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Combined Heat and Power Economic Dispatch Using Hybrid Constriction Particle Swarm Optimization

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***Abstract*— The Combined Heat and Power Economic Load Dispatch (CHPED) is an optimization problem to minimize the cost while ensuring the minimum transmission loss and fulfilling the power and heat demand. This paper presents the hybrid constriction particle swarm optimization (HCPSO) technique to solve CHPED with bounded feasible operating region. The main potential of this technique is that it enhances the balance between global and local search area in comparison to PSO. A comparative analysis of the proposed technique with PSO, evolutionary programming (EP), differential evolution (DE), and classic particle swarm optimization (CPSO) respectively is presented.**

Keywords*— *Combined Heat And Power; Economic Load Dispatch; Hybrid Constriction Particle Swarm Optimization

I. INTRODUCTION

With the rising standard of living being the consumption and dependencies on conventional and non-conventional form of energy is increasing day by day. But the excessive use of non-conventional form of energy is a great matter of concern for the society as it is having hazardous impact on the environment like greenhouse effect etc. This has forced the power industry to make optimal utilization of the fuels. Combined Heat and Power is one of the most efficient and reliable method for generation of heat and power. The generated heat can be efficiently used to support local industry development and thus increasing the overall efficiency of the power plant. In combined heat and power, the heat and power demands are to be met simultaneously which make the CHPED complex. Number of techniques has been evolved in last decades to solve this complex CHPED problem.

Several methods which have been used to find out CHPED with constraints are Mixed Integrating Programming, Lagrange Relaxation etc. But all these methods have drawbacks like problems related to constraints handling, convergent problem etc. So, to overcome the above mentioned problem of traditional techniques some alternative approaches have to be used. These alternative approaches include Genetic Algorithm (GA), PSO, EP, DE, etc [1- 6]. PSO is an active random search technique that traverses good regional solution very quickly. The main problem with PSO is that it cannot go out of regional optimal solution to reach the global solution [12-13]. The concurrence towards a stable solution is the primary requirement of any search algorithm so a new factor has been introduced called constriction factor [8]. This paper presents the solution to CHPED problem by HCPSO.

II. PROBLEM FORMULATION OF CHPED

The main aim of CHPED problem is to obtain the optimal scheduling of power and heat with minimum cost while ensuring the heat and power constraints. Mathematically, the problem can be formulated as:

$$\text{Min FT}= \sum_{k=1}^{n_t} F_{t,k}\left(p_k\right)+\sum_{l=1}^{n_s} F_{s,l}\left(h_l\right)+\sum_{m=1}^{n_{co}} F_{co,m}\left(p_{m,} h_m\right) \quad (1)$$

Cost of thermal units can be defined as:

$$F_t\left(p_k\right)=a_k\left(p_k\right)^2+b_k\left(p_k\right)+c_k+|d_k \sin\left(e_k(p_k^{min}-p_k)\right)| \quad (2)$$

Cost of heat only units can be defined as:

$$F_s(h_l)=\delta_l(h_l)^2+\beta_l(h_l)+\gamma_l \quad (3)$$

Cost of cogeneration units can be defined as:

$$F_{co}(p_m, h_m)=\theta_m(p_m)^2+\sigma_m(p_m)+\rho_m+\mu_m(h_m)^2+\tau_m(h_m)+\varphi_m(p_m, h_m) \quad (4)$$

where n_t, n_s and n_{co} are the number of thermal, heat and cogeneration units respectively. F_t (p_k)represent cost of k_{th} thermal units for producing power. a_k, b_k, c_k cost coefficients of k_{th} thermal units. d_k, e_k are the cost coefficients of k_{th} thermal units including valve point effect. $F_s(h_l)$ represent cost of l_{th} for producing heat(h_l). λ_l , β_l , γ_l are cost coefficients of heat only units. $F_{co}(p_m,h_m)$ represent cost of m_{th} cogeneration units for producing heat(h_m) and power(p_m).

CHPED problem is subjected to following constraints:

A. *Equality Constraints*

Power balance constraints

$$\sum_{k=1}^{n_t} p(k)+\sum_{m=1}^{n_{co}} p(m) = p_L+p_D \quad (5)$$

where p_D is electrical power demand, p_L is power transmission loss and may be defined as:

$$p_L = \sum_{i=1}^{n_t}\sum_{j=1}^{n_t} p_i B_{ij} p_j+\sum_{r=1}^{n_t}\sum_{s=1}^{n_{co}} p_r B_{rs} p_s+\sum_{s=1}^{n_{co}}\sum_{t=1}^{n_{co}} p_s B_{st} p_t \quad (6)$$

where B_{ij}, B_{rs}, B_{st} are transmission loss coefficients.

Heat balance constraints

$$\sum_{l=1}^{n_s} h(l)+\sum_{m=1}^{n_{co}} h(m) = h_D \quad (7)$$

where h_D is heat demand.

B. Inequality Constraints

Limits of thermal only units

$$p_i^{min} \le p_i \le p_i^{max} \quad (8)$$

Limits of heat only units

$$h_i^{min} \le h_i \le h_i^{max} \quad (9)$$

Limits of CHP units

$$p_m^{min}(h_m) \le p_m(h_m) \le p_m^{max}(h_m) \quad (10)$$

$$h_m^{min}(p_m) \le h_m(p_m) \le h_m^{max}(p_m) \quad (11)$$

where, p_i^{min} and p_i^{max} are the minimum and maximum power limits of thermal units. h_i^{min} and h_i^{max} are the minimum and maximum limits of heat only units. $h_m^{min}(p_m)$ and $h_m^{max}(p_m)$ are the minimum and maximum heat limit of mth CHP which are the function of power produced. $p_m^{min}(h_m)$ and $p_m^{max}(h_m)$ are the minimum and maximum power limit of mth CHP which are the function of heat produced. $p_{m,}h_m$ coordinates should lie in the feasible operating region of cogeneration units as shown in Fig.1 and should satisfy the test system equations for two cogeneration units.

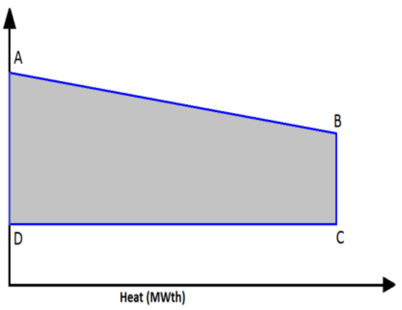

Fig.1. Feasible operating region of the cogeneration units

C. Constraints Handling

Power balance constraints in order to determine the actual cost of the system it is necessary to include the transmission losses. So to satisfy the equality constraint criterion for power a decision variable is arbitrarily chosen as dependent generator (d).

$$p_d = p_D - p_L - \sum_{k=1,k\neq d}^{n_t} p_k - \sum_{m=1}^{n_{co}} p_m \quad (12)$$

Heat balance constraints to satisfy the equality constraint criterion for heat a decision variable is arbitrarily chosen as dependent generator (d).

$$h_d = h_D - \sum_{l=1,l\neq d}^{n_s} h_l - \sum_{m=1}^{n_{co}} h_m \quad (13)$$

III. HYBRID CONSTRICTION PARTICLE SWARM OPTIMIZATION

PSO is population based stochastic search algorithm introduced by Kennedy & Eberhart in 1995[7]. A particle 'i' at iteration 'itr' has a position vector $y_i^{itr}=(y_{i1}^{itr},y_{i2}^{itr},---y_{in}^{itr})$ and a velocity, $u_i^{itr}=(u_{i1}^{itr},u_{i2}^{itr},---u_{in}^{itr})$. The best known position of ith particle is as $P_{best\ i}^{itr}=(P_{best\ i1}^{itr},P_{best\ i2}^{itr},---P_{best\ in}^{itr})$.The best known position of entire swarm is known as global best G_{best}^{itr}. The velocity of the particle is given by

$$\mu^{itr+1}_{i,j}=\begin{cases}\mu^{itr+1}_{i,j}=K[w\times V^k_{i,j}+C_1\times rand()\times(y^{best}_{i,j}-y^{itr}_{i,j})+C_2\times rand()\times(G^{best}_j-y^{itr}_{i,j})]; \\ (C\ factor>k)\ \text{and}\ (FT(k-1)=FT(k-N)) \\ \mu^{itr+1}_{i,j}=w\times V^k_{i,j}+C_1\times rand()\times(y^{best}_{i,j}-y^{itr}_{i,j})+C_2\times rand()\times\left(G^{best}_j-y^{itr}_{i,j}\right); \\ (k>0)\ \text{and}\ (FT(k-1)\neq FT(k-N))\end{cases} \quad (14)$$

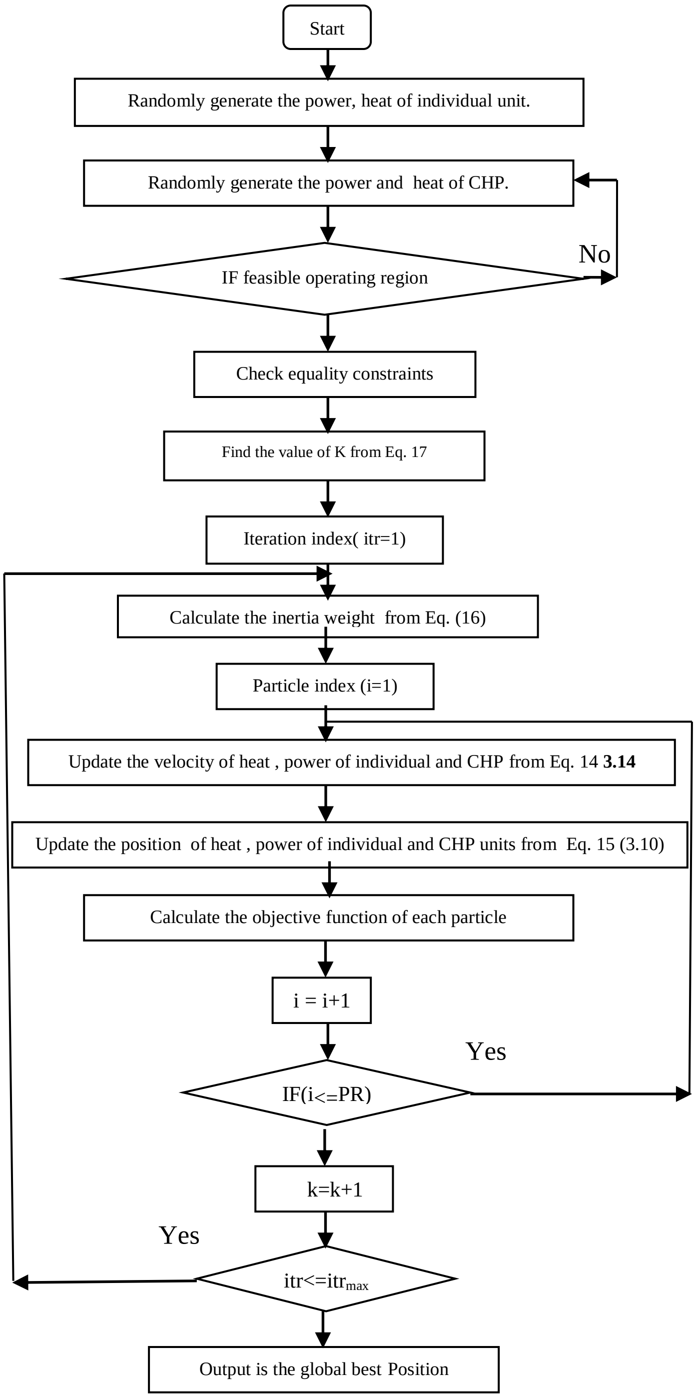

FIG.2. IMPLEMENTATION OF HCPSO

The position of the particles keeps on updating by utilizing earlier positions and velocities.

$$y^{itr+1}_{i,j}=\mu^{itr+1}_{i,j}+y^{itr}_{i,j} \ (15) \quad (i=1,2,3.PR;j=1,2,3,\ldots\ldots G;itr=1,2,3\ldots.itr_{max})$$

The inertia weight (W) can be expresses as:

$$w=w^{max}-\left(\left(w^{max}-w^{min}\right)\times k\right)/itr_{max} \quad (16)$$

$$K=2/|2-\emptyset-\sqrt{(\emptyset^2-4\emptyset)}| \quad (17)$$

When, $\emptyset^2-4\emptyset\ge0$ $(\phi=C_1+C_2\ ,\ \phi>4)$

Constriction factor is taken into account when PSO struck into local optimum[8-10]. To improve the quality of solution, these acceleration coefficient[14] are updated in a way that rate of convergence increases and give better results.

IV. RESULTS AND DISCUSSIONS

In order to show the effectiveness of the proposed method two test systems are considered for simulation study. Results obtained from this HCPSO method have been compared with PSO, EP, DE, RCGA, BCO and CPSO. This paper, proposes a HCPSO based CHPED problem which is implemented using FORTRAN 90 on a computer system. Proposed method has been applied on two test systems named test system 1 and test system 2**.** The feasible operating regions of different CHP units of different test systems are shown in Fig3-6.

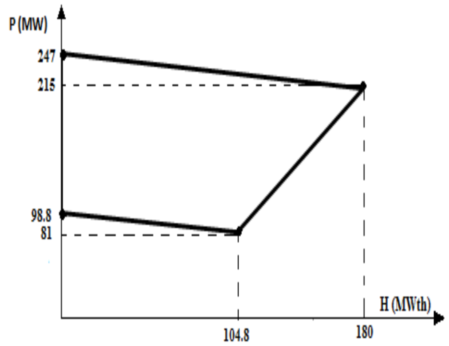

Fig.3. Feasible operating region of CHP (5 of test case 1)

To find the stable and optimal solution, program is run for different value of C_1 , C_2, C_3, C_4, w^{max} , w^{min} , itr_{max} and S. After 50 trials of run following parameter set mentioned as: Table 1 Set of Parameters gives the optimal results.

PR	itr_{max}	w^{max}	w^{min}	C_1	C_2	C_3	C_4	S
50	300	.9	.4	2	2	2.05	2.05	70

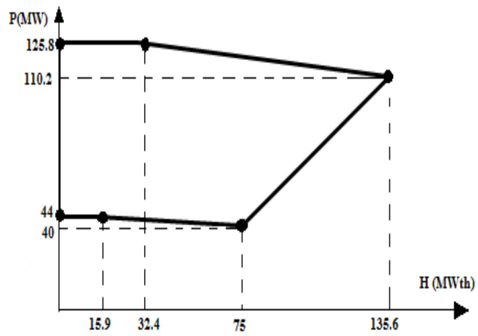

Fig.4. Feasible operating region of CHP units (6 of test case 1)

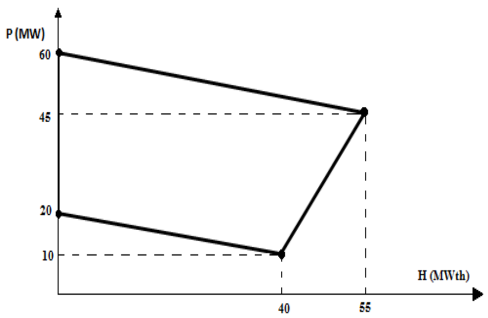

Fig.5. Feasible operating region of CHP units (18 of test case 2)

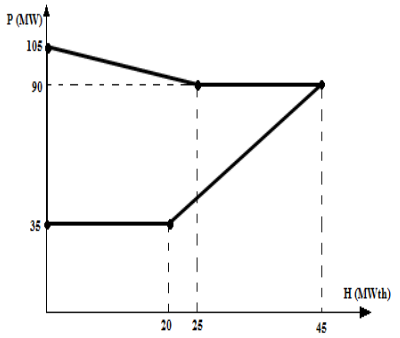

Fig.6. Feasible operating region of CHP units (18 of test case 2)

Test System 1

this test system there are total seven units as shown in Table2 out of which the four power only units, two cogeneration units and one heat only unit. The feasible operating region of cogeneration units are shown in fig3 and fig4 respectively. The total demand of heat and power for the test system is 150MWth and 600MW respectively. The simulation results of the proposed HCPSO are shown in Table3. It is observed from Table 3 that the cost($/h) obtained by applying the proposed technique HCPSO (10225) is much less in comparison to previously proposed techniques like PSO (10613), EP (10390), DE (10317),RCGA (10667), BCO (10317), CPSO (10325). Moreover, proposed technique HCPSO is not only cost efficient but also it gives better results in terms of average fuel cost, computational time and power loss as shown in Table 4.

Convergence Behavior

Convergence characteristics of fuel costs obtained by the proposed technique HCPSO for test system 1 and test system 2 are shown in fig7- fig10. From the convergence curve, it is observed that the fuel cost values converge smoothly for proposed technique HCPSO without any abrupt oscillations in comparison with PSO. Thus, ensuring convergence reliability as well results are obtained in lesser iteration

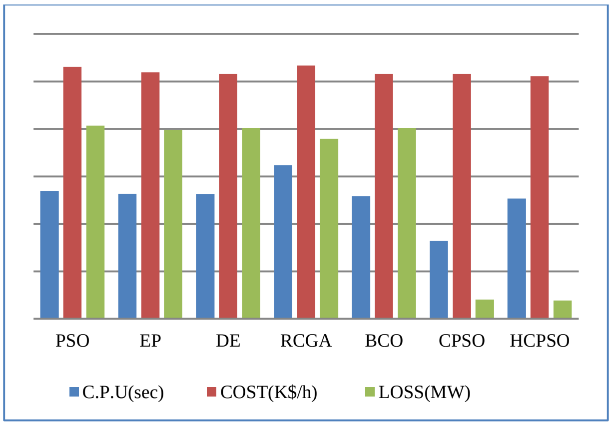

Fig.7. Optimal cost, Computational time and Power losses for different techniques

Table 2: System data of test case 1

Unit	P^{min}(MW)	P^{max}(MW)	a($/MW^2)	b($/MW)	c ($)	d($)	e(rad/MW)
Power only units:							
1	10	75	0.008	2	25	100	0.042
2	20	125	0.003	1.8	60	140	0.04
3	30	175	0.0012	2.1	100	160	0.038
4	40	250	0.001	2	120	180	0.037
Feasible operating coordinates		a($/MW^2)	b($/MW)	c ($)	d($/MWth^2)	e($/MWth)	f($/MW MWth)
CHP unit:							
5	[98.8,0],[81,104.8],[215,180], [247,0]	0.0345	14.5	2650	0.03	4.2	0.031
6	[44,0],[44,15.9], [40,75], [110.2,135.6], [125.8,32.4], [125.8, 0]	0.0435	36	1250	0.027	0.6	0.11
	h^{min}(MWth)	h^{max}(MWth)	a($/MWth^2)	b($/MWth)	c($)		h^{min}(MWth)
Heat only unit:							
7	0	2695.20	0.038	2.0109	950	7	0

Table 3: Results obtained by different techniques for test system1

Control variables	PSO	EP	DE	RCGA	BCO	CPSO	HCPSO
P1	18.4626	61.361	44.2118	74.6834	43.9457	75	10
P2	124.2602	95.1205	98.5383	97.9578	98.5888	112.38	101.8
P3	112.7794	99.9427	112.6913	167.2308	112.932	30	175.32
P4	209.8158	208.7319	209.7741	124.9079	209.7719	250	173.2
P5	98.814	98.8	98.8217	98.8008	98.8	93.2701	99.28584
P6	44.0107	44	44	44.0001	44	40.1585	41.26551
H5	57.9236	18.0713	12.5379	58.0965	12.0974	32.5655	1.18241
H6	32.7603	77.5548	78.3481	32.4116	78.0236	72.6738	56.30214
H7	59.3161	54.3739	59.1139	59.4919	59.879	44.7606	92.51544
COST($)	10,613	10,390	10,317	10667	10317	10325	10225

Table 4: Comparison of optimal costs obtained by different techniques after 50 trials for test system

Algorithms	Best fuel cost($)	Average fuel cost($)	Average CPU time	P LOSS
PSO	10613	-	5.3844	8.1427
EP	10390	-	5.275	7.9561
DE	10317	-	5.2563	8.0372
RCGA	10667		6.4723	7.5808
BCO	10317		5.1563	8.0384
CPSO	10325		3.29	.8086
HCPSO	10225	10244.53	3.37	.76651

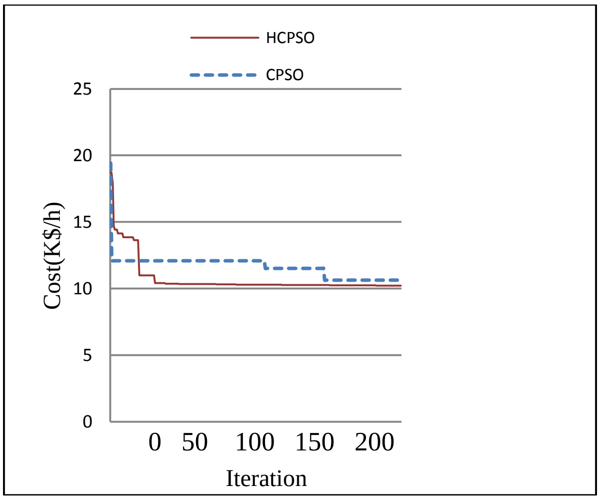

Fig.8. Convergence curve of HCPSO and PSO

Table 6: Simulation results obtained by different techniques for test case2.

	CPSO	HPSO		CPSO	HPSO
P1 (MW)	680.00	567.8467	P16 (MW)	117.4854	81
P2 (MW)	0.00	325.7905	P17 (MW)	45.9281	40
P3 (MW)	0.00	345.7023	P18 (MW)	10.0013	10
P4 (MW)	180.00	105.8591	P19 (MW)	42.1109	35
P5 (MW)	180.00	105.6171	H14 (MWth)	125.2754	104.8
P6 (MW)	180.00	105.5029	H15 (MWth)	80.1175	75
P7 (MW)	180.00	105.3421	H16 (MWth)	125.2754	104.8
P8 (MW)	180.00	105.6443	H17 (MWth)	80.1174	75
P9 (MW)	180.00	105.6949	H18 (MWth)	40.0005	40
P10 (MW)	50.5304	40	H19 (MWth)	23.2322	20
P11 (MW)	50.5304	40	H20 (MWth)	415.9815	470.4
P12 (MW)	55.00	55	H21 (MWth)	60.00	60
P13 (MW)	55.00	55	H22 (MWth)	60.00	60
P14 (MW)	117.4854	81	H23 (MWth)	120.00	120
P15 (MW)	45.9281	40	H24 (MWth)	120.00	120
Cost($/hr)				59736.2635	57998.77

Table 5: System data of test case2.

Unit	P_{min} (MW)	Pmax (MW)	a ($/MW^2)	b ($/MW)	c ($)	d ($)	e (rad/MW)
Power only units							
1	0	680	0.00028	8.1	550	300	0.035
2	0	360	0.00056	8.1	309	200	0.042
3	0	360	0.00056	8.1	309	200	0.042
4	60	180	0.00324	7.74	240	150	0.063
5	60	180	0.00324	7.74	240	150	0.063
6	60	180	0.00324	7.74	240	150	0.063
7	60	180	0.00324	7.74	240	150	0.063
8	60	180	0.00324	7.74	240	150	0.063
9	60	180	0.00324	7.74	240	150	0.063
10	40	120	0.00284	8.6	126	100	0.084
11	40	120	0.00284	8.6	126	100	0.084
12	55	120	0.00284	8.6	126	100	0.084
13	55	120	0.00284	8.6	126	100	0.084
	Feasible operating coordinates	a($/MW^2)	b($/MW)	c ($)	d($/MWth^2)	e($/MWth)	f($/MW MWth)
CHP unit							
14	[98.8, 0], [81, 104.8], [215,180], [247,0]	0.0345	14.5	2650	0.03	4.2	0.031
15	[44, 0], [44, 15.9], [40, 75], [110.2, 135.6], [125.8, 32.4], [125.8, 0]	0.0435	36	1250	0.027	0.6	0.011
16	[98.8, 0], [81, 104.8],[215, 180], [247,0]	0.0345	14.5	2650	0.03	4.2	0.031
17	[44, 0], [44, 15.9], [40, 75], [110.2,135.6], [125.8, 32.4], [125.8, 0]	0.0435	36	1250	0.027	0.6	0.011
18	[20, 0], [10, 40], [45, 55], [60, 0]	0.01035	34.5	2650	0.025	2.203	0.051
19	[35, 0], [35, 20], [90, 45], [105, 0]	0.072	20	1565	0.02	2.34	0.04
	h^{min}(MWth)	h^{max}(MWth)	a($/MWth^2)	b($/MWth)	c($)		
Heat only unit							
20	0	2695.20	0.038	2.0109	950		
21	0	60	0.038	2.0109	950		
22	0	60	0.038	2.0109	950		
23	0	120	0.052	3.0651	480		
24	0	120	0.052	3.0651	480		

Test case2

In this test system there total of 24 units, out of which 13 are power only units, 6 cogeneration units and 5 heat only units. The full system data along with cost coefficients and operating limits of power only units and heat only units are taken as shown in Table 5 Total demand of power and heat are respectively. The feasible operating regions of 6 cogenerations unit are shown in fig3-6. The simulation results of the proposed HCPSO are shown in Table 6 and their results are compared with the results obtained using CPSO. It is clear from the results that the proposed HCPSO can avoid the shortcomings of premature convergence and can obtain better results. The obtained optimum power and heat generated by all the units are well within the limits.

$$B=\begin{bmatrix} 49 & 14 & 15 & 15 & 20 & 25 \\ 14 & 45 & 16 & 20 & 18 & 19 \\ 15 & 16 & 39 & 10 & 12 & 15 \\ 15 & 20 & 10 & 40 & 14 & 11 \\ 20 & 18 & 12 & 14 & 35 & 17 \\ 25 & 19 & 15 & 11 & 17 & 39 \end{bmatrix} X10^{-7}$$

V. CONCLUSION

This paper proposes a new technique HCPSO for solving CHPED problems. All the complications present in CHPED problems can be handled effectively by HCPSO. The results clearly illustrate its effectiveness. Proposed technique HCPSO
is not only cost efficient but also it gives better results in terms of average fuel cost, computational time and power loss.

REFERENCES

[1] Tao, G, Henwood, MI and Van, OM, “An algorithm for heat and power dispatch”, IEEE Trans Power Syst, vol. 11, no.4, pp:1778–84, 1996.

[2] Achauthakan, C. and Srivastava, S. C., “A genetic algorithm based economic load dispatch solution for eastern region of EGAT system having combined cycle and cogenerating plants, ”Proceedings of IEEE International Conference on Energy Management and Power Delivery, vol. 1, pp: 165–170, 1998.

[3] Wong, K. P., and Algie, C., “Evolutionary programming approach for combined heat and power dispatch”, Electric Power System Research, vol. 61, pp:227–232, 2002.

[4] Basu, M., “Combined heat and power economic dispatch by using differential evolution”, Electric Power Compon Syst vol. 38, no.8, pp: 996–1004, 2010.

[5] Basu, M., “Bee colony optimization for combined heat and power economic dispatch”, Expert Syst Appl, vol. 38, no.11, pp:13527–31, 2011.

[6] Ivatloo, BM, Dalvand, MM and Rabiee, A. “Combined heat and power economic dispatch problem solution using particle swarm optimization with time varying acceleration coefficients”, Electr Power Syst Res, vol.95, pp: 9–18, 2013.

[7] Kennedy,J., Eberhart, R.C., “Particle swarm optimization,” In Proc. IEEE conference on Neural Networks, pp: 1942–1948, Nov. 1995.

[8] Shi ,Y., Eberhart ,R., “Parameter selection in particle swarm optimization” In Evolutionary programming VIZ Proc. EP98, New York: Springer Verlag, pp: 591-600, 1988.

[9] Clerc, M.; Kennedy, J., “The particle swarm-explosion, stability and convergence in a multidimensional complex space,” IEEE Transanction on evolutionary computation, vol. 6, no. 2, pp: 58–73, Feb. 2002.

[10] Anand, Himanshu, Kumar Kar Pratik, “A novel optimized & energy efficient hybrid PSO algorithm for emission constrained economic load dispatch”, *International Journal of Electrical and Electronics Engineering*, vol. 7, no. 1, January2015.

[11] Zhisheng, Zhang., “Quantum-behaved particle swarm optimization algorithm for economic load dispatch of power system,” Expert systems with applications, vol. 37, no. 2, pp: 1800-1803, March 2010.

[12] Dos, Leandro.; Coelho, Santos.; Lee, Chu-Sheng., “Solving economic load dispatch problems in power systems using chaotic and gaussian particle swarm optimization approaches,” International journal of electrical power & energy systems, vol. 30, no. 5, pp: 297-307, June 2008.

[13] Hosseinnezhad, Vahid.; Babaei, Ebrahim., “Economic load dispatch using θ-PSO,” International journal of electrical power & energy systems, vol. 49, pp: 160-169, july 2013.

[14] Chaturvedi, K.T.; Pandit, Manjaree.; Srivastava, Laxmi., “Particle swarm optimization with time varying acceleration coefficient for non-convex economic power dispatch,” International journal of electrical power & energy systems, vol. 31, no. 6, pp: 249-257, July 2009.