEMENTATION OF PROPOSED SPSO ON SAPD/MAPD PROBLEM

Recent research proves that the PSO based methods show advantageous results in wide variety of multi objective optimization problems in terms of convergence, robustness and simplicity. In this paper, PSO is hybridized with SSM to deal with multi area power dispatch problem.

A. Particle Swarm optimization.

In 1995, a stochastic optimization approach developed by Eberhart and Kennedy, motivated from the social behavior of bird flocking [9]. This study is based on the fact that during the movement, each swarm modifies its position as per its own observation also as per the observation of other swarms. With this, the finest observation depends on that achieved by itself and other swarms.

Mathematically, a set of random particles is required to start this optimization technique. The particle is upgraded by the two best values, *pbest* i.e., the best solution it has achieved so far between all particles in particular iteration and *gbest* is the best solution from the whole population.

B. Initialization of velocity and position

The number of swarms p_i , is equal to the total number of generating units, G in A areas plus the total tie lines, TL interconnecting the A areas. N_p is the total number of particles in a swarm.

$$p_i = [P_{11}, P_{12}, \dots, P_{1G}, P_{21}, P_{22}, \dots, P_{2G}, \dots \dots, P_{A1}, P_{A2}, \dots, \quad (15)$$

Initial velocity of particles is calculated as

$$v_{pi}(0) = v_{pi}^{min} + r\left(v_{pi}^{max} - v_{pi}^{min}\right); (i = 1,2,\dots,G,T_{12},T_{13},\dots,T_{23},\dots,TL) \quad (p = 1,2,\dots\dots,N_P) \quad (16)$$

$$where,\ v_{pi}^{min} = -0.5P_{i,min}\ and\ v_{pi}^{max} = +0.5P_{i,max} \quad (17)$$

Initial positions of particle members is calculated as,

$$P_{pi}(0) = P_{i,min} + r\left(P_{i,max} - P_{i,min}\right);\ \ (i = 1,2,\dots,G,T_{12},T_{13},\dots,T_{23},\dots,TL) \quad (p = 1,2,\dots\dots,N_P) \quad (18)$$

$P_{i,min}$ and $P_{i,max}$ are the minimum and maximum limits for generating units and tie lines.

Updation of velocity and position

Velocity and position of individual particle is updated as,

$$v_{pi}(k+1) = wv_{pi}(k) + c_1 r_1(k)\left(pbest_{pi}(k) - P_{pi}(k)\right) + c_2 r_2(k)\left(gbest_i(k) - P_{pi}(k)\right) \quad (19)$$

$$P_{pi}(k+1) = P_{pi}(k) + v_{pi}(k+1) \quad (20)$$

$$w = w^{max} - \left(\frac{w^{max} - w^{min}}{iter^{max}}\right) iter\ with\ w^{min} = 0.4\ and\ w^{max} = 0.9 \quad (21)$$

where, $v_{pi}(k)$ represents the velocity of p^{th} particle during k^{th} movement, w is inertia weight, $P_{pi}(k)$ is the position of p^{th} particle during k^{th} movement which is the optimum solution obtained in terms of power from generating units and on tie lines. With different penalty factors, (10) will decide the non-inferior solution against the optimum set of swarm particles.

$$F_{Tp} = min\{F_{Tp1}, F_{Tp2}, F_{Tp3}, F_{Tp4}\} \quad (22)$$

c_1 and c_2 are the acceleration constants usually both are equal to 2, $r_1(k)$ and $r_2(k)$ are the random numbers between (0,1), $iter^{max}$ represents the maximum number of iterations and *iter* is the current iteration number. The updated velocity and position of the particle must satisfy their inequality generator and tie line constraints as given in (13,14). The updated velocity of the particle must satisfy its minimum and maximum inequality constraints as given in (23)

$$-0.5P_{pi}^{min} \le V_{pi} \le +0.5\ P_{pi}^{max},\ (i = 1,2,\dots,G;\ p = 1,2,\dots,N_P) \quad (23)$$

For the balancing of power demand constraint, one of the generators in each area is selected as dependent generator [11], (5) can be re-written as,

$$\sum_{i=1}^{A} P_{id} = \sum_{i=1}^{A} PD_i + \sum_{i=1}^{A} PL_i + \sum_{m=1}^{L} P_{Tm} - \sum_{\substack{j=1 \\ j \ne d}}^{G} P_{ij} \quad (i = 1,2,\dots,A;\ j = 1,2,\dots,G) \quad (24)$$

C. Simplex Search Method.

In 1965, Nelder and Mead proposed this method for finding local minima among a function of several variables. The number of variables in the initial simplex is much less as compared to evolutionary optimization method [5]. This method iteratively produces a sequence of simplexes to approximate an optimal point. To improve the solution obtained from PSO, this method is applied on the G+1 best solutions (where, G is the total number of generators in the region), which act as variables for initial simplex. This method iteratively improves the worst point by different operations as reflection, expansion and contraction as,

1. Determine the worst point *(x_h)*, the best point *(x_l)* and the next to worst point *(x_g)* from the initial set of simplex variables.
2. Calculate centroid (x_{cj}) of all the initial points except the worst point using (25)
$$x_{cj} = \frac{1}{G} \sum_{i=1, i \ne h}^{G+1} x_{ij}\ (j = 1,2,\dots,G) \quad (25)$$
3. Calculate the new reflected point (x_{rj}) as,
$$x_{rj} = 2x_{cj} - x_{hj}\ (j = 1,2,\dots,G) \quad (26)$$
4. $If\ f(x_{rj}) < f(x_{lj})$, perform expansion operation as,
$$x_{new,j} = (1+\gamma)x_{cj} - \gamma x_{hj}\ (j = 1,2,\dots,G) \quad (27)$$
where, γ is the factor to control the amount of expansion.
5. $If\ f(x_{rj}) \ge f(x_{hj})$, perform the inside contraction as,
$$x_{new,j} = (1-\beta)x_{cj} + \beta x_{hj}\ (j = 1,2,\dots,G) \quad (28)$$
6. $If\ \ f(x_{gj}) < f(x_{rj}) < f(x_{hj})$, perform the outside contraction as,
$$x_{new,j} = (1+\beta)x_{cj} - \beta x_{hj}\ (j = 1,2,\dots,G) \quad (29)$$

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 (30) is satisfied.

$$\left[\sum_{i=1}^{G+1}\frac{\left(f\left(x_{new,i}\right)-f\left(x_{ci}\right)\right)^{2}}{G+1}\right]^{1/2}\leq\epsilon \qquad (30)$$

where, ∈ is the termination parameter.

The recommended values for the parameters are γ ≈ 2.0, β ≈ 0.5 and ∈ ≈ 0.001.Final MAPD is then calculated using (1) against x_{new} obtained after performing both PSO and SSM.

D. Proposed SPSO algorithm for MAPD problem

The simplex based particle swarm optimization (SPSO) algorithm combines the stochastic and deterministic methods to improve the solution quality and can be explained as,

1. Input the system data, generator and proposed algorithm coefficients.
2. Compute minimum and maximum initial velocities as in (17)
3. Set movement counter k=0
4. Compute of initial velocity and position of swarm particles as in (16, 18)
5. Checking of power demand constraint using (24) by selecting one of the generators as dependent generator in each area.
6. Checking of inequality constraints for velocity using (23) and for position using (13, 14).
7. Calculation of the objectives, $f_p(k)=F_T\left(P_{pi}(k)\right)$ from (22) at various PPF from (6-9) and compute best MAPD.
8. Increment movement counter, k=k+1
9. Calculation of the best solution of all the particles, $pbest_{pi}$ and best solution from all the particles, $gbest_i$.
10. Calculation of inertia weight using (21), new velocity using (13) and new position using (14). Checking the velocity constraints from (17) for minimum and maximum values of velocities.
11. Again checking of constraints for this new position and velocity as done in steps 5, 6.
12. Calculation of new values for PPF and objective functions as described in step 7.
13. If $(k\leq iter^{max})$ go to step 9 and repeat for the overall best results from PSO.
14. Input the individual particle's best solution obtained from the PSO to the SSM algorithm. The total number of best solutions taken must be one greater than the number of total particles in a swarm and this is considered as the initial simplex.
15. Set simplex iteration counter *itr=1*.
16. Set the worst point (x_h), the best point (x_l) and the next to worst point (x_g) from the initial simplex.
17. Calculate the centroid and reflected points using (25) and (26). After this perform the expansion and contraction operations to get the new optimum points using (27-29).
18. Again checking of power demand constraint as done in step 5 and inequality constraint as done in step 6 for the new points obtained in step 7.
19. IF (convergence criterion using (30) is not met), replace the worst point (x_h) of the initial simplex with the new points obtained and increment the counter *itr=itr+1*.
20. Go to Step 17 and repeat to get best solution until the convergence criteria should be satisfied.
21. Calculate final fuel cost, emissions, power losses and MAPD again at different PPF and compute optimal solution as per (10).
22. STOP.

IV. RESULTS AND DISCUSSION

To study the effectiveness of the proposed algorithm, it is implemented on four areas, twelve generators system connected with six tie lines. The algorithm is developed in MATLAB 7.11.0.635 version on a personal computer of Intel i3, 3.2 GHz and 4 GB RAM. Different parameters for the proposed SPSO are taken as: Total particles in swarm =10, total members in one particle= number of generators + tie lines taken in each case, minimum and maximum inertia i.e., w^{min}= 0.4, w^{max} = 0.9, acceleration constants i.e., c_1 = c_2 =2, expansion factor (γ) = 2.0, contraction factor (β) = 0.5 and tolerance (∈) = 0.001.

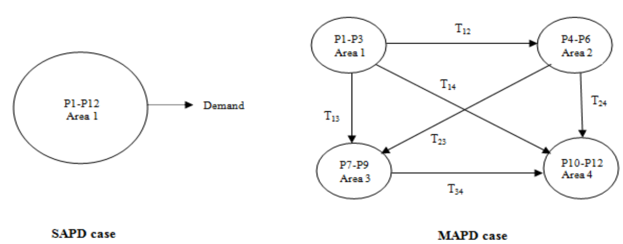

Fig. 1 Network models for *SAPD* and *MAPD* cases

The proposed algorithm is tested on two cases,

Single Area power Dispatch (SAPD) case: The whole power system is considered as single area with twelve generators and no tie lines in between before decomposing into the multiarea system.

Multi Area Power Dispatch (MAPD) case: The whole power system is decomposed into four areas with three generators in each area connected with six tie lines.

A four area test system [4, 11] is considered with three generators in each area connected using six tie lines. The power demand in the areas is 500,410, 580 and 600 MW with a total demand of 2090 MW in the region. The proposed algorithm is firstly applied for the *SAPD* and then for the *MAPD* considering transmission losses in both cases.

Table I and II shows the results obtained for *SAPD* and *MAPD* at different PPF.

TABLE I RESULTS OBTAINED FOR SAPD CASE AT DIFFERENT PPF WITH POWER DEMAND OF 2090 MW

<table>
<tr><th colspan="2">Unit power output (MW)</th><th>SAPD case</th></tr>
<tr><td colspan="2">P1</td><td>210</td></tr>
<tr><td colspan="2">P2</td><td>302.79</td></tr>
<tr><td colspan="2">P3</td><td>230.04</td></tr>
<tr><td colspan="2">P4</td><td>150</td></tr>
<tr><td colspan="2">P5</td><td>110</td></tr>
<tr><td colspan="2">P6</td><td>215</td></tr>
<tr><td colspan="2">P7</td><td>120.04</td></tr>
<tr><td colspan="2">P8</td><td>135.04</td></tr>
<tr><td colspan="2">P9</td><td>248.24</td></tr>
<tr><td colspan="2">P10</td><td>120.04</td></tr>
<tr><td colspan="2">P11</td><td>135.04</td></tr>
<tr><td colspan="2">P12</td><td>331.12</td></tr>
<tr><td colspan="2">Total Power</td><td>2307.34</td></tr>
<tr><td colspan="2">Power losses, (MW)</td><td>217.35</td></tr>
<tr><td colspan="2">Total Fuel cost ($/ hr.)</td><td>142545.03</td></tr>
<tr><td colspan="2">Total Emissions (Kg/ hr.)</td><td>2011.81</td></tr>
<tr><td rowspan="4">CEED with PPF ($/hr.)</td><td>min-max</td><td>172538.81</td></tr>
<tr><td>min-min</td><td>377600.54</td></tr>
<tr><td>max-max</td><td>264943.13</td></tr>
<tr><td>max-min</td><td>1414109.9</td></tr>
</table>

TABLE II RESULTS OBTAINED FOR MAPD AT DIFFERENT PPF

<table>
<tr><th rowspan="2">Area No.</th><th rowspan="2">Power Demand (MW)</th><th colspan="3">Gen. real power values (MW)</th><th rowspan="2">Power Losses (MW)</th><th rowspan="2">Fuel cost ($ /hr)</th><th rowspan="2">Emission (Kg/hr)</th><th colspan="4">CEED cost ($/hr.) with PPF</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>min-max</th><th>min-min</th><th>max-max</th><th>max-min</th></tr>
<tr><td>1</td><td>500</td><td>165</td><td>260</td><td>265</td><td>15.20</td><td>32537.51</td><td>308.31</td><td>37472.63</td><td>42582.02</td><td>38598.01</td><td>44897.80</td></tr>
<tr><td>2</td><td>410</td><td>150</td><td>75</td><td>175</td><td>4.30</td><td>25274.82</td><td>245.13</td><td>239549</td><td>52185.83</td><td>328018.57</td><td>64714.96</td></tr>
<tr><td>3</td><td>580</td><td>145</td><td>160</td><td>280</td><td>11.36</td><td>43714.27</td><td>651.00</td><td>59719.95</td><td>66868.57</td><td>64564.18</td><td>73525.39</td></tr>
<tr><td>4</td><td>600</td><td>145</td><td>160</td><td>280</td><td>15.80</td><td>37833.25</td><td>393.70</td><td>56970.15</td><td>70864.25</td><td>62887.23</td><td>80679.62</td></tr>
<tr><td>Total</td><td>2090</td><td colspan="3">2260</td><td>46.67</td><td>139359.86</td><td>1598.14</td><td>393711.74</td><td>232500.67</td><td>494067.99</td><td>263817.77</td></tr>
</table>

TABLE III RESULTS FOR POWER FLOW AND TRANSMISSION COST ON TIE LINES IN MAPD CASE

Tie Line Power (in MW)	**PT12**	**PT13**	**PT14**	**PT23**	**PT24**	**PT34**
From Area	1	1	1	2	2	3
To Area	2	3	4	3	4	4
Power transmitted (MW)	15.238045	50	15.238045	15.238045	15.238045	15.238045
Transmission cost, TC ($/hr.)	10.8093	37.7343	4.2061	10.3573	9.9824	2.4779

From the results in Table I and II, it is concluded that the minimum combined economic emission dispatch (CEED) cost in *SAPD* is obtained using min-max PPF and in *MAPD* using min-min PPF. Table III shows the results obtained for the power flow and transmission cost on tie lines in *MAPD* case.

TABLE IV COMPARISON OF RESULTS OBTAINED FOR SAPD AND MAPD

Unit power output (MW)	SAPD (with min-max PPF)	MAPD (with min-min PPF)
P1	210	165
P2	302.79	260
P3	230.04	265
P4	150	150
P5	110	75
P6	215	175
P7	120.04	175
P8	135.04	160
P9	248.24	280
P10	120.04	175
P11	135.04	160
P12	331.12	280
Total Power	2307.34	2320
PT12	…	15.24
PT13	…	50
PT14	…	15.24
PT23	…	15.24
PT24	…	15.24
PT34	…	15.24
Transmission cost (TC) ($/hr.)	…	75.57
Power losses (P_L) (MW)	217.35	43.804
Total Fuel cost, ($/hr.)	142545.03	134557.603
Total operating cost (TOC) ($/hr.)	…	134633.1704
Total Emissions, (Kg/hr.)	2011.81	1473.935
CEED, ($/hr.)	172538.81	232500.6653

Table IV shows the comparison of the results for both the cases. It is observed that the fuel cost and emissions obtained are 134557.603 $/hr. and 1473.935 Kg/hr. in case of MAPD which are much less when compared with SAPD. So, it is recommended to connect the multi areas to get less fuel cost and pollutants emissions while satisfying the whole system constraints and power demand through tie lines. Fig. 2 graphically shows the comparison of fuel cost and pollutants emission for both the cases and Fig. 3 shows this comparison for different areas in the region.

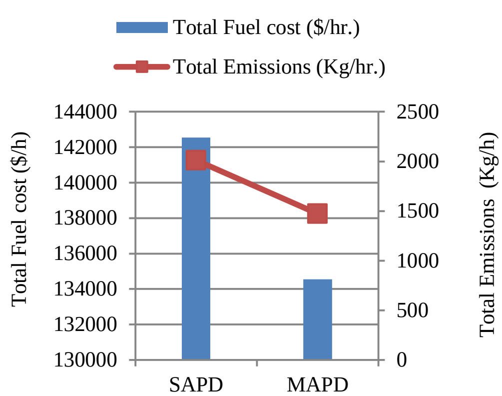

Fig. 2 Comparison of fuel cost and emission for *SAPD* and *MAPD* case

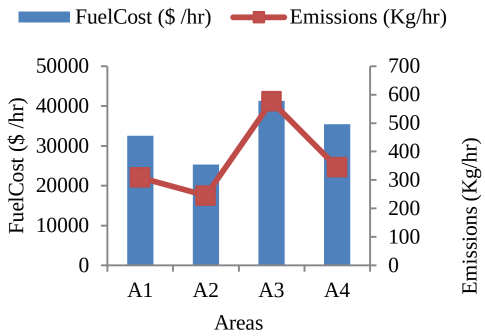

Fig. 3 Comparison of fuel cost and emission for *MAPD* case

From the comparison of results shown in Table V and graphically in Fig. 4, it is observed that for MAPD using SPSO, fuel cost obtained is 134557.6 $/hr. and pollutants' emission are 1473.935 Kg/hr. which are comparatively lower when compared with methods like Lagrange's decomposition-coordinating method (LDCM) [11] and Particle Swarm Optimization (PSO) [4].

TABLE V COMPARISON OF RESULTS OBTAINED FOR MAPD USING SPSO WITH THE OTHER AVAILABLE METHODS

Unit power output (MW)	**SPSO**	**LDCM [11]**	**PSO [4]**
P1	165	131.45	160.9
P2	260	209.49	163.3
P3	265	202.25	289.4
P4	150	150	109.6
P5	75	110	117.1
P6	175	191.63	184.4
P7	175	175	171.5
P8	160	215	197.5
P9	280	236.38	198.3
P10	175	164.09	230
P11	160	180.2	144.8
P12	280	306.18	211.5
Total Power	2320	2271.67	2178.3
PT12	26.67	9.9944	77.94
PT13	50	9.9944	0
PT14	26.67	9.9944	18.35
PT23	26.67	9.9881	46.99
PT24	26.67	9.9881	8.45
PT34	26.67	9.9876	12.25
P_L, (MW)	43.804	61.82	48.22
Total Fuel cost ($/hr.)	134557.6	144058.2	136598.3
Total Emissions (Kg/hr.)	1473.935	1923.7	3713.93
CEED ($/hr.)	232500.67	266400.92	277258.2

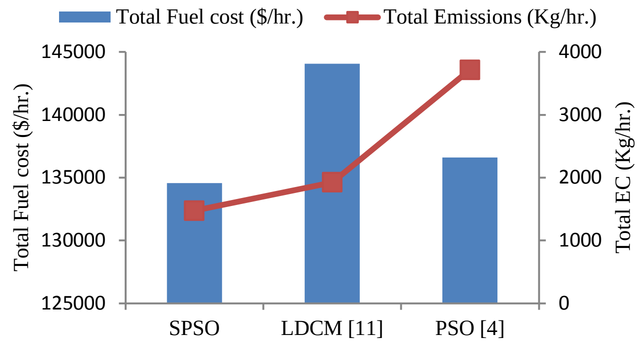

Fig. 4 Comparison of MAPD solution for fuel cost and emissions with other methods

Thus the proposed SPSO method shows its effectiveness as compared to other methods available in literature in terms of fuel cost, pollutants' emission and CEED.

VI. CONCLUSION

This paper presents a new approach for solving multiarea power dispatch (MAPD) problem which includes the objectives of minimizing the overall fuel cost and pollutants' emissions in the whole region. Simplex based modified particle swarm optimization (SPSO) is used to achieve the optimal solution. Hybridization of particle swarm optimization (PSO) and simplex search method (SSM) is done to improve the results obtained from stochastic approach by deterministic approach, i.e., the global solution is further improved using local search. The tie line power flow limits and transmission losses are also considered for the practical aspect of power system. For converting the non-interactive objectives problem, an approach of price penalty factor method is used, which convert the multiobjective problem into multicriteria problem. A comparative analysis of the proposed method is made with the conventional PSO and Lagrange decomposition method available in the literature. The SPSO is effectively tested on both single area power dispatch (SAPD) and MAPD. The results of both are compared and it is concluded that the interconnection of small areas is benefitted economically and as per from environmental aspects also. Also, it has been observed that the hybridization of PSO with SSM helps in achieving the overall improved results.

REFERENCES

[1] J.H. Talaq, F. El-Hawary and M.E. El-Hawary, "A summary of environmental/economic dispatch algorithms", *IEEE Transactions on Power Systems*, Vol. 9, No. 3, pp. 1508-1516, 1994.

[2] J. Kennedy and R. Eberhart, "Particle swarm optimization" *Proc. IEEE Conf. on Neural Networks (ICNN'95) IV, Perth Australia*, pp. 1942-48, 1995.

[3] D. Streiffert, "Multi-Area Economic Dispatch with Tie Line Constraints", *IEEE Transactions on Power Systems*, Vol. 10, No. 4, pp. 1946-1951, 1995.

[4] A.J. Wood and B.F., "Wollenberg, Power Generation, Operation, and Control", 2nd edition, Prentice-Hall Series in Electrical and Computer Engineering, John Wiley & Sons, 1996.

[5] T. Jayabarathi, G. Sadasivam and V. Ramachandran, "Evolutionary Programming Based Multi-Area Economic Dispatch with Tie-Line Constraints", *Electrical Machines and Power Systems*, Vol. 28, pp. 1165-1176, 2000.

[6] L. Wang and C. Singh, "Reserve-Constrained Multiarea Environmental/Economic Dispatch Using Enhanced Particle Swarm Optimization", *Systems and Information Engineering Design Symposium IEEE*, pp. 96-100, 2006.

[7] P.S. Manoharan, P.S. Kannan, S. Baskar and M.W. Iruthayarajan, "Evolutionary Algorithm Solution And KKT Based Optimality Verification To Multi-Area Economic Dispatch", *International Journal of Electrical Power and Energy Systems*, Vol. 31, pp. 365–373, 2009.

[8] Y.M. Chen and W.S. Wang, "A Particle Swarm Approach To Solve Environmental/Economic Dispatch Problem" International Journal of Industrial Engineering Computations, Vol. 1, pp. 157–172, 2010.

[9] Y.M. Chen and W.S. Wang, "Application of Particle Swarm Optimization Algorithm to the Distributed Multi-Area Service Demands and Emission Controlled", *International Journal of Industrial Engineering*, Vol. 17, No. 4, pp. 279–286, 2010.

[10] K. Deb, "*Optimization for Engineering Design: Algorithms and Examples*", PHI Eleventh Edition, New Delhi, 2010.

[11] M. Sharma, M. Pandit and L. Srivastava, "Multi-Area Economic Dispatch With Tie-Line Constraints Employing Evolutionary Approach", *International Journal of Engineering, Science and Technology*, Vol. 2, No. 3, pp. 132-149, 2010.

[12] D.P. Kothari and J.S. Dhillon, "*Power System Optimization*", PHI Second Edition, New Delhi, 2011.

[13] M. Basu, "Artificial Bee Colony Optimization For Multi-Area Economic Dispatch", *International Journal of Electrical Power and Energy Systems*, Vol. 49, pp. 181–187, 2013.

[14] B. Hadji, B. Mahdad, K. Sriari and N. Mancer, "Multiobjective PSO-TVAC For Environmental/ Economic Dispatch Problem" *Energy Procedia*, Vol. 74. pp. 102 – 111, 2015.

[15] V.K. Jadoun, N. Gupta, K.R. Niazi, A. Swarnkar and R.C. Bansal, "Improved Particle Swarm Optimization for Multi-area Economic Dispatch with Reserve Sharing Scheme", *IFAC-Papers On Line*, Vol. 48-30, pp. 161–166, 2015.

[16] M. Basu, "Group Search Optimization For Combined Heat And Power Economic Dispatch", *International Journal of Electrical Power & Energy Systems*, Vol. 78, pp. 138–147, 2016.

[17] S. Krishnamurthy and R. Tzoneva, "Decomposition-Coordinating Method for Parallel Solution of a Multi Area Combined Economic Emission Dispatch Problem", *International Journal of Electrical and Computer Engineering (IJECE)*, Vol. 6, No. 5, pp. 2048-2063, 2016.

[18] M. Singh and J.S. Dhillon, "Multiobjective Thermal Power Dispatch Using Opposition-Based Greedy Heuristic Search", *International Journal of Electrical Power & Energy Systems*, Vol. 82, pp. 339–353, 2016.

[19] N.J. Singh and J.S. Dhillon, D.P. Kothari, "Synergic Predator-Prey Optimization For Economic Thermal Power Dispatch Problem" *Applied Soft Computing*, Vol. 43, pp. 298–311, 2016.

[20] J. Li, Q. Pan, P. Duan, H. Sang and K. Gao, "Solving Multi-Area Environmental/economic Dispatch By Pareto-Based Chemical-Reaction Optimization Algorithm", *IEEE/CAA Journal of Automatica Sinica*, Vol. 1, pp. 1-11, 2017.