ISSN: 2278-0181
NCFTET - 2020 Conference Proceedings

Power and Heat Dispatch using an Adaptive Algoritham

Dr. J. Rameshkumar[1], Dr. N. Jayakumar[2]
[1, 2]Asst. Prof. Deputed from Annamalai University,
Department of Electrical Engineering, Government Polytechnic College,
Jolarpettai-635 851, Tamil Nadu, India

Abstract:- The purpose of this paper is to obtain the best feasible solutions for combined heat and power dispatch problems. The optimization tool used in this study is an Adaptive version of Teaching Learning Algorithm (ATLA). Though the Teaching Learning Algorithm (TLA) approach is a parameter free technique, the basic deficiency of the original TLA is the fact that, it gives near optimal solution rather than an optimal one in a limited run time period. Some modifications have been applied in the position of learners in order to improve its exploration and exploitation ability. Practical operational constraints such as feasible operating regions of co-generators, prohibited operating zones of thermal generators are considered. Standard test systems having non-linear and non-convex operating characteristics are chosen to show the effectiveness of ATLA. The results obtained using the ATLA algorithm are highly feasible than or as well as the best known solutions by state-of-the-art algorithms reported in the literature, suggesting that the proposed approach is capable of efficiently determining higher quality solutions addressing CHP dispatch problems.

***Keywords:** Combined heat and power dispatch, Economic Dispatch, Valve point effect, prohibited operating zone, Adaptive teaching learning algorithm*

1. INTRODUCTION

1.1. Combined Heat and Power System - In brief

Combined Heat and Power (CHP) system that concurrently generates electricity and useful heat from a single fuel-is a versatile technology that can generate useful energy more efficiently, and thereby significantly and economically improve energy efficiency and deliver substantial benefits for end-user facilities, utilities, and communities. As the society needs heat and power, combined heat and power generation is environmentally and economically advantageous. The objective of Combined Heat and Power Economic Dispatch (CHPED) plant is to find the heat and power generation of each unit with low fuel cost while satisfy the necessary demands and constraints. Incorporating cogeneration units into the existing utility makes economic dispatch problem further complexity to the solution methodology.

2. REVIEW OF EXISTING METHODS

The solution methods can be categorized into two groups: mathematical and heuristic. The mathematical approaches including direct search method [1], mesh adaptive direct search algorithm [2] and Lagrangian relaxation [3, 4]etc., were applied to solve this problem. These methods require approximations in the modeling of the cost curves and are not practical as the actual cost curves are highly non linear, non-monotonic and sometimes contain discontinuities.

The heuristic search techniques have provided alternative methods for solving CHPED problem such as, Evolutionary Programming (EP) [5], Differential Evolution (DE) [6], Genetic Algorithm (GA) [7], Harmony Search (HS) algorithm [8,9], Benders Decomposition (BD) [10], Self Adaptive Real Coded Genetic algorithm (SARGA) [11], Artificial Immune System (AIS) [12], Particle Swarm Optimization (PSO) [13], Artificial Bee colony algorithm (ABC) [14], Harmony Search-Genetic Algorithm (HSGA) [15] and Canonical Coordinates Method (CCM) [16] have been suggested for solving CHPED problem.

Recently, Charged System Search Algorithm (CSSA) [17], Improved Group Search Optimization (IGSO) [18], Oppositional Teaching Learning Based Optimization (OTLBO) [19], Grey Wolf Optimization (GWO) [20] and Improved GA (IGA) [21] have also been applied to solve CHPED problem considering valve-point effects of thermal generators.

3. ATLA AS AN OPTIMIZATION TOOL

The Teaching Learning Algorithm (TLA) is a new optimization algorithm based on learning of students' from teacher through classroom teaching first introduced by Rao *et al*. [22]. Unlike other evolutionary algorithms, the TLA approach does not have any algorithm-particular parameters to control. In this paper, an Adaptive Teaching Learning Algorithm (ATLA) is applied for solving combined heat and power system problem. Despite the fact that the TLA algorithm is an algorithmic parameter-free technique, the fundamental deficiency of this algorithm is overwhelmed to enhance search capability and to accelerate the speed through some modifications in changing the position of learner's [23]. The proposed method is tested on different scale of test systems. The obtained results are compared with the earlier reports and ETLBO emerges out to be a stout optimization technique for solving CHPED problem for linear and nonlinear models.

4. PROBLEM FORMULATION OF CHPED

Conventional power only unit, combined heat and power unit and heat only unit are considered in this study. The main issues, is to minimize the cost subjected to system and operational constraints The CHP system's total fuel cost (1) can be mathematically represented in the following form.

$$Min\ C_T = \sum_{i=1}^{Np} C_p(P_i) + \sum_{j=1}^{Nc} C_c(P_{cj}, H_{cj}) + \sum_{k=1}^{Nh} C_h(H_k) \quad (\$/h) \qquad (1)$$

i.e. (1) is expanded as follows

$$C_T = \left[\begin{array}{l} \underbrace{\sum_{i=1}^{Np} a_i + b_i P_i + c_i P_i^2 + \left| e_i \sin(f_i (P_i^{\min} - P_i)) \right|}_{Power\ only\ units} + \\ \underbrace{\sum_{j=1}^{Nc} \alpha_j + \beta_j P_{cj} + \gamma_j P_{cj}^2 + \varepsilon_j H_{cj} + \eta_j H_{cj}^2 + \phi_j P_{cj} H_{cj}}_{Combined\ Heat\ and\ Power\ units} + \\ \underbrace{\sum_{k=1}^{Nh} \varphi_k + \lambda_k H_k + \mu_k H_k^2}_{Heat\ only\ units} \end{array} \right] \quad (\$/h) \qquad (2)$$

The system and operating constraints are as follows:

4.1 Power demand

The eelectric power generation must be equal to the power demand.

$$\sum_{i=1}^{Np} P_i + \sum_{j=1}^{Nc} P_{cj} = P_d \quad (MW) \qquad (3)$$

4.2 Heat demand

Heat generated by the cogeneration and heat only units must be equal to the heat demand.

$$\sum_{j=1}^{Nc} H_{cj} + \sum_{k=1}^{Nh} H_k = H_d \quad (MWth) \qquad (4)$$

4.3 Operating limits

The power-only unit, cogeneration unit and heat-only unit has its own operating limit which is bounded by upper and lower values and is represented as:

$$P_i^{\min} \le P_i \le P_i^{\max} \qquad i = 1,......., Np \qquad (5)$$

$$P_{cj}^{\min}(H_{cj}) \le P_{cj} \le P_{cj}^{\max}(H_{cj}) \qquad j = 1,......., Nc \qquad (6)$$

$$H_{cj}^{\min}(P_{cj}) \le H_{cj} \le H_{cj}^{\max}(P_{cj}) \qquad j = 1,......., Nc \qquad (7)$$

$$H_k^{\min} \le H_k \le H_k^{\max} \qquad i = 1,......., Np \qquad (8)$$

4.4 Prohibited operating zones

The generating units may have certain ranges where operation is restricted on the grounds of physical limitations of machine components or instability, for example, because of steam valve or vibration in shaft bearings. Consequently, discontinuities are produced in cost function according to the prohibited operating zones. So, there is a quest to avoid operation in these zones in order to economize the production. The feasible operating zones of unit can be described as follows:

$$P_i^{\min} \le P_i \le P_{i,1}^{LB}$$

$$P_{i,j-1}^{UB} \le P_i \le P_{i,j}^{LB} \quad j = 2,3,...Np_i \qquad (9)$$

$$P_{i,j}^{UB} \le P_i \le P_i^{\max} \quad j = Np_i$$

4.5 Feasible operating region combined heat and power units

Fig. 1 shows the heat power feasible operation region of a combined heat and power unit, the power outputs and heat outputs operating region is enclosed by the boundary curve 4.1 – 4.5.

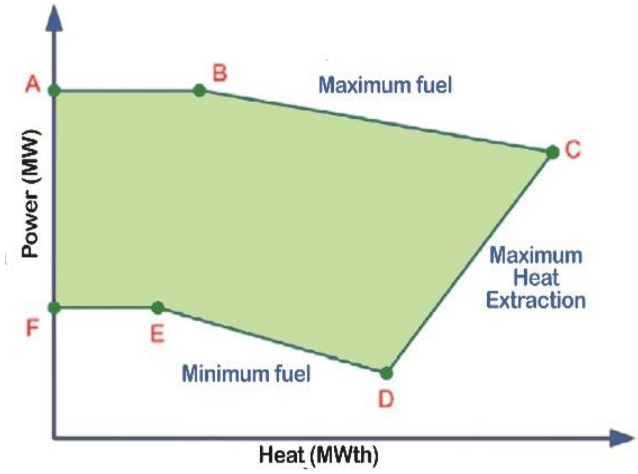


Fig.1 Feasible operating region for the combined heat and power units

5. ADAPTIVE TEACHING LEARNING ALGORITHM (ATLA)

In the original TLA algorithm, the position of learners is not changed among the learners, which causes the knowledge of learners in same level. (i.e.) the learner can learn same level of knowledge from his/her teacher. For this reason the original TLA algorithm is modified in order to enhance the exploration and exploitation the position of learner's is changed using adaptive exponential distribution inertia weight mechanism had been introduced. The purpose of this modification is to enhance the convergence speed and increase solution qualities during the early part of optimization process.

5.1 Modified position of learners using adaptive exponential distribution inertia weight

In basic TLA, the teacher is identified by finding the knowledge from the best solution $X_{teacher,\,k}$ in addition, old positions of the individual are updated in the each iterations. As this reason, TLA can quickly trap into local search space. The old position has not yet been systematically updated the information of individuals in the TLA method. En- courage from basic TLA, we produce the learners together from the old position and best position (teacher) by new position-updating rule through inertial weight strategy on TLBO [23] using the equation

$$X^{new}_{i,k} = \omega * X^{old}_{i,k} + r_3 * (X_{teacher,k} - T_f * M_{i,k}) \quad (10)$$

$$\omega = \{ -\rho 1\ e^{-\rho\lambda} + \rho 2\ e^{\rho\lambda} \} \quad (11)$$

$$\rho 1 = \omega 2\ e^{-\lambda} + \omega 1\ e^{\lambda} \quad \text{and} \quad \rho 2 = -\omega 1\ e^{2\lambda} - \omega 2 \quad (12)$$

Where $X^{new}_{i,k}$ represent the updated value of current position of learner, ω represent the adaptive exponential distribution inertia weight, r_3 is random number lies between (0, 1); and T_f is teaching factor. ρ is the sigmoid function and the value lies between lower and upper bound.

6. NUMERICAL SIMULATION RESULTS AND DISCUSSION

The performance of the proposed ATLA based CHPED problem is coded in the MATLAB 7.9 platform and is executed in the personal computer with the hardware configuration of Intel i3 processor 2.40 GHz and 4GB RAM. Numerical simulation results obtained using the ATLA for the standard test systems varying with different scale and operational characteristic are elaborated in this section.

6.1 Description of the test systems

Test system 1:

This is the fundamental model to study the economic operation of CHP plants, Guo *et al.*, 1996 developed this test system. This system consists of 4 units with second order cost functions are used to show the validity and effectiveness of the ATLA for non-convex problems. It has one thermal unit, two cogenerating units and a heat unit to satisfy the required demands.

System particulars involving feasible regions and capacity limits of the aforementioned units are obtained from [3]. For the sake of comparison the economic emission dispatch is carried out for a demand of Pd=200 MW and Hd=115 MWth. The ATLA is executed and is converged to the total fuel cost of $9257.07/h. The dispatch schedules corresponding to the minimum fuel cost is presented in the Table 1. The numerical simulation results indicate the solution is feasible as the dispatches satisfy the power balance, heat balance and operational limits of generating units. The power and heat outputs settings of cogenerating units are also within the FOR region. In order to validate the numerical results obtained by the ATLA, a comparison has been made with the earlier reports and is also presented in the Table 1.

The comparison indicates that the GWO provides the best feasible dispatches for the test system under consideration. The obtained numerical results are in close agreement with LR, SARGA, HS and TVAC-PSO methods. Though SPSO, SGA, RGA and EDHS have reported least cost than ATLA there are few errors in their reports such as SPSO converged with the real power mismatch of 0.4 MW; RGA attains the heat mismatch of around 2 MWth; the actual cost for the obtained dispatch using SGA is $9591.94/h; EDHS attains the zero real power output for cogenerating unit 2 but its minimum generation limit is 40 MW. Considering these errors, the solution attained by the ATLA cannot be compared with these reports. For the basic CHP plant economic operation problems, the optimal dispatches are well determined and the ATLA attains the same best feasible schedule.

Test system 2:

Further the ATLA is tested with a medium size CHP plant which is having 24 units. The CHP plant comprises of 13 power-only units, 6 cogenerating units and 5 heat only units. The valve point loadings are included along with quadratic cost characteristics of power-only units. Further, prohibited operating zones are included that further increases the complexity in determining the optimal operating point. The test system data is extracted from [20]. The economic operation is carried out for the power and heat demands of 2350 MW and 1250 MWth respectively.

Initially, the ATLA is executed for the best feasible solution neglecting POZ. The best cost of $57773.2/h is found using ATLA and the attained desirable output settings are presented in Table 2. The applicability of ATLA can be verified by comparing the total fuel cost with the earlier reports such as CPSO, TVAC-PSO, IGSO, OTLBO and IGA, and the comparison is also presented in the Table II. It is evident that the ATLA has settled with the new least cost dispatch.

Further, POZ of power-only units are included in the test system for economic operation that leads to multiple minima's in the search space. Due to the inclusion of POZ constraint, the total fuel cost increases and is found to be $58024.8/h. The best dispatch attained by the ATLA and numerical results comparisons with recent reports are presented in the Table II. The obtained total fuel cost using ATLA is the least when comparing with the earlier reports such as GSO, IGSO and GWO.

6.2 Convergence test

The convergence behaviour of proposed method for the two test systems is illustrated in Figs. 3(a), 3(b).

Table: 1 CHP dispatch results for 4-unit test system and comparison with other algorithms (P_d=200MW and H_d= 115MWth)

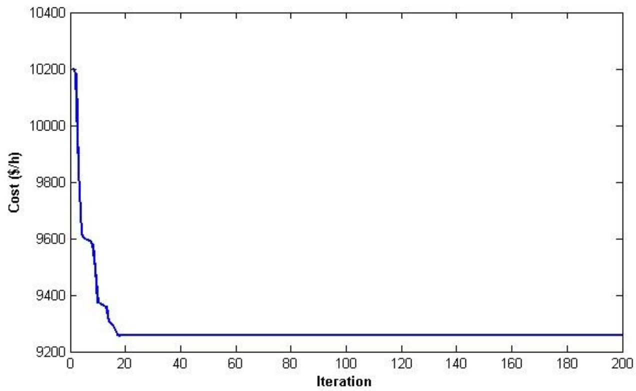
Methods	Power Output (MW)			Heat Output (MWth)			P_d (MW)	H_d (MWth)	Cost ($/h)
	P_1	P_2	P_3	H_2	H_3	H_4			
IACS	0.08	150.93	49	48.84	65.79	0.37	200.1	115	9452.2
GA-PF	0	159.23	40.77	39.94	75.06	0	200	115	9267.28
PSO	0.05	159.43	40.57	39.97	75.03	0	200.05	115	9265.1
IGA	0	160	40	39.99	75	0	200	114.99	9257.09
CPSO	0	160	40	40	75	0	200	115	9257.08
LR	0	160	40	40	75	0	200	115	9257.07
SARGA	0	159.99	40.01	39.99	75	0	200	114.99	9257.07
HS	0	160	40	40	75	0	200	115	9257.07
TVAC-PSO	0	160	40	40	75	0	200	115	9257.07

EDHS	0	200	0	0	115	0	200	115	8606.07*
SPSO	0	159.706	39.909	40	75	0	199.6162	115	9248.17*
SGA	0	155.867	44.420	72.622	42.37	0	200.29	115	9168.67*
RGA	0	155.867	44.132	0.3989	112.63	0	200	113.04	9151.07*
OTLBO	0	160	40	40	75	0	200	115	9257.07
GWO	0	160	40	40	75	0	200	115	9257.07
ATLA	**0**	**160**	**40**	**40**	**75**	**0**	**200**	**115**	**9257.07**

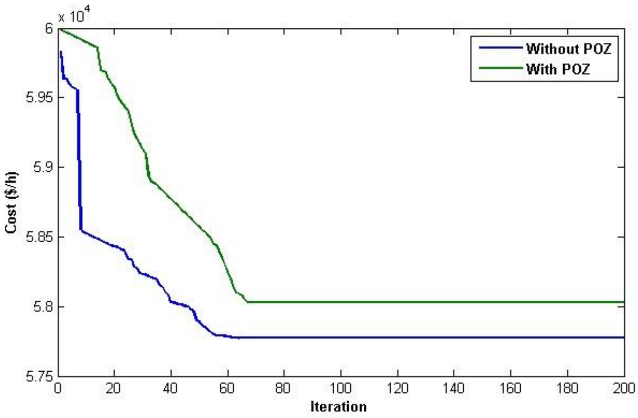
Table: 2 Simulation results obtained by ATLA and other methods- 24-unit test system (Pd=2350MW and Hd= 1250MWth)

	Without POZ							**With POZ**			
Output	**CPSO**	**TVAC-PSO**	**IGSO**	**OTLBO**	**GWO**	**IGA**	**ATLA**	**GSO**	**IGSO**	**GWO**	**ATLA**
P_1	680	538.558	628.152	538.565	538.584	628.318	627.943	269.750	268.943	538.524	538.519
P_2	0	224.460	299.477	299.212	299.342	299.198	298.521	360	224.152	299.277	299.142
P_3	0	224.460	154.553	299.122	299.342	299.166	300.254	77.0947	294.910	299.009	299.150
P_4	180	109.866	60.846	109.992	109.965	109.867	109.866	161.180	162.259	109.239	109.137
P_5	180	109.866	103.853	109.954	109.965	109.866	109.866	116.471	110.282	109.739	109.840
P_6	180	109.866	110.055	110.404	109.965	60	60.1120	160.118	159.055	109.739	109.740
P_7	180	109.866	159.077	109.804	109.965	109.860	109.542	123.115	158.872	141.919	141.910
P_8	180	109.866	109.825	109.686	109.965	109.823	109.852	162.264	109.653	109.864	109.968
P_9	180	109.866	159.992	109.899	109.965	109.852	109.775	161.955	109.552	109.864	109.968
P_{10}	50.5304	77.521	41.103	77.3992	77.6223	40.0001	40	113.852	268.943	44.6264	44.4061
P_{11}	50.5304	77.521	77.7055	77.8364	77.6223	77.0316	76.5420	116.989	114.639	80.1476	80.1671
P_{12}	55	120	94.9768	55.2225	55.0000	55.0098	55.1452	120	114.406	55.0000	55
P_{13}	55	120	55.7143	55.0861	55.0000	55	55	114.283	117.432	55.0000	55
P_{14}	117.485	88.3514	83.9536	81.7524	83.4650	81.0035	81.0010	81	118.245	81.3948	81.3952
P_{15}	45.9281	40.5611	40	41.7615	40.0000	40.0003	40.0100	40	81.2429	40.2800	40
P_{16}	117.485	88.3514	85.7133	82.273	82.7732	81.0035	81.0452	85.4377	40	81.0685	81.0710
P_{17}	45.9281	40.5611	40	40.5599	40.0000	40.0003	40	40	81.3534	40.2599	40.2500
P_{18}	10.0013	10.0245	10	10.0002	10.0000	10.0002	10.5214	10	40	10.0357	10.0357
P_{19}	42.1109	40.4288	35	31.4679	31.4568	35.0003	35.0002	36.4886	10	35.0084	35.0084
H_{14}	125.275	108.925	106.456	105.221	106.099	104.801	106.772	104.803	35	105.019	105.020
H_{15}	80.1175	75.4844	74.998	76.5205	75.0000	75.0001	74.9990	74.998	104.94	75.2167	75.0965
H_{16}	125.275	108.925	107.407	105.514	105.789	104.799	106.789	107.289	74.998	104.837	104.837
H_{17}	80.1174	75.484	74.998	75.4833	75.0000	74.9988	74.9980	74.998	104.99	75.223	75.2230
H_{18}	40.0005	40.0104	40	39.9999	40.0000	39.9993	39.9890	40.001	74.998	40.0107	40.0200
H_{19}	23.2322	22.4676	20	18.3944	18.3782	20	20.0010	20.6773	40.001	20.0038	20.0038
H_{20}	415.981	458.702	466.257	468.904	469.733	470.408	466.448	467.582	20	469.688	469.798
H_{21}	60	60	60	59.9994	60.0000	60	60	60	470.09	60.0000	60
H_{22}	60	60	60	59.9999	60.0000	60	60	60	60	60.0000	60
H_{23}	120	120	120	119.985	120.000	120	120	119.879	60	120.00	120
H_{24}	120	120	119.882	119.976	120.000	119.991	120	119.771	120	120.000	120
Cost ($/h)	59736.2	58122.7	58049	57856.2	57846.8	57826	**57773.2**	58650.2	58292	58033.9	**58024.8**

At beginning the acceleration speed is very high; it shows the convergence of the ATLA. The ATLA method can reach to the optimum solution more quickly than the other methods reported in literature. The proposed method is thus demonstrated to have a better convergence property. Over 100 iterations with several initial random solutions, the ATLA has confirmed it as trustworthy solution procedure by generating the global best solution.



(a)



(b)

Fig.2 Convergence characteristic of (a) 4-unit and (b) 24- unit systems

7. CONCLUSION

This paper demonstrated the feasibility of employing adaptive TLA for efficient solving of combined heat and power economic dispatch with cogeneration sources. Two test systems have been employed to illustrate the applicability of the adaptive teaching learning algorithm for solving CHP problems. In the case of CHPED problem with second order cost functions aspects, our proposal found better solutions compared to what was known as best until now. Further the problems considering valve point effects and prohibited operating zones, our method established solutions better than so for best known results. In a nutshell considering all the results for study with different characteristic, dimensions, demands and constraints it can be concluded ATLA yields better feasible solutions mostly within the feasible operating region in terms of cost, than the previously reported results. Any advantage in this area will cause great improvement in engineering application, which by reducing generator fuel consumption, both increases the profit of Energy Company and serves the environment.

8. REFERENCES

[1] Chung-Lung Chen, Tsung-Ying Lee, Rong-Mow Jan, and Chia-Liang Lu, “A novel direct search approach for combined heat and power dispatch”, Elect. Power Energy Syst., vol. 43, pp. 766-773, 2012.

[2] Seyyed Soheil Sadat Hosseini, Ali Jafarnejad, Amir Hossein Behrooz, and Amir Hossein Gandomi, “Combined heat and power economic dispatch by mesh adaptive direct search algorithm”, Expert Syst. Appl., vol. 38, pp. 6556-6564, 2011.

[3] Tao Guo, Henwood, M.I., and van Ooijen M, “An algorithm for combined heat and power economic dispatch”, IEEE Trans. Power Syst., vol. 11, no. 4, pp. 1778-1784, 1996.

[4] Sashirekha, A., Pasupuleti, J., Moin, N.H., and Tan, C.S, “Combined heat and power (CHP) economic dispatch solved using Lagrangian relaxation with surrogate subgradient multiplier updates”, Elect. Power Energy Syst., vol. 44, pp. 421-430, 2013.

[5] Kit Po Wong, and Cameron Algie, “Evolutionary programming approach for combined heat and power dispatch”, Elect. Power Syst. Res., vol. 61, pp. 227-232, 2002.

[6] Basu, M, “Combined heat and power economic dispatch by using differential algorithm”, Elect. Power Comp. and Syst., vol. 38, pp. 996-1004, 2010.

[7] Chang, C.S., and Fu, W, “Stochastic multiobjective generation dispatch of combined heat and power systems”, IEE Proc.-Gener. Transm. Distrib., vol. 145, no. 5, pp. 583-591, 1998.

[8] Vasebi, A., Fesanghary, M., and Bathaee, S.M.T, “Combined heat and power economic dispatch by harmony search algorithm”, Elect. Power Energy Syst., vol. 29, pp. 713-719, 2007.

[9] Esmaile Khorram, and Majid Jaberipour, “Harmony search algorithm for solving combined heat and power economic dispatch problems”, Energy Convers. Manage., vol. 52, pp. 1550-1554, 2011.

[10] Hamid Reza Abdolmohammadi, and Ahad Kazemi, “A benders decomposition approach for a combined heat and power economic dispatch”, Energy Convers. Manage., vol. 71, pp. 21-31, 2013.

[11] Subbaraj, P., Rengaraj, R., and Salivahanan, S, “Enhancement of combined heat and power economic dispatch using self adaptive real coded genetic algorithm”, Appl. Energy, vol. 86, pp. 915-921, 2009.

[12] Basu, M, “Artificial immune system for combined heat and power dispatch”, Elect. Power Energy Syst., vol. 43, pp. 1-5, 2012.

[13] Lingfeng Wang, and Chanan Singh, “Stochastic combined heat and power dispatch based on multi-objective particle swarm optimization”, Elect. Power Energy Syst., vol. 30, pp. 226-234, 2008.

[14] Basu, M, “Bee colony optimization for combined heat and power economic dispatch”, Expert Syst. Appl., vol. 38, pp. 13527-13531, 2011.

[15] Shan-Huen Huang, and Pei-Chun Lin, “A harmony- genetic based heuristic approach toward economic dispatching combined heat and power”, Elect. Power Energy Syst., vol. 53, pp. 482-487, 2013.

[16] Hung-Chieh Chang, and Pei-Chun Lin, “A demonstration of the improved efficiency of the canonical coordinates method using nonlinear combined heat and power economic dispatch problems”, Eng. Optim., vol. 46, pp. 261-269, 2014.

[17] Bahman Bahmani-Firouzi, Ebrahim Farjah, and Alireza Seifi, “A new algorithm for combined heat and power dynamic economic dispatch considering valve-point effects”, Energy, vol. 52, pp. 320-332, 2013.

[18] Mehrbad Tarafdar Hagh, Saeed Teimourzadeh, Manijeh Alipour, and Parinaz Aliasghary, “Improved group search optimization method for solving CHPED in large scale power systems”, Energy Convers. Manage., vol. 80, pp. 446-456, 2014.

[19] Provas Kumar Roy, Chandan Paul, and Sheha Sultana, “Oppositional teaching learning based optimization approach for combined heat and power dispatch”, Elect. Power Energy Syst.,, vol. 57, pp. 392-403, 2014.

[20] Jayakumar, N, Subramanian, S., Ganesan, S., and Elanchezhian, E.B, “Grey wolf optimization for combined heat and power dispatch with cogeneration systems”, Elect. Power Energy Syst., vol. 74, pp. 252–264, 2016.