International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 9, Issue 11 (February 2014), PP. 15-23

Economic Load Dispatch Solution Including Transmission Losses Using MOPSO

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Abstract:- Economic Dispatch is an important task in power system. It is the process of allocating generation among the committed units such that the constraints imposed are satisfied and the energy requirements are minimized. This paper presents efficient approach for Dynamic Economic Load Dispatch (DELD) solution with transmission losses based on Multi Objective Particle Swarm Optimization (MOPSO). The main objective is to determine the most economic dispatch of on line generating units with the predicted load demands over a certain period of time.The proposed algorithm evaluates a set of Pareto solutions systematically and preserves the diversity of Pareto by crowding entropy diversity. The crowding entropy strategy is able to measure the crowding degree of the solutions more accurately and efficiently. Here, an attempt is made to find the minimum cost using MOPSO method for 6 and 15 unit test systems with continuous demands for 24 hours. The effectiveness and feasibility of the proposed method is demonstrated in this paper. The MATLAB results are compared with the recent reports using Brent method in terms of solution quality. Numerical results indicate an improvement in total fuel cost saving and hence the superiority of the proposed is also revealed for dynamic economic dispatch problems.

Keywords:- MOPSO, Dynamic Economic Load Dispatch, Pareto Optimal Solution, Transmission Loss.

I. INTRODUCTION

Power systems should be operated under a high degree of economy for competition of deregulation. Unit commitment is an important optimization task addressing this crucial concern for power system operations. Since Economic Dispatch (ED) is the fundamental issue during unit commitment process, it should be important to obtain a higher quality solution from ED efficiently. The primary objective of the economic dispatch problem is to schedule the generations of the online thermal units so as to meet the required load demand at minimum operating cost while satisfying the unit and system equality and inequality constraints. Dynamic Economic Dispatch (DED) is an extension of the economic dispatch problem and it aims to schedule the online thermal units with the predicted load demands over a scheduling period at minimum operating cost. DED problem is formulated as minimization of total fuel cost is the main objective while satisfying system constraints. The DED problem has been formulated as a second order quadratic optimization problem that takes into the consideration of the ramp rate limits of the generating units [1-2].

These evolutionary based methods are heuristic population-based search procedures that incorporate random variation and selection operators. Although, these methods seem to be good approaches to find a feasible and reasonable solution for the DED problem, however, when the system has a highly epistatic objective function (i.e. where parameters being optimized are highly correlated), and number of parameters to be optimized is large, then they have degraded effectiveness to obtain the global optimum solution. In recent years, the particle swarm optimization (PSO) technique is used to find the optimal solution of DED problem [3].

In order to overcome premature convergence and to speed up the searching process, a new Multi Objective PSO (MOPSO) technique is developed and proposed for the solution of the DED problem in this paper. In general changing standard single objective PSO to a MOPSO needs redefinition of global and local best particles in order to obtain a front of optimal solutions. There is no absolute global best in MOPSO, but rather a set of non dominated solutions. Also, there may be no single local best particle for each individual of the swarm. Selecting the global best and local best to guide the swarm particles becomes nontrivial task in multiobjective domain. Thus, for non-dominance solutions sorting the Pareto archive maintains approach and to ensure proper diversity amongst the solutions of the nondominated solutions in Pareto archive maintains the crowding distance method is used, two approaches namely niche count and crowded distance method [4] are used. To illustrate the robustness of the proposed MOPSO algorithm and their ability to provide efficient solution for the DED problem, it is tested on two test power systems, including 6 and 15 unit generating in comparison with the performance of Brent method [5]. The results evaluation reveals that the proposed MOPSO algorithm achieves good quality solution for DED problem and is superior to the Brent method one.

II. PROBLEM FORMULATION

The DED problem is formulated as the minimization of total fuel cost of generating units for the entire scheduling period subject to variety of constraints. The DED problem formulation is as follows.

A. Objective function

The main objective of DED problem is to minimize the generation cost of 'n' online thermal units over a scheduling period 'T' is given as,

$$\min \sum_{t=1}^{T} \sum_{i=1}^{N} FC_i(P^t{}_i) \quad \text{... (1)}$$

Where, FCi,t is the fuel cost of unit i at time interval t in $/h and Pi,t is the real power output of generating unit i at time period t in MW.

The fuel cost (FC) of generating unit at any time interval't' is normally expressed as a quadratic function is as,

$$F_i(P^t{}_i) = a_i + b_i P_i + c_i P_i^2 \qquad \text{... (2)}$$

Where, ai, bi and ci are the cost coefficients of generating unit i.

B. Constraints

The objective function is minimized subject to variety of constraints.

1) Power balance constraint

This constraint is based on the principle of equilibrium that the total generation at any time interval 't' should satisfy the load demand at the interval 't' and transmission loss. This constraint is mathematically expressed as,

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

Where, PD,t and PL,t are the load demand and transmission loss in MW at time interval 't' respectively.

The transmission loss can be expressed using through B coefficients.

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

Where, Bij, B0i and B00 are the loss coefficients.

2) Generator operational constraints

The generating unit operational constraints such as minimum/maximum generation limit, ramp rate limits and prohibited operating zones are as follows.

a) Generator capacity constraint

$$P_{i,min} \leq P_i \leq P_{i,max} \quad \text{... (5)}$$

Where, Pi,min and Pi,max are the minimum and maximum real power generation of unit i in MW.

b) Ramp rate limits

The inequality constraints due to ramp rate limits for unit generation changes are given

1) as generation increases

$$P_i - P_i^0 \leq UR_i \quad \text{... (6)}$$

2) as generation decreases

$$P_i - P_i^0 \leq DR_i \quad \text{... (7)}$$

The generator operation constraint after including ramp rate limit of generators can be described as,

$$\max(P_{i,min}, P_i^0 - DR_i) \leq P_i \leq \min(P_{i,max}, P_i^0 + UR_i) \quad \text{...(8)}$$

where, P_i^0, DR_i and UR_i are the real power output of generator i before dispatched hour in MW, down ramp and up ramp limit of generator i in MW/h respectively.

III. MULTI OBJECTIVE PARTICLE SWARM OPTIMIZATION

3.1. PSO Overview

Particle swarm optimization (PSO) is a population-based optimization method first proposed by Kennedy and Eberhart in 1995, inspired by social behavior of bird flocking or fish schooling [6]. The PSO as an optimization tool provides a population-based search procedure in which individuals called particles change their position (state) with time. In a PSO system, particles fly around in a multidimensional search space. During flight, each particle adjusts its position according to its own experience (This value is called Pbest), and according to the experience of a neighboring particle (This value is called Gbest), made use of the best position encountered by itself and its neighbor (Figure 1).

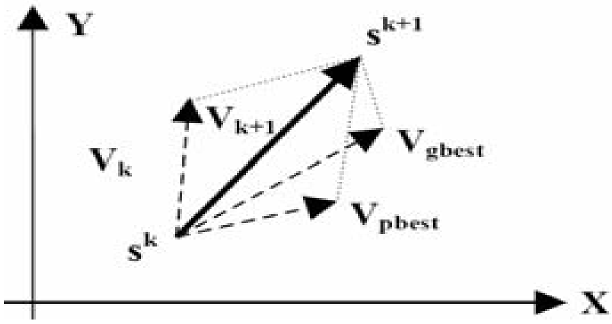

Figure 1: Concept of a searching point by PSO

This modification can be represented by the concept of velocity. Velocity of each agent can be modified by the following equation:

$$v_{id}^{k+1} = \omega v_{id}^{k} + c_1 \text{ rand}* \left(pbest_{id} - s_{id}^{k}\right) + c_2 \text{ rand}* \left(gbest_{d} - s_{id}^{k}\right) \quad (9)$$

Using the above equation, a certain velocity, which gradually gets close to pbest and gbest can be calculated. The current position (searching point in the solution space) can be modified by the following equation:

$$s_{id}^{k+1} = s_{id}^{k} + v_{id}^{k+1} \quad (10)$$

where s^k is current searching point, s^{k+1} is modified searching point, $v^k$is current velocity, $v^{k+1}$is modified velocity of agent i, v_{pbest} is velocity based on pbest, , v_{gbest} is velocity based on gbest, n is number of particles in a group, m is number of members in a particle, $pbest_i$ is pbest of agent i, $gbest_i$ is gbest of the group, ω_i is weight function for velocity of agent i, C_i is weight coefficients for each term. Appropriate value ranges for C1 and C2 are 1 to 2, ω_i is taken as 1.

3.2 MULTI OBJECTIVE PSO (MOPSO)

A lot of realistic life problems entail simultaneous optimization of some objective functions. In general, these functions are non-commensurable and often competing and conflicting objectives. The application of a multi objective optimizer makes it possible to envisage the trade off among different conflicting objectives to direct the engineer in making his compromise and gives rise to a set of optimal solutions, in place of one optimal solution. The concept of Pareto dominance formulated by Vilfredo Pareto is used for the evaluation of the solutions [7].

The solutions that are nondominated within the whole search space are signified as Pareto-optimal and constitute the Pareto-optimal set. This set is also known as Pareto optimal front. Pareto dominance concept classifies solutions as dominated or non-dominated solutions and the "*best solutions*" are selected from the non-dominated solutions. The implemented algorithm is the non-dominated sorting PSO which is currently used in many other practical design problems. To sort non-dominated solutions, the first front of the non-dominated solution is assigned the highest rank and the last one is assigned the lowest rank. When comparing solutions that belong to a same front, another parameter called crowding distance [17] is calculated for each solution. The crowding distance is a measure of how close an individual is to its neighbours.

Large average crowding distance will result in better diversity in the population. In order to investigate multi-objective problems, some modifications in the PSO algorithm were made. A multiobjective optimization algorithm must achieve: guide the search towards the global Pareto-optimal front and maintain solution diversity in the Pareto-Optimal front. The main steps of the MOPSO algorithm for DED problem are explained in more detail as follows:

Step 1: Input parameters of system, and specify the lower and upper boundaries of each variable.
Step 2: Initialize randomly the speed and position of each particle and maintain the particles within the search space.
Step 3: For each particle of the population, employ the Newton-Raphson power flow analysis method to calculate power flow and system transmission loss, and evaluate each of the particles in the population.
Step 4: Store the positions of the particles that represent non-dominated vectors in the repository NOD.
Step 5: Generate hypercubes of the search space explored so far, and locate the particles using these hypercubes as a coordinate system where each particle's coordinates are defined according to the values of its objective function.
Step 6: Initialize the memory of each particle in which a single local best for each particle is contained.
Step 7: Update the time counter $t=t+1$.
Step 8: Determine the best global particle *Gbest* for each particle *i* from the repository NOD. First, those hypercubes containing more than one particle are assigned a fitness value equal to the result of dividing any

number *x*>1 by the number of particles that they contain. Then, we apply crowding distance method using these fitness values to select the hypercube from which we will
take the corresponding particle. Once the hypercube has been selected, we select randomly a particle as the best global particle *Gbest* for particle *i* within such hypercube.
Step 9: Compute the speed and its new position of each particle using Equations (12) and (13), and maintain the particles within the search space in case they go beyond its boundaries.
Step 10: Evaluate each particle in the population by the Newton-Raphson power flow analysis method.
Step 11: Update the contents of the repository NOD together with the geographical representation of the particles within the hypercubes.
Step 12: Update the contents of the repository *Pbest*.
Step 13: If the maximum iterations *iter*max are satisfied then go to Step 14,otherwise, go to step7.
Step 14: Input a set of the Pareto-optimal solutions from the repository NOD.

3.3. Non-Dominated Sort

The initialized population is sorted based on nondomination. The fast sort algorithm as given in [8] is used here for NOD.

3.4. Crowding Distance

Once the non-dominated sort is complete, the crowding distance is assigned. As the individuals are selected based on rank and crowding distance all the individuals in the swarm are assigned a crowding distance value. Crowding distance is allocated front wise and comparing the crowding distance between two individuals in different front is meaningless. The algorithm as given in [8] is used here for the crowding distance. The flowchart of the proposed MOPSO algorithm is shown in **Figure 2.**

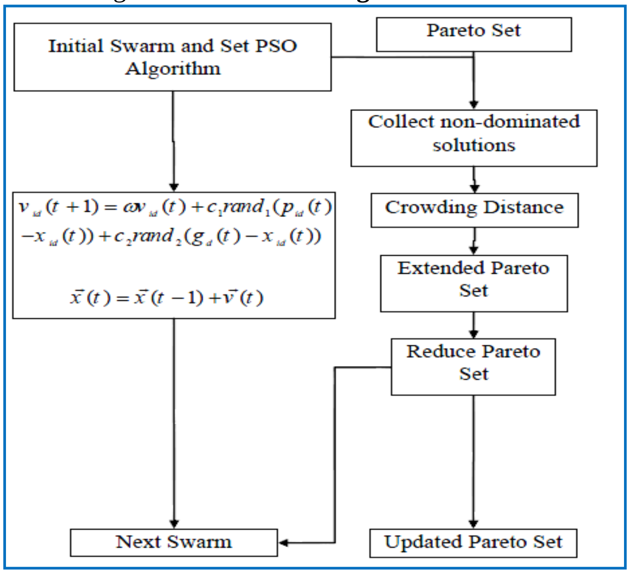

Figure 2: Flow chart for proposed MOPSO algorithm

IV. RESULTS AND DISCUSSIONS

The proposed methodology for solving DED problem is implemented in Matlab 7.8 platform and executed with personal computer. The effectiveness of the proposed methodology has been tested with two different scales of power system cases. The six unit and fifteen unit system are considered for the analysis. The generating unit operational constraint, ramp rate limits and transmission loss are considered. The results obtained from the proposed method were compared in terms of the solution quality and computation efficiency with the Brent method [9]. In each test system, 30 independent runs were made for each of the optimization methods.

Case 1: Six unit system

The system contains six thermal units and the details including cost coefficients, generation limits, ramp rate limits, transmission loss coefficients and forecasted load demand of each interval are presented in the literature [10]. The transmission loss is calculated using B coefficients. The one day scheduling period is divided into 24 intervals. The optimal dispatch of generating units is determined by MOPSO. The minimum and maximum operating limit of each generating unit is obtained by enforcing the ramp down and ramp up limits of generating unit with the real power dispatch of previous interval. The proposed method is applied to the electrical network on IEEE 30 bus including six thermal generating units as shown in Figure 3 to assess the suitability of the algorithm. The fuel cost (in \$/hr), ramp rate limits and data of predicted power demands is extracted from [11] are given in Tables 1-3, respectively.

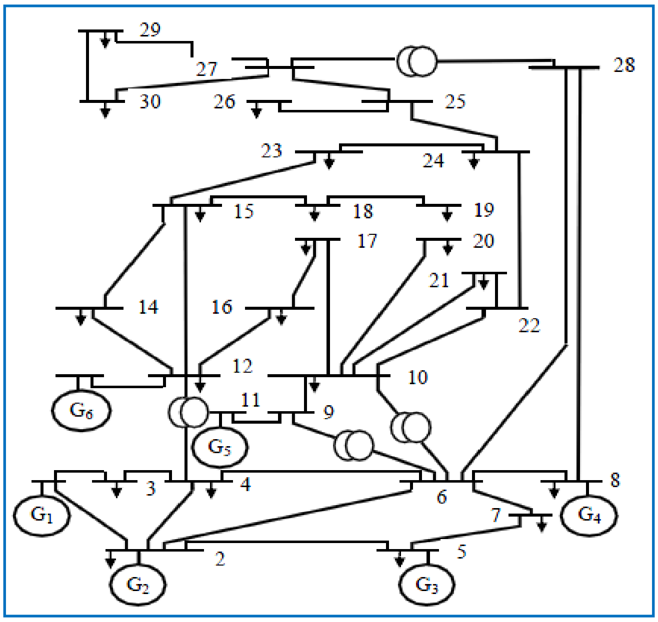

Figure 3: IEEE 6 unit test system

Table 1: Fuel cost of six units system

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

Table 2: Ramp rate limits of six units system

Unit	P_i^0 (MW)	UR_i (MW/h)	DR_i (MW/h)
1	340	80	120
2	134	50	90
3	240	65	100
4	90	50	90
5	110	50	90
6	52	50	90

Table 3: Predicted power demand of six units in 24 hours

H	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
PD (MW)	955	942	935	930	935	963	989	102.3
H	9	10	11	12	13	14	15	16
PD (MW)	112	6115	120	1123	5119	125	1126	3125
H	17	18	19	20	21	22	23	24
PD (MW)	122	1120	2115	9109	2102.3	984	975	960

Table 4 and figure 4 represents the optimal output powers and power loss for all power demands using the proposed MOPSO method and also it is clear that this technique provides better solutions for DED problem compared with the other reported methods in the paper. Figure 5 represents the generation of each unit in 6 unit test system for 24 hours.

Table 4: Output power for all power demands of 6-unit system in MW

T \ U	1	2	3	4	5	6
1	380.3484	124	211	84	113	50
2	377	121	209.1497	82	110	50
3	375	120	208.0632	80	109	50
4	374	119	206..9952	79	108	50
5	375	120	208.0632	80	109	50
6	382	125	213.4453	86	114	50
7	389	130	217.8196	91	119	50
8	397	136	224.3228	98	126	50
9	419	152	241.8625	116	143	64
10	424	156	245.2431	120	147	68
11	434	164	254.0921	128	155	77
12	441	169	256.6832	134	161	82
13	432	162	251.9155	126	154	75
14	445	171	261.9562	137	163	85
15	447	173	264.1730	139	165	87
16	445	171	261.9535	136	163	85
17	439	167	257.4419	131	158	80
18	435	164	254.1117	128	155	77
19	426	157	247.3925	121	148	70
20	412	147	236.3508	110	138	58
21	397	136	224.3228	98	126	50
22	388	129	216.7470	90	118	50
23	385	127	215.6239	88	117	50
24	381	125	212.4087	85	114	50

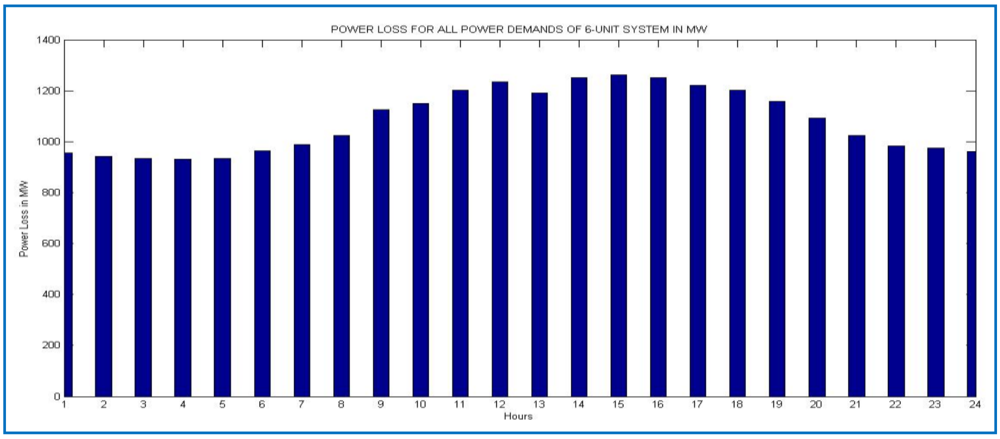

Figure 4: Power Loss for all power demands of 6-unit system in MW

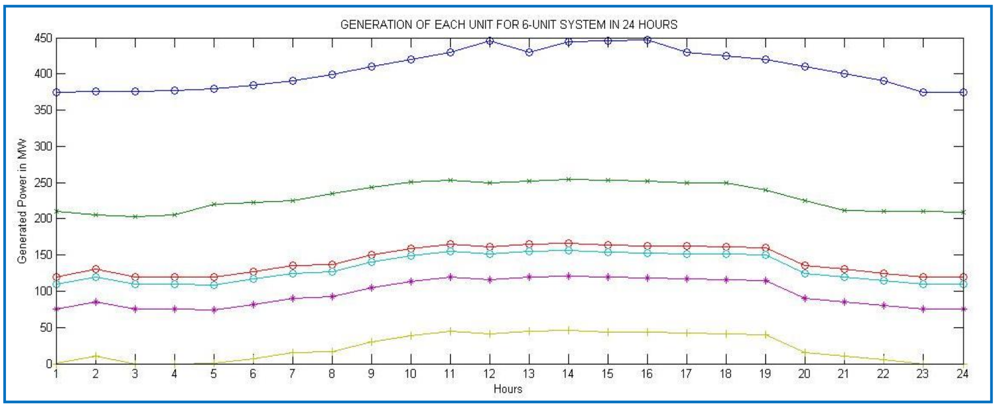

Figure 5: Generation of each unit for 6-unit system in 24 hours

Case 2: Fifteen unit system

The system contains 15 thermal units and the details including cost coefficients, generation limits, ramp rate limits, transmission loss coefficients and forecasted load demand of each interval are presented in the literature [12]. The transmission loss is calculated using B coefficients. The one day scheduling period is divided into 24 intervals. The optimal dispatch of generating units is determined by MOPSO. The minimum and maximum operating limit of each generating unit is obtained by enforcing the ramp down and ramp up limits of generating unit with the real power dispatch of previous interval. The proposed method is applied to the electrical network on IEEE 69 bus including 15 thermal generating units as shown in Figure 6 to assess the suitability of the algorithm.

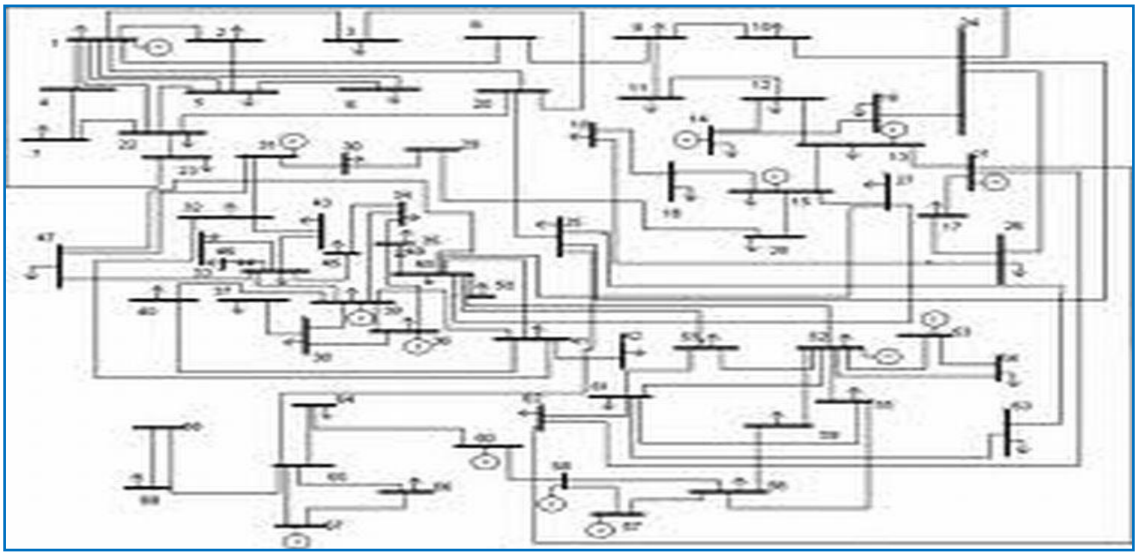

Figure 6: IEEE 69 bus system with 15 thermal generating units

Table 5 and figure 7 represents the optimal output powers and power loss for all power demands using the proposed MOPSO method and also it is clear that this technique provides better solutions for DED problem compared with the other reported methods in the paper. Figure 8 represents the fuel cost for the 15-unit system and Figure 9 represents the generation of each unit in 15 unit test system for 24hours.

Table 5: Output power for all power demands of 15-unit system in MW

H	OUTPUT POWER IN MW															LOSS MW
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	
1	204.43	388.14	130	90.96	190.56	460	454.37	60	66.01	33.71	66.74	21.16	25	20.44	46.15	21.6640
2	172.45	455	130	130	202.6	361.28	406.86	76.11	47.08	25	80	60.35	77	16.94	19.42	19.7916
3	155.32	402.06	91.55	120.52	162.68	460	452.56	65.56	65.09	25	36.62	80	58.14	53.17	17.51	19.5049
4	313.71	196.95	130	130	195.49	395.55	465	60	43.43	25	80	80	76.07	44.87	15.07	18.8160
5	322.28	455	82.35	130	193.91	460	397.14	60	30.44	25	68.62	27.81	34.97	16.30	15.04	20.5173
6	185.72	449.02	130	116.93	173.32	453.32	465	60	34.23	48.05	40.61	80	31.64	33.24	36.31	21.0411
7	246.93	381.80	130	130	158.21	460	465	60	88.46	26.52	67.02	80	28.08	15.22	15	20.9092
8	261.95	455	130	130	177.51	460	465	60	83.43	25.02	63.73	80	25	34.13	15.86	22.1049
9	455	455	114.44	112.68	207.20	460	465	67.36	35.76	40.60	55.34	80	46.83	44	17.10	26.3608
10	455	455	130	130	248.08	460	465	67.46	84.45	31.01	80	80	31.32	22.89	16.84	28.0837
11	455	455	130	130	254.67	460	465	60	25.34	145.2	80	70.34	25	15	15	31.1440
12	455	455	129.94	129.26	262.74	457.85	444.69	60.1	25.25	150.15	80.63	65.07	25.01	15.01	15.03	31.2921
13	455	455	127.73	128.32	265.11	429.34	465	63.31	76.49	55.31	68.77	80	25.63	15.94	16.23	29.2897
14	455	455	130	130	280.85	457.04	465	64.81	26.93	157.60	77.81	75.07	25	15	15	33.4710
15	455	452.64	128.03	127.40	390	460	458.91	70	25.70	157.88	75.05	75.72	26.32	15.22	15.78	39.3182
16	455	455	130	130	360.23	460	465	65	75.53	160	80	80	25.95	15	15.20	40.4463
17	455	451.29	128.07	126.44	370	455	455.55	62.80	35.15	158.22	76.98	78.27	25.06	15.16	15.57	37.9225
18	450	455	130	130	290.23	457.76	465	60	25	134.23	80	73.19	25	15	15	32.3263
19	455	455	128.97	130	185.43	460	465	56.44	25	123.56	80	43.54	25.54	15.78	15.01	28.0054
20	454.43	454.87	127.98	128.99	150	460	465	60	25	93.54	69.56	38.65	25	15	15	25.6883
21	455	435.43	129.76	129.90	136.98	404.32	455	60	25	49.34	44.76	61.54	25	15	15	22.5091
22	435.65	445	130	130	150	373.76	430	60	25	25.21	27.76	20	25	15	15	21.2422
23	455	231.98	111	68.42	156.32	460	309.33	9321.29	42.96	66.96	77.35	62.23	77.36	47.70	22.45	19.4106
24	95.63	325.49	130	125.10	184.70	380.16	460.07	60	42.95	26.42	67.23	80	35.40	42	18.92	19.3458

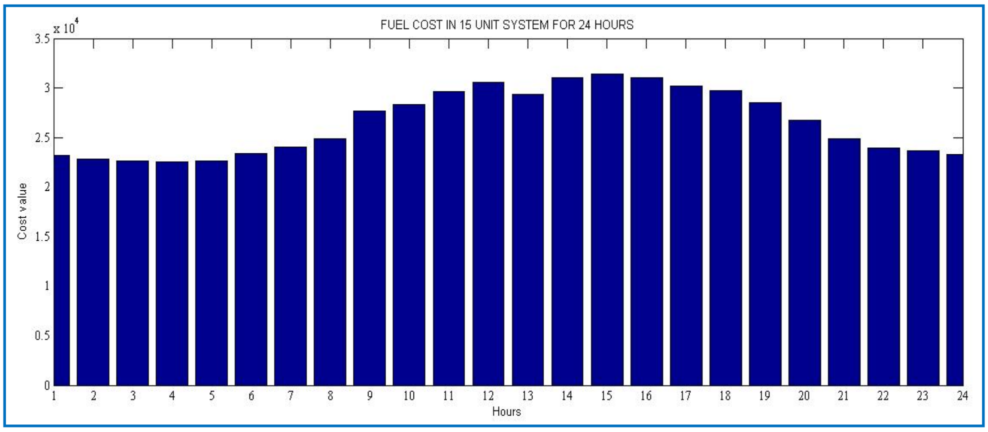

Figure 7: Fuel cost of 15-unit system for 24 hours

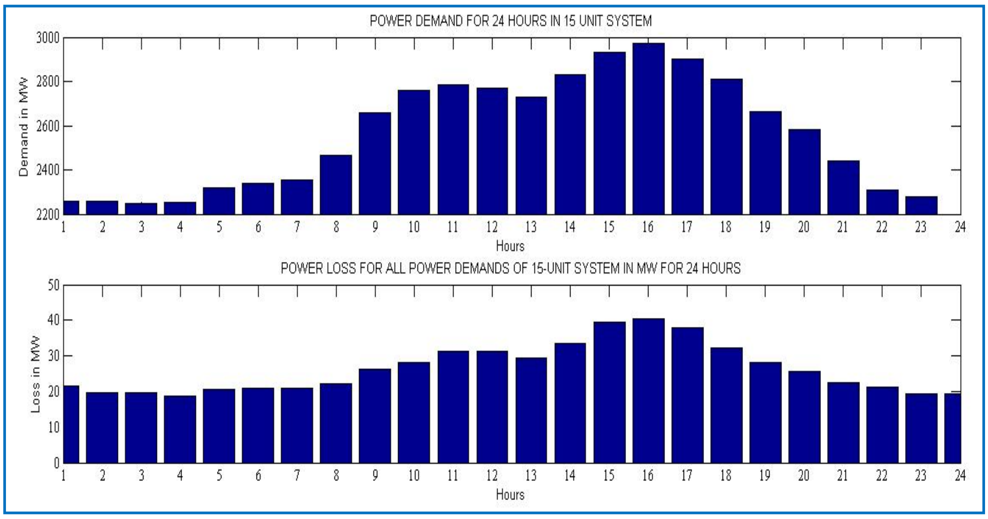

Figure 8: Power demand & Power loss of 15-unit system in MW

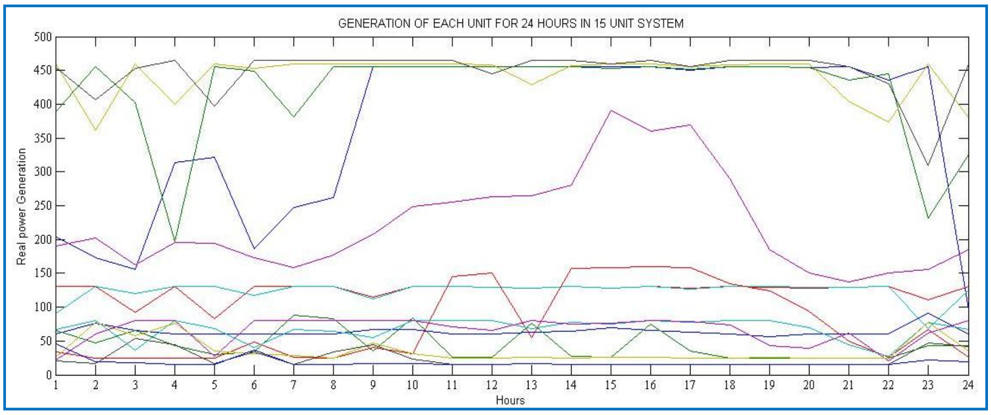

Figure 9: Generation of each unit for 24 hours in 15-unit system

V. CONCLUSION

A MOPSO optimization technique has been successfully applied for the solution of the dynamic economic dispatch in power system in this paper. The proposed MOPSO algorithm addresses is a multiobjective version of the standard PSO technique and make uses of its efficacy for the solution of multiobjective optimization problems. The DED problem has been formulated with competing fuel cost and transmission losses objectives. The successful implementation of the approach on two different test systems (6-unit and 15-unit) has resulted as better one when compared with the previous meta heuristic algorithms. From these comparative studies, it is apparent that the MOPSO can be successfully applied to solve DED problems in the real-world power systems.

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