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DYNAMIC ECONOMIC DISPATCH OF COGENERATION SYSTEMS BY ENHANCED TEACHING LEARNING ALGORITHM

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ABSTRACT:

The Combined Heat and Power Dispatch (CHPD) is an important optimization task in power system operation for allocating generation and heat outputs to the committed units. This paper presents an Enhanced Teaching Learning Based Optimization (ETLBO) algorithm equipped with adaptive teaching factor, more number of teachers, tutorial training and self motivated learning to explore the performance and practical applicability of CHPD problems. The effectiveness of the proposed method is validated by carrying out extensive test on 11 unit system under dynamic environment. Valve -point effects, ramp-rate limits and spinning reserve constraint along with network loss are considered. The simulation experiments reveal that ETLBO performs better in terms of solution quality and consistency.

KEYWORDS: Cogeneration systems; Valve-point effects; Ramp-rate; Dynamic dispatch; Enhanced teaching learning algorithm;

1 INTRODUCTION

1.1 General

Nowadays the energy conservation has been globally highlighted due to an expected sharp increase in energy demands and the resultant increased pollution. Also the conversion of electric energy into heat energy needs efficient process because most of the energy is wasted during conversion process. In order to improve the efficiency of the existing system, cogeneration is introduced which refers to the simultaneous production of electric and heat energy from a single source. Cogeneration minimizes the energy loss during aforesaid conversion process and can significantly reduce a facility's energy use by decreasing the amount of fuel to meet the facility's electrical and thermal base loads. This reduction in energy use can produce a number of benefits, including energy cost savings; reducing gas emissions, and other environmental impacts, especially when renewable fuel sources are used.

In Combined Heat and Power Economic Dispatch (CHPED) problem, the cogeneration units, heat-only units and power-only units are combined together and their outputs are optimized. This problem is a complex, non-linear optimization problem and the main issue in this formulation is finding the Feasible Operating Region (FOR) of cogeneration units. The complexity of the problem increases further considering the valve point effects. This formulation can be extended to dynamic load patterns, in which the units are scheduled according to load demands over a certain period of time. In this formulation, Spinning Reserve Requirements (SRRs) is considered along with ramp rate limits, is called as Reserve Constrained Combined Heat and Power Dynamic Economic Dispatch (RCCHPDED) problem.

1.2 Literature Survey

The solution methods can be categorized into two groups: mathematical and heuristic. The mathematical approaches including Lagrangian multiplier, linear programming, quadratic programming, dynamic programming etc., were applied to solve this problem (Rooijers & Amerongen, 1994; Guo et al, 1996; Chang & Fu, 1998). 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.

Genetic Algorithm (GA) and its modified versions including Genetic Algorithm based Penalty Function (GA-PF), Improved Genetic Algorithm (IGA), Self Adaptive Real Coded Genetic Algorithm (SARGA) have been reported for the solution of CHPED problems (Song & Xuan, 1998; Su & chiang, 2004; Subbaraj et al, 2009). Non-dominated Sorting Genetic Algorithm-II (NSGA-II) (Basu, 2013) suggested but the major drawback of this method is crowded comparison that restricts the convergence. The distributed autocatalytic process had been included in the conventional Ant Colony Search (ACS) in order to enhance its solution quality namely Improved ACS was applied to CHPED problems (Song et al, 1999). Evolutionary programming (Tsay et al, 2001; Wong & Algie, 2002) was applied to solve CHPED problem considering environmental factors but suffers with premature convergence to a local extremum. Harmony Search Algorithm (HSA) and Economic Dispatch with Harmony Search (EDHS) problems which uses a stochastic random search but it suffer with

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the premature convergence (Vasebi et al, 2007; Khorram & Jaberipour, 2011). Particle Swarm Optimization (PSO) and its modified versions including Time Varying Acceleration Coefficients Particle Swarm Optimization (TVAC-PSO), Selective Particle Swarm Optimization (SPSO) were applied for solving CHPED problems (Wang & Singh, 2008; Mohammadi-Ivatloo et al, 2013; Ramesh et al, 2009). Differential Evolution (DE), Bee Colony Optimization (BCO) and Artificial Immune System (AIS) were applied for the optimal solution of CHPED system (Basu, 2010; Basu, 2011, Basu, 2012). A new mutation strategy was introduced in the firefly algorithm to enhance its search capability called Enhanced Firefly Algorithm (EFA) and was applied to find the optimal solution in dynamic environment (Niknam et al, 2012).

The decomposition approaches such as Lagrangian relaxation with the surrogate sub gradient multiplier updating technique (Sashirekha et al, 2013) and Bender's decomposition (Abdolmohammadi & Kazemi, 2013) were used to solve the CHPED problem. Self Adaptive Learning Charged System Search Algorithm (SALCSSA) was applied to find the optimal dispatches in dynamic environment (Bahmani-Firouzi et al, 2013). Multi-objective line up competition algorithm was applied to solve CHPED problem (Shi et al, 2013) but (Ahmadi & Ahmadi, 2014) commented that the algorithm was implemented on test system which contains erroneous data; hence the reported results were inaccurate. Group Search Optimization (GSO), Improved Group Search Optimization (IGSO) (Hagh et al, 2014) and a hybrid harmony – genetic approach was also been reported to solve CHPED problem (Huang & Lin, 2013).

A natural inspiring optimization algorithm developed by (Rao et al, 2011), the so called Teaching Learning Based Optimization (TLBO), which mimics teaching learning process in a class between the teacher and the learners. This algorithm has no user-defined parameter which makes it superior than earlier ones. TLBO is applied for solving the various engineering optimization problems (Rao et al, 2012).

In order to improve the search capability of original TLBO, adaptive teaching factor, the number of teachers, tutorial training and self motivated learning are included in the Enhanced TLBO. The ETLBO is effectively proposed in CHPD problems. The proposed method is tested on 11-unit test system. The obtained results are compared with the earlier reports and ETLBO emerges out to be a stout optimization technique for solving CHPD problem for linear and nonlinear models.

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2 PROBLEM FORMULATION

Considering a system, that consists of power-only units, cogeneration units and heat-only units. The outputs of power-only unit and heat-only unit are limited by their own upper and lower limits. Figure 1 illustrates the heat–power FOR of a cogeneration unit which is enclosed by the boundary curve ABCDEF. The CHPD problem is concerned to determine the power and heat production of each unit so that the fuel cost and the pollutant emissions of system are minimized simultaneously while the power and heat demands and other constraints are met.

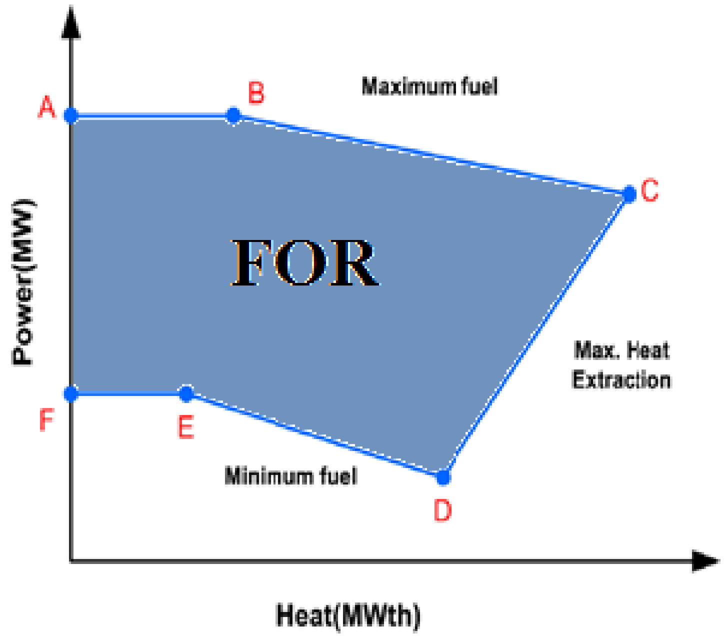

Figure 1: Heat-power feasible operating region for a cogeneration unit.

The objective function of the problem for the time interval is expressed as follows:

$$Minimize\ F_T = \sum_{t=1}^{NT} \left(f_1\left(P_t^{PU}\right) + f_2\left(P_t^{CHP}, H_t^{CHP}\right) + f_3\left(H_t^{HU}\right) \right) \qquad t=1......., NT \qquad (1)$$

i.e. Equation (1) becomes

$$F_T = \sum_{t=1}^{NT} \left(\begin{array}{l} \sum_{i=1}^{N_{PU}} \left(a_i + b_i P_{i,t}^{PU} + c_i \left(P_{i,t}^{PU}\right)^2 + \left| d_i \times \sin\left(e_i \times \left(P_{i,\min}^{PU} - P_{i,t}^{PU}\right)\right) \right| \right) + \\ \sum_{j=1}^{N_{CHP}} \left(\alpha_j + \beta_j P_{j,t}^{CHP} + \zeta_j \left(P_{j,t}^{CHP}\right)^2 + \gamma_j H_{j,t}^{CHP} + \lambda_j \left(H_{j,t}^{CHP}\right)^2 + \phi_j P_{j,t}^{CHP} H_{j,t}^{CHP} \right) + \\ \sum_{h=1}^{N_{HU}} \left(\sigma_h + \mu_h H_{h,t}^{HU} + \rho_h \left(H_{h,t}^{HU}\right)^2 \right) \end{array} \right) \quad (2)$$

Constraints of the objective functions are listed as follows:

a) Power balance

$$\sum_{i=1}^{N_{PU}} P_{i,t}^{PU} + \sum_{j=1}^{N_{CHP}} P_{j,t}^{CHP} = P_{D,t} + P_{Loss,t} \qquad t=1,\ldots\ldots, NT \quad (3)$$

The transmission line loss is obtained by using B-coefficients and is given by,

$$P_{Loss,t} = \sum_{i=1}^{(N_{PU}+N_{CHP})} \sum_{j=1}^{(N_{PU}+N_{CHP})} P_{i,t} B_{i,j,t} P_{j,t} + \sum_{i=1}^{(N_{PU}+N_{CHP})} B_{0,i,t} P_{i,t} + B_{00,t} \qquad t=1,\ \ldots\ldots, NT \quad (4)$$

b) Heat balance

$$\sum_{j=1}^{N_{CHP}} H_{j,t}^{CHP} + \sum_{h=1}^{N_{HU}} H_{h,t}^{HU} = H_{D,t} + H_{Loss,t} \qquad t=1,\ldots\ldots, NT \quad (5)$$

c) Generating unit ramp rate limits

The power generated at the output of the i[th] PU and the j[th] CHP unit at time t may affect its output power in the next time step. This limitation can be formulated as follows:

$$P_{i,t}^{PU} - P_{i,t-1}^{PU} \le UR_i^{PU} \quad i=1,\ldots\ldots, N_{PU};\ t=1,\ldots\ldots,NT \quad (6)$$

$$P_{i,t-1}^{PU} - P_{i,t}^{PU} \le DR_i^{PU} \quad i=1,\ldots\ldots, N_{PU};\ t=1,\ldots\ldots,NT \quad (7)$$

$$P_{j,t}^{CHP} - P_{j,t-1}^{CHP} \le UR_j^{CHP} \quad j=1,\ldots\ldots, N_{CHP};\ t=1,\ldots\ldots,NT \quad (8)$$

$$P_{j,t-1}^{CHP} - P_{j,t}^{CHP} \le DR_j^{CHP} \quad j=1,\ldots\ldots, N_{CHP};\ t=1,\ldots\ldots,NT \quad (9)$$

d) Power output limits

According to previous discussion, the limits of power-only and CHP units will be

$$\max\left(P_{i,\min}^{PU}, P_{i,t-1}^{PU} - DR_i^{PU}\right) \le P_{i,t}^{PU} \le \min\left(P_{i,\max}^{PU}, P_{i,t-1}^{PU} + UR_i^{PU}\right) \quad i=1,\ldots N_{PU};\ t=1,\ldots, NT \quad (10)$$

$$\max\left(P_{j,\min}^{CHP}, P_{j,t-1}^{CHP} - DR_j^{CHP}\right) \le P_{j,t}^{CHP} \le \min\left(P_{j,\max}^{CHP}, P_{j,t-1}^{CHP} + UR_j^{CHP}\right) \quad j=1,., N_{CHP};\ t=1,.,NT \quad (11)$$

e) Heat output limits

The heat operating limit of CHP units and heat units are expressed as follows:

$$H_{j,\min}^{CHP}\left(P_{j,t}^{CHP}\right) \le H_{j,t}^{CHP} \le H_{j,\max}^{CHP}\left(P_{j,t}^{CHP}\right) \quad j=1,\ldots\ldots, N_{CHP};\ t=1,\ldots\ldots,NT \tag{12}$$

$$H_{h,\min}^{HU} \le H_{h,t}^{HU} \le H_{h,\max}^{HU} \quad h=1,\ldots\ldots., N_{HU};\ t=1,\ldots\ldots,NT \tag{13}$$

f) Spinning reserve requirements

$$\left(\Delta_t = \sum_{ii=1}^{(N_{PU}+N_{CHP})} \min\left(P_{ii,\max} - P_{ii,t}, \frac{UR_{ii}}{6}\right) - SR_t\right) \ge 0 \quad t=1,\ldots\ldots,NT \tag{14}$$

This formulation will exactly satisfy the SRRs from the spinning generators in each time within 10 min of being required and its amount is related to ramp-up constraints of electric power generating unit. For time t to t+1, the ramp-up rate of unit i is UR_{ii} (MWe/h) the corresponding amount for 10 min is $UR_{ii}/6$ (Bahmani-Firouzi et al, 2013).

3 ENHANCED TEACHING LEARNING BASED OPTIMIZATION (ETLBO)

In original TLBO, the performance of learners enhanced by single teacher or by interacting with other learners only. Sometime learners are self motivated and try to learn by themselves. Moreover, the teaching factor in the original TLBO algorithm is either 1 or 2 which reflects two extreme circumstances where learner learns either everything or nothing from the teacher. In this system, the adaptive learning and increase in number of teacher will lead to improve the results of learners. In order to speed up the search process and to improve the convergence rate, some modifications have been introduced in the original TLBO algorithm.

3.1 Adaptive Teaching Factor

The original TLBO is enhanced by adaptive generation of the teaching factor (T_f) instead of heuristic step (1 or 2). Since T_f decides the value of mean to be changed.

$$T_{f\,i} = \frac{M_{D,i}}{M\_new_{D,i}} \quad D=1, 2,\ldots\ldots,D_n \quad i=1, 2, \ldots\ldots,N_G \tag{15}$$

Where, D_n is the number of design variable; N_G is the number of generations, $M_{D,i}$ is the mean of the learners in any subject at iteration i and $M\_new_{D,i}$ is the position of the teacher for the same subject iteration i. Thus in ETLBO algorithm the T_f varies automatically and improves the performance the algorithm.

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3.2 Number of Teachers

Another modification in original TLBO algorithm is introducing more than one teacher to the learner. Thus the entire class is split into different groups of learners and individual teacher is assigned to individual group of learners. Now, each teacher tries to improve the results of his/her assigned group and if the level of the group reaches up to the level of the assigned teacher then this group is assigned to next better teacher. The increase in teachers will avoid the premature convergence of the algorithm.

3.3 Learning through Tutorial

This modification is based on the fact that the students can also learn by discussing with their classmates or even with the teacher during the tutorial hours while solving the problems and assignments. Since the students can increase their knowledge by discussion with other students or the teacher, the knowledge acquired by learner during the tutorial hours is obtained as:

$$X'_{new,i} = (X_{old,i} + \text{Difference\_Mean}_i) + r\,(X_{hh} - X_k),\ \text{if } f(X)_{hh} > f(X)_k \text{ ,Where } hh \neq k \tag{16}$$

$$X'_{new,i} = (X_{old,i} + \text{Difference\_Mean}_i) + r\,(X_k - X_{hh}),\ \text{if } f(X)_k > f(X)_{hh} \text{ ,Where } hh \neq k \tag{17}$$

3.4 Self-motivated Learning

In TLBO algorithm, the results of the students are enhanced either by learning from teacher or by interacting with the other students. However, it is also possible that students are self motivated and improve their knowledge by self-learning and is obtained as:

$$X''_{new,i} = X'_{new,i} + r\,(X'_{i,j} - X'_{i,p}) + r\,(X\text{teacher} - E_F\, X'_{i,j}),\ \text{If } f(X'_i) < f(X'_p) \tag{18}$$

$$X''_{new,i} = X'_{new,i} + r\,(X'_{i.p} - X'_{i,j}) + r\,(X\text{teacher} - E_F\, X'_{i,j}),\ \text{If } f(X'_p) < f(X'_i) \tag{19}$$

Where E_F = exploration factor = round $(1 + r)$

4 ETLBO based CHPD

Step 1: Read problem statement and initialize algorithmic parameters.

Step 2: Initialization

The design variables chosen for the CHPD problem are the real power outputs of power- only units (P^{PU}), real power (P^{CHP}) and heat outputs (H^{CHP}) of cogeneration units and heat outputs (H^{HU}) of heat-only units. According to the population size, the design variables are generated randomly within the limits.

$$P_{k,i}^{PU} = P_{k,\min}^{PU} + \left(P_{k,\max}^{PU} - P_{k,\min}^{PU}\right) \times r\,(0,1) \qquad k \in N_{PU} \tag{20}$$

$$P_{k,i}^{CHP} = P_{k,\min}^{CHP} + \left(P_{k,\max}^{CHP} - P_{k,\min}^{CHP}\right) \times r(0,1) \qquad k \in N_{CHP} \tag{21}$$

$$H_{k,i}^{CHP} = H_{k,\min}^{CHP} + \left(H_{k,\max}^{CHP} - H_{k,\min}^{CHP}\right) \times r(0,1) \qquad k \in N_{CHP} \tag{22}$$

$$H_{k,i}^{HU} = H_{k,\min}^{HU} + \left(H_{k,\max}^{HU} - H_{k,\min}^{HU}\right) \times r(0,1) \qquad k \in N_{HU} \tag{23}$$

An individual in the population consists of (N_{PU}+2N_{CHP}+N_{HU}) variables that are represented as given in (24) and fitness of each individual in the population is also calculated.

$$PS_i = \left[P_{1,i}^{PU},..,P_{N_{PU},i}^{PU},P_{1,i}^{CHP},....,P_{N_{CHP},i}^{CHP},H_{1,i}^{CHP},..,H_{N_{CHP},i}^{CHP},H_{1,i}^{HU},..,H_{N_{HU},i}^{HU}\right] \tag{24}$$

Step 3: An individual having the minimum fitness (i.e $f\,(PH)_{min}$) is mimicked as the chief teacher for that cycle. Assign him/her to first rank.

$$(PH_{teacher})_1 = f\,(PH)_1 \;\text{ where } f\,(PH)_1 = f\,(PH)_{min} \tag{25}$$

Step 4: Select the other teachers (T) based on the chief teacher and rank them in the ascending order of $f\,(PH)$ value.

$$f\,(PH)_s = f\,(PH)_1 - r\,f\,(PH)_1,\text{ where s = 2, 3, ..., n.} \tag{26}$$

$$PH_{s,teacher} = f(PH)_s\text{ , where s = 2, 3, ..., n.} \tag{27}$$

Step 5: Assign the learners to the teachers according to their fitness value as,

$$\text{If } f\,(PH)_s \leq f\,(PH)_1 < f\,(PH)_{s+1},\text{ s = 1, 2, ...,}T\text{-1, L = 1, 2, ...}P_n \tag{28}$$

Assign the learner $f\,(PH)_1$ to teacher ‘s’, else assign him/her to teacher ‘s + 1’.

Step 6: Calculate the mean result of each group of learners in each subject

$$M\_new_{s,j} = PH_{s,j},\text{ s = 1, 2, ..., }T\text{, j = 1, 2, ...,}j_n \tag{29}$$

Step 7: Evaluate the difference between the current mean and the corresponding result of the teacher of that group for each subject by utilizing the adaptive (given by Eq. 15) as:

$$\text{Difference\_Mean}_{s,j} = r\,(M\_new_{s,j} - T_f M_{s,j})\quad \text{s = 1,2, ..., T, j = 1, 2, ..., }j_n \tag{30}$$

Step 8: Updates the learner knowledge through the tutorial hours using the Eq 16 – 17.

Step 9: Updates the learner knowledge by self learning, using the Eq 18 – 19.

Step 10: Replace the worst solution of each group with a best solution.

Step 11: Remove the duplicate solutions randomly.

Step 12: Join all the groups.

Step 13: Termination Criterion

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Repeat the procedure from step 3 to 12 until the maximum number of iteration is reached.

5 VERIFICATION VIA TEST STSTEMS

This section details the performance of ETLBO in solving various types of CHPD problems. The proposed method has been implemented on the standard test systems comprise of 11 units. The program has been written in MATLAB-7.9 language and executed on a 2.3 GHz Intel core i3 personal computer with 4 GB RAM. The obtained simulation results are compared with the recent reports in term of solution quality.

5.1 Reserve Constrained Dynamic Dispatch with Transmission Loss

This test system consists of 11 units, in that 5th and 8th units are CHP units, 11th unit is heat-only unit and remaining units are power-only units to meet out required demands over the scheduling interval of 24 periods. System particular are available in (Bahmani-Firouzi et al, 2013).Along with reserve requirements, ramp rate and transmission loss are also considered. B-coefficients method is adopted for transmission loss evaluation.

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Table 1

Dynamic dispatch obtained by **ETLBO -** 11-unit system.

Hour	Power Output (MW)										P_{loss} (MW)	Reserve Δt	P_D (MW)	Heat Output (MWth)			HD (MWth)
	P_1	P_2	P_3	P_4	CHP_1	P_6	P_7	CHP_2	P_9	P_{10}				CHP_1	CHP_2	Heat-only	
1	150.000	135.000	185.1961	60.000	151.3049	122.450	129.5896	40.000	20.000	55	12.5399	73.4441	1036	135.0975	75.000	190.9025	401
2	226.5879	135.000	199.1909	60.000	135.8729	122.450	129.5105	40.000	20.000	55	13.6917	72.8273	1110	135.0819	75.000	196.9181	407
3	303.2479	135.000	279.1909	60.000	130.89	122.450	129.591	40.000	20.000	55	17.3679	71.5941	1258	132.1829	75.000	209.8171	417
4	379.9998	215.000	297.5209	60.000	110.3605	122.4508	129.5895	40.000	20.000	55	23.9299	70.3606	1406	121.28	75.000	234.7200	431
5	379.8241	222.4973	297.5609	110.000	128.3369	122.4503	129.6001	40.000	20.000	55	25.2702	69.7335	1480	131.359	75.000	231.641	438
6	379.8509	302.498	298.069	120.3995	155.474	160.000	129.5893	40.000	20.000	55	32.8714	60.1769	1628	146.8209	75.000	228.1791	450
7	456.6001	309.3421	297.2951	134.7745	136.0244	160.000	129.5893	40.000	20.000	55	36.6255	59.5605	1702	135.674	75.000	244.326	455
8	456.5438	389.3419	297.207	184.7745	123.264	122.4498	129.5893	40.000	20.000	55	42.1691	67.2769	1776	128.5161	75.000	258.4839	462
9	456.4438	396.7871	301.3714	234.7745	177.6011	160.000	129.5893	40.000	20.000	55	47.5675	57.7105	1924	158.8915	75.000	238.1085	472
10	456.4795	460.000	340.000	284.7745	152.0951	160.000	129.5893	40.000	50.000	55	55.9391	29.8107	2072	145.4511	75.000	253.5489	474
11	469.9981	460.000	340.000	300.000	171.2141	160.000	129.5893	40.000	80.000	55	59.800	2.52951	2146	155.000	75.000	248.000	478
12	470.000	460.000	340.000	300.000	234.8767	160.000	130.000	52.9719	80.000	55	62.8484	1.50021	2220	57.7371	83.2708	341.9921	483
13	456.8879	396.9284	340.000	300.000	193.8134	160.000	129.7591	40.000	52.114	55	52.5051	34.4194	2072	168.110	75.000	230.8900	474
14	456.4899	397.3541	297.9829	300.000	149.5939	122.4059	130.000	40.000	22.114	55	46.9429	57.3017	1924	142.4700	75.000	252.5300	470
15	379.8771	393.1218	297.8332	250.000	127.7304	122.6928	130.000	40.000	20.000	55	40.2552	66.8666	1776	130.4252	75.000	256.5748	462
16	301.4056	313.1218	297.4889	200.000	103.4795	122.4884	130.000	40.000	20.000	55	28.9841	68.7166	1554	117.2934	75.000	250.7066	443
17	224.3633	310.4459	290.6599	181.0394	133.911	122.443	129.5895	40.000	20.000	55	27.4517	69.7438	1480	133.7072	75.000	229.2928	438
18	304.3733	388.0404	295.2629	181.1387	103.5049	146.6039	129.5626	40.000	20.000	55	35.4868	68.5374	1628	116.9873	75.000	258.0127	450
19	379.9892	458.4681	298.7931	181.0394	99.1432	129.6145	129.5893	40.000	50.000	55	45.6367	55.4759	1776	113.978	75.000	273.022	462
20	459.9862	460.000	340.000	231.0394	169.1337	159.6145	129.5895	44.640	80.000	55	57.0032	21.8764	2072	153.7558	79.000	241.2442	474
21	456.5509	389.2865	314.1283	233.8726	168.0475	134.6914	129.5895	40.000	50.000	55	47.1666	66.0438	1924	148.9915	75.000	244.0085	468
22	383.4379	309.8515	298.6241	183.8726	135.3649	104.2073	129.5839	40.000	20.000	55	31.9421	68.5161	1628	129.2464	75.000	244.7536	449
23	314.3211	229.8981	223.8443	133.8726	84.1209	122.4498	129.5895	40.000	20.000	55	21.0959	70.9771	1332	104.800	75.000	250.000	430
24	234.7014	220.7385	180.6971	115.9469	82.1200	122.4499	129.5893	40.000	20.000	55	17.2429	72.2107	1184	104.7999	75.000	234.2000	414

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Table 2
Total fuel cost comparison with different methods for CHPDED -11 unit system.

Methods	Cost ($)		
	Minimum	Mean	Maximum
EFA [19]	1252462	1253032	1253883
CSSA [22]	1256142	1257281	1258061
SALCSSA [22]	1252462	1253032	1253883
TLBO	1252377	1254012	1252412
ETLBO	1251999	1253745	1252098

The Table 1 shows dispatch attained by ETLBO for 11-unit system. The total fuel cost obtained by ETLBO is compared with TLBO, EFA, CSSA and SALCSSA and the comparison is presented in the Table 1. Referring the Table 2, it is clear that the proposed ETLBO attains the least cost schedule as compared with earlier reports. To demonstrate the power loss and SRR Δ_t is calculated for entire scheduling period and are also presented in the Table 1. The dispatches are presented that make clear the solution quality of the proposed method.

5.2 Robustness

The performance of any heuristic search based-optimization algorithm is judged through repetitive trail runs so as to compare the strength of the algorithm. Since ETLBO technique is a stochastic simulation method, randomness in the simulation result is understandable. Many trials therefore are required to find out the optimum results. Again CHPED, CHPEED, RCCHPDED are a real time problem, so it is desirable that each run of the program should reach close to optimum solution. Figure 2 clearly indicates excellent success rate of the ETLBO algorithm which signifies robustness and superiority of the ETLBO compared to other existing approaches.

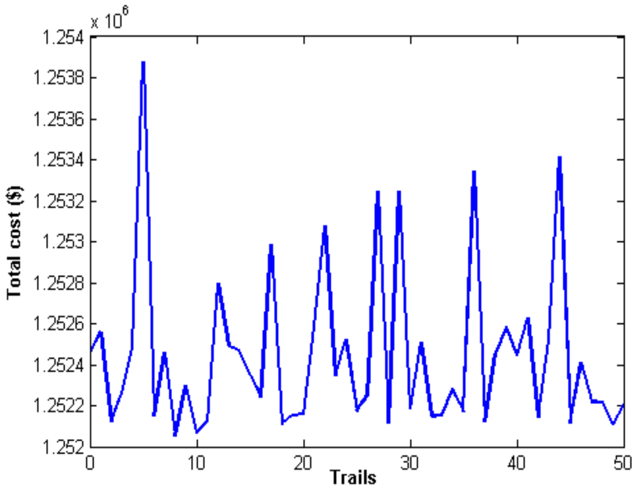

Figure 2: Robustness characteristics of 11-unit system.

6 CONCLUSION

In this paper an enhanced version of the teaching learning algorithm is proposed for the solution of mixed power source dispatch involving power, cogenerating systems and heat sources. Four test systems have been implemented to illustrate the applicability of the proposed Enhanced Teaching Learning Based Optimization (ETLBO) in solving the mixed power source dispatch problems. Nonlinear characteristics of generators such as valve point loadings and ramp rate limits are considered for practical generator operation. This approach considers network loss and emission into account to make dispatch more practical and meaningful. Thus the approach presented is a good tool for the power industry to aid curbing pollution and hostile environment, which are harmful for the welfare of the society. A compromise solution has also been obtained between the cost and emission by using a Pareto optimal graph. Further the results obtained substantiate the applicability of the proposed method for solving dynamic economic dispatch with non-smooth functions. Numerical testing and a comparative analysis show that the proposed algorithm, in all test cases, outperforms other approaches reported in the literature, in that it provides a higher quality solutions and a good computational efficiency. Further study can be extended with the use of renewable energy sources.

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NOMENCLATURE

a_i,b_i,c_i,d_i,e_i	cost coefficients of power –only unit i
$B_{i,j,t},B_{o,i,t},B_{oo,t}$	transmission loss coefficients
DR_i^{PU} ,DR_j^{CHP}	down- ramp rate of power-only unit i and CHP unit j (MW/h)
F_T	total operational costs at time span NT ($)
$f_1\,(P_t^{PU})$	total fuel cost of power-only units at time t ($)
$f_2\,(P_t^{CHP},H_t^{CHP})$	total fuel cost of CHP units at time t ($)
$f_3\,(H_t^{HU})$	total fuel cost of heat-only units at time t ($)
$H_{D,t}$,$P_{D,t}$	heat and power demands at time t
$H_{h,t}^{HU}$	output of heat-only unit h at time t (MWth)
$H_{h,max}^{HU}$, $H_{h,min}^{HU}$	maximum and minimum heat outputs of heat-only unit h
$H_{j,max}^{CHP}$, $H_{j,min}^{CHP}$	maximum and minimum heat outputs of CHP unit j (MWth)
$H_{Loss,t}$,$P_{Loss,t}$	heat and power losses at time t
N_{CHP}, N_{HU}, N_{PU}	number of CHP units, heat-only units and power-only units
NT	number of time intervals
$P_{i,max}^{PU}$, $P_{i,min}^{PU}$	maximum and minimum power outputs of power-only unit i
$P_{i,t}^{PU}$	power output of power-only unit i at time t (MW)
$P_{ii,,t}^{PU}$	power output of electric power generation unit ii at time t
$P_{ii,max}$	power capacity of electric power generation unit ii, respectively
$P_{j,max}^{CHP}$, $P_{j,min}^{CHP}$	maximum and minimum power outputs of CHP unit j (MW)
$P_{j,t}^{CHP}$,$H_{j,t}^{CHP}$	power and heat outputs of CHP unit j at time t
SR_t	10 minute spinning reserve requirements at time t (MW)
UR_i^{PU},UR_j^{CHP}	up-ramp rate of i^{th} power-only unit and j^{th} CHP unit (MW/h)
UR_{ii}	up-ramp rate of power generating unit ii (MW/h)
$\alpha_j,\beta_j,\zeta_j,\gamma_j,\lambda_j,\varphi_j$	cost coefficients of CHP unit j
σ_h,μ_h,ρ_h	cost coefficients of heat-only unit h