Solution of Economically Load Scheduling Problem using Teaching Learning and Bio-Geography Based Hybrid Optimization Algorithm

Deblina Maity, Sumit Banerjee, Chandan Kumar Chanda

Abstract: ***The article presents a new optimization algorithm view namely hybridization of teaching learning (TLBO) and biogeography based (BBO) optimization algorithm used to solve the convex economic dispatch (ED) problem with non-linear constraints like ramp rate limit, valve point loading effect etc. Hybridization of TLBO and BBO is the mixed combination of superior properties of TLBO and BBO. Teaching learning algorithm (TLBO) is based on teacher learner relationship in class and bio-geography algorithm (BBO) is based on geographical representation of biological species. The main goal of ED is to allocate power allocation economically meeting load demand. The proposed algorithm is tested for 13-unit, 15-unit, 40-unit and 140 unit systems. For proving superiority properties of proposed algorithm, obtained result are compared with recent algorithm. It gives optimum fuel cost compared to other optimization algorithm.***

Keywords : ***Economic Dispatch; Algorithm based on Biogeography; Uneven Power Generation; Forbidden Operating Zone.***

I. INTRODUCTION

In recent trend of electrical engineering market, load demand is increased day by day. But the electricity production is not so much to fulfill load demand. So that fuel cost is very increasing. From electrical engineer point of view, load allocation for individual electricity generator is very crucial such that cost will be minimized and demand will be fulfilled. For ELD problem with linear constraint the fuel cost function has been described by a linear quadratic function. So it is solved using simple optimization algorithm like lambda iteration method, gradient-based method, etc [1]. But using lambda iteration method, linear cost function should be solved. When transmission loss is included, then fuel cost equation will be non-linear. In practical cases, cost equation will be non-convex because of multi non-linear constraints such as effect of loadings due to opening and closing of valve, considering different types of fuel etc. To solve non-linear cost function, population based optimization algorithm will be incorporated in the solution of ED problem. Before incorporation of optimization algorithm, Wood et. al. suggested dynamic programming method [2] which has no restriction about characteristics of cost nature for ED problems. Then artificial intelligence is imposed into electrical engineering market. Multiple techniques like artificial networks based on neural system [3]; algorithm based on genetic behaviour (GA) [4]; algorithm based evolution system [5]; optimization based swarm analysis (PSO) [6] etc. suggested and tested for convex ED problem.

Simon proposed [7] first a species based optimization algorithm i.e biogeography based optimization algorithm. Jitendra Singha et. al proposed above mentioned algorithm based on environmental distribution of species [8] for solution of economic load scheduling approach. Recently, Mirjalili et al. [9] proposed a new meta-heuristic technique called grey wolf optimization based on leadership ladder and hunting process of the grey wolves. This artificial technique has been implemented for solution of ELD problem by Sharma [10]. The method divided into two main modules: single-solution based and population based. Last one has some advantages than the first which encourage the engineer to implement this technique for solving various practical problems.

Rao et. al [11] proposed a new optimization algorithm based on relationship between teacher and students in the class that is teaching learning based on optimization (TLBO) algorithm. It has been implemented on economic load dispatch problem by Banerjee[12] et. al. In ‘Teacher Phase’, best teacher are kept corresponding optimum solution i.e economic fuel cost. In ‘Learner Phase’, learners improve themselves by sharing knowledge with each other. Then optimum solution is obtained. Author compared result from TLBO with other optimization algorithm like optimization based on swarm analysis (PSO), algorithm based on genetic behavior (GA), simulated annealing – genetic algorithm (SA-GA) etc. to prove optimized properties of algorithm.

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However, BBO & TLBO algorithm has certain properties which can overcome some disadvantage of several methods.

- For evolutionary algorithm, there is cross-over operation where optimum solutions are best at first stage, but in later the solution is lost. But in TLBO and BBO has 'Teacher phase' and 'Migration' operation respectively. In teacher phase, best teacher is kept aside according to optimum solution obtained from initialization process. In BBO, elitism habitat is kept unaltered before going to mutation operator. So, in these algorithms best solution does not lose their quality. It can intact their quality.
- For BBO and TLBO has some unique supreme features that can face convex and non-convex constraints easily. The computational time taken very less compared to grey wolf optimization algorithm.

Due to superiority properties of above discusses both algorithms these two algorithms are hybridized in this paper for solution of convex and non-convex ED problem. That is hybridization of TLBO and BBO (HTLBBO).

The proposed method is compared with TLBO [12], BBO [13] etc. for 13 generator system in case of ELD with loading effect by opening and closing of valve. In case of ELD with other above mentioned constraints, HTLBBO cost is compared with MBA and modified BBO (MBBO) for 15 generator systems. For 40 and 140 generator systems cost from HTLBBO is compared with TLBO [12].

Segment 2 describes the overview of economic load dispatch problem along with mathematical description. The brief introduction of TLBO and BBO are presented in Section 3. Then algorithm of HTLBBO along with pseudo code is explained in Section 4. Section 5 presents implementation of HTLBBO algorithm to ELD problem with above mentioned constraints. The performance of test systems are evaluated in Segment 6 and conclusions presented in Segment 7.

II. OUTLINE OF LOAD SCHEDULING PROBLEM

The load scheduling economically problem may be presented as a nonlinear constrained problem. ELD with both linear and non-linear constraints have been described in this paper.

1.1 *Load Dispatch Solution with Linear Cost Function (Linear Constraints)*

It can be described as process with the following objective function shown in eq. (1) along with constraints equality and inequality nature.

$$\begin{cases} Min.C = \sum_{i=1}^{M} C_i(X_i) \\ \sum_{i=1}^{M} X_i - (X_D + X_L) = 0 \end{cases} \tag{1}$$

Where

$C_i(X_i)$	Cost function which should be minimized.
X_i	Output power of generators
M	Number of generators
X_D	Total demand of load
X_L	Loss due to Transmission

The fuel cost function of ith unit can be defined by

$$C_i(X_i) = p_i X_i^2 + q_i X_i + r_i \tag{2}$$

Where p_i, q_i, r_i are running cost, semi fixed cost and fixed cost respectively of unit i.

1.1.1 *ELD with Power Generation Limits*

The generators produced electricity within their operating limits.

$$X_i^{\min} \le X_i \le X_i^{\max} \tag{3}$$

Where $X_i^{\min}$ and $X_i^{\max}$ are the minimum and maximum operating limits of generator i.

1.1.2 *ELD with Effect of Loading with Closing and Opening valve (Non-linear constraint)*

To make the fuel cost non-linear, some non-linear term is included with linear quadratic function. C is represented with non-linear function, eq. (4).

$$C = \min\left(\sum_{i=1}^{N} C_i(X_i)\right) = \min\left(\sum_{i=1}^{N} p_i X_i^2 + q_i X_i + r_i + \left|e_i * \sin\left\{f_i * \left(X_i^{\min} - X_i\right)\right\}\right|\right) \tag{4}$$

Where p_i, q_i, r_i, d_i, e_i are the cost coefficients of unit i.

$X_i^{\min}$ Minimum generated power of unit i.

Fig '1' represents characteristics with loading effect of opening and closing valve. The nature of curve is nonlinear due to sinusoidal term.

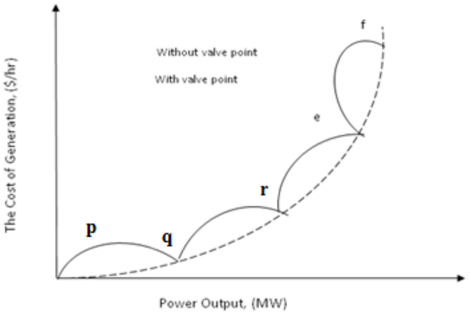

Fig. 1. Cost vs Output Power Characteristics with p, q, r, d, e—valve points

1.1.3 *ELD with Ramp Rate limit (Non-linear constraint)*

When operation of generators is increased and decreased then other non-linear constraints is raised, called ramp rate limits.

For increasing generation,

$$X_i(t) - X_i(t-1) \le Upper\_Ramp_i \tag{5}$$

For decreasing generation,

$$X_i(t-1) - X_i \le Down\_Ramp_i \tag{6}$$

Combining these two above equations,

$$\max\left(X_i^{\min}, X_i(t-1) - DR_i\right) \le X_i(t) \le \min\left(X_i^{\max}, P_i(t-1) + UR_i\right) \tag{7}$$

1.1.4 *ELD with Generator's Prohibited Zone (Non-linear constraint)*

Due to the valve operation or vibration in a shaft bearing, generator's production will be bounded within prescribed range. This zone is called 'Prohibited Zone'.

It can be described in eq. (8).

$$X^{\min} \leq X(t) \leq X^{l}_{i,1}$$
$$X^{u}_{i,k-1} \leq X_i(t) \leq X^{l}_{i,k}; \quad k = 2,3,.......nz_i \tag{8}$$
$$X^{\;u}_{i,nz_i} \leq X_i(t) \leq X^{\max}_{i}$$

Where $X^{l}_{i,k}$ and $X^{u}_{i,k}$ are the lower and upper bound of the kth prohibited zone of generator i. nz_i represents the number of prohibited zones for ith generation.

1.2 *ELD with transmission losses (Slack Generator Calculation)*

Let us consider M generator generates output power output subjected to equality and inequality constraints. Suppose the power output of first (M-1) generators is identified then the power output of last generator is called slack generator which is given by (9).

$$X_N = X_D + X_L - \sum_{i=1}^{M-1} X_i \tag{9}$$

The transmission loss formula is given by (10).

$$P_L = \sum_{i=1}^{M-1}\sum_{j=1}^{M-1} X_i B_{ij} X_j + 2X_M\left(\sum_{i=1}^{M-1} B_{Mi} X_i\right) + B_{MM} X_M^2 + \sum_{i=1}^{M-1} B_{0i} X_i + B_{0M} X_M + B_{00} \tag{10}$$

The eq. can be simplified in (11).

$$DP_M^2 + EX_M + F = 0 \tag{11}$$

Where

$$D = B_{MM} \tag{12}$$

$$E = 2\sum_{i=1}^{M-1} B_{Mi} X_i + B_{0M} - 1 \tag{13}$$

$$F = X_D + \sum_{i=1}^{M-1}\sum_{j=1}^{M-1} X_i B_{ij} X_j + \sum_{i=1}^{M-1} B_{0i} X_i - \sum_{i=1}^{M-1} X_i + B_{00} \tag{14}$$

The last generator power output is obtained by calculating positive root of (9) if the discriminator is greater than or equal to zero.

$$X_N = \frac{-E \pm \sqrt{E^2 - 4Df}}{2D} \quad if \quad E^2 - 4DF \geq 0 \tag{15}$$

Equality constraint (9) is to be satisfied; the positive root of (11) is selected as power output of the Nth generator.

III. BRIEF INTRODUCTION OF TEACHING BASED ALGORITHM (TLBO) & ALGORITHM BASED BIOLOGICAL NATURE (BBO)

In this paper hybridization of TLBO and BBO proposed for solution of convex and non-convex ED problem. Next section presents about this. Before that, overview of TLBO and BBO is remembered in this section.

3.1 *TLBO algorithm*

This method is a artificial intelligence algorithm based on how learners motive themselves with the help of guides in class. The number of subjects represented as no. of variables in proposed problem and the marks is analogous to the "fitness function". It has two main steps; 'Teacher Phase' and 'Learner Phase'.

3.1.1 *Initialization*

In this step, variables are randomly initialized within their prescribed limits following eq. (16).

$$S^{0}_{i,j} = S^{\min}_{j} + rand * \left(S^{\max}_{j} - S^{\min}_{j}\right) \tag{16}$$

3.1.2 *Teacher Phase*

For every subject, the mean value will be calculated of each learners using eq. (17). From initialization process, teacher is identified with corresponding minimum objective function as the 'Teacher' ($X_{Teacher}$).

$$M^{g} = \left[m^{g}_{1}, m^{g}_{2}, ...m^{g}_{j}, ...m^{g}_{D}\right] \tag{17}$$

New vector is obtained using eq. (18).

$$Snew^{g}_{i} = S^{g}_{i} + rand\left(S^{g}_{Teacher} - T_F * M^{g}\right) \tag{18}$$

T_F can be calculated using eq. (19),

$$T_F = round\left[1 + rand(0,1)\{2-1\}\right] \tag{19}$$

3.1.3 *Learner Phase*

In phase, they improve their knowledge by interaction between themselves. $Snew^{g}_{i}$ is replaced using eq. (20).

$$Snew^{g}_{i} = S^{g}_{i} + rand * \left(S^{g}_{i} - S^{g}_{r}\right) \quad if \quad f\left(S^{g}_{i}\right) < f\left(S^{g}_{r}\right) \tag{20}$$

$$Snew^{g}_{i} = S^{g}_{i} + rand * \left(S^{g}_{r} - S^{g}_{i}\right) \quad if \quad f\left(S^{g}_{i}\right) > f\left(S^{g}_{r}\right) \tag{21}$$

3.1.4 *Termination*

When the stopping criteria that means when MAXIT iteration is completed, then the algorithm is stop, otherwise repeat from 'Teacher Phase'.

3.2 *BBO algorithm*

Biogeography which deals with how new species arise and how they extinct resulting in their migration from one island to other. Suitability index variables (*SIVs*) are that variables which judge habitability. Obviously suitable areas have a high habitat suitability index (*HSI*) analogous to fitness function. Immigration process can be defined as when species enters into best habitat from other. Emigration process is just opposite path of immigration process. The immigration rate and the emigration are described as (λ) (μ). Fig. 2 describes emigration and immigration rate of single habitat.

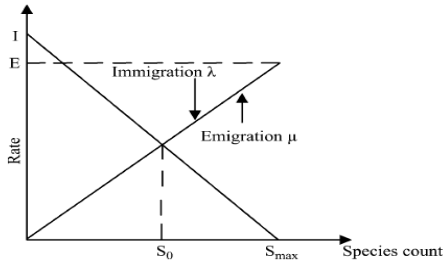

Fig 2: Immigration and Emigration Rate of Single Habitat

I is the maximum possible immigration rate. When immigration rate becomes zero i.e. S_{max} then no species can enter into this habitat. At the point of S_0 the immigration and emigration rates are equal. At S_{max} the emigration rate is maximum. Probability Q_S follows using eq. (22).

$$Q_S(t+\Delta t)=Q_S(t)(1-\lambda_S\Delta t-\mu_S\Delta t)+Q_{S-1}\lambda_{S-1}\Delta t+Q_{S+1}\lambda_{S+1}\Delta t \quad (22)$$

The equation (10) holds for having S species at time $t+\Delta t$. Neither no species will come into best habitat nor will no species go from that particular habitat.

There will (S-1) species at time t after immigration process of one habitat.

There exist (S+1) species at time t after emigration process of one habitat.

Taking the limit $\Delta t \to 0$, the equation (22) will be following

$$\dot{Q}_S=\begin{cases}-(\lambda_S+\mu_S)Q_S+\mu_{S+1}Q_{S+1} & ;S=0\\ -(\lambda_S+\mu_S)Q_S+\lambda_{S-1}Q_{S-1}+\mu_{S+1}Q_{S+1} & ;1\le S\le S_{max}-1\\ -(\lambda_S+\mu_S)Q_S+\lambda_{S-1}Q_{S-1} & ;S=S_{max}\end{cases} \quad (23)$$

The emigration rate and immigration rate can be calculated using following equation (24) and (25).

$$\mu_k=\frac{E_k}{n} \quad (24)$$

$$\lambda_k=I\left(1-\frac{k}{n}\right) \quad (25)$$

$$\lambda_k+\mu_k=E \qquad when \quad E=I \quad (26)$$

This technique has two main steps: Migration and Mutation

1.2.1 Migration

In migration, SIV is considered each no. of variables. Using this SIV, HSI is calculated. Here SIV is called candidate solution. By P_{mod} which is called habitat modification probability population can be replaced. Suppose S_i is selected for modification but its P_{mod} take the decision whether its each SIV is modified or not. Emigration rates of other solutions are used to select which solutions will migrate which is randomly chosen *SIVs* to the selected after selecting the *SIV* for modification. According to the elitism parameter some best solutions are to be kept for preventing the best solution from being corrupted.

1.2.2 Mutation

Mutation is occurred because of HSI can be changed due to natural events. In mutation the mutation rate can be calculated with the help of species count probabilities. If the probability of a given solution is very low, then that solution has chances to mutate to some other solution and vice versa also. So very high *HSI* solution and very low *HSI* solutions have low chance to generate more improved *SIV* in the later stage. And medium *HSI* solutions have better chance to generate much better solutions after mutation operation. The probabilities of each species count can be calculated using equation (23). Mutation rate of each set of solution determined using (27).

$$m(s)=m_{max}\left(\frac{1-\dot{Q}_S}{P_{max}}\right) \quad (27)$$

Here m_{max} is a parameter. Here also best solutions are kept.

IV. HYBRIDIZATION OF TLBO & BBO (HTLBBO)

As per Section I discussion, TLBO and BBO have multiple advantage compared to existing optimization algorithms. Still it has some disadvantage due to its high computational time, complex behavior of algorithm. If this two algorithms are combined in crucial manner then this demerits will be overcome. This is called 'Hybridization of TLBO & BBO' (HTLBBO). The algorithm of this new proposed technique is in brief.

Step 1: Initialization of Particle

Initialize all BBO & TLBO parameter.

Particles are randomly initialized within their limits. It follows eq. no. (28)

$$X_{i,j}^{0}=X_{j}^{\min}+rand*\left(X_{j}^{\max}-X_{j}^{\min}\right) \quad (28)$$

$X_{i,j}^{0}=$ Initialized matrix of particle

$X_{j}^{\max}=$ Maximum value of particle

$X_{j}^{\min}=$ Minimum value of particle

Step 2: Identification of best teacher

The mean parameter of each subject of the learners in the class at generation g is given as eq. (17). From the initialization matrix, fitness function is obtained. If it is minimizing function, then best solution corresponding minimum fitness function is selected. It will be kept unaltered. This solution is called 'Best Teacher'. Except best teacher solution, remaining solution are undergo for next operation. That population will be updated using eq. (18) with the help of best teacher population.

Now fitness function is to be arranged in ascending order. Now the number of valid species out of all habitats depending their HSI values is calculated.

Step 3: Migration Operation

Now non-elite habitat undergo for migration operation using calculated immigration rate and emigration rate. That habitat whose probability is proportional to immigration rate λ_i that enters into migration operation. And the resource of the modification comes from a habitat which is proportional to the emigration rate μ_j .Assume i is the habitat for modification and j is the habitat that is resource of modification. Migration process already described in Article III (2).

Step 4: Mutation Operation

If it is greater than a randomly generated number, then that habitat is selected for mutation. Habitat set which is selected for mutation is replaced by another randomly generated new habitat set in migration operation. The new habitat set should be satisfied with equality and in-equality constraints. After mutation of non-elite habitats, the unchanged elite habitats are added with the migrated non-elite habitats. Then the HSI of all habitats are calculated.

Step 5: Termination

For next iteration, returns to step 3. Program will be terminated after satisfying stopping criteria.

V. IMPLEMENTATION OF HTLBBO ALGORITHM ON NONCONVEX PROBLEM

In this segment, proposed hybridization algorithm is implemented on economically loading problems. Power output of the generator is considered as SIV in a habitat in HTLBBO algorithm. No. of SIV in HTLBBO is considered as number of generators in ED problem. Number of habitat in HTLBBO is represented as number of popsize. Here number of SIV and number of popsize equals D and N are chosen respectively.

The following steps brief that how proposed algorithm has been tested:

Step 1: Initialization:

HTLBBO parameters are initialized. After initialization one complete matrix have obtained whose row presents no. of habitats and columns represents no. of variables..

Step 2: Identification of Best Teacher

After initialization the variables are placed into cost equation for getting fuel cost. The fittest solution will be treated as “Teacher”. Fittest solution is considered that solution whose corresponding fuel cost is minimum. Some best solution will be kept aside which does not go any further steps according to elitism parameter. The pseudo code of teacher phase is given below.

1) First select teacher and calculation of mean in teacher phase

```
[min_fuel_cost index]=min (fuel cost);
Select_Teacher=Initialized matrix (index,:);

for i=1:No. Of generator
Mean(:,i)=[mean(initialized matrix(:,i))];
End
```

2) Perform teacher phase operation

```
for i=1:No. Of generator
Gaussian distribution is calculated with mean and standard deviation,
End
For $i \rightarrow population\quad size$
Calculate teaching factor
Modify solution based on best solution (teacher)
$P_{1,j} = X_{i,j} + rand * \left( X_{Teacher} - T_F * M^g \right)$
$P_{2,j} = G\left( \left( \frac{X_{Teacher} + M^g}{2} \right) * \left( X_{Teacher} - M^g \right) \right)$
$Xnew_i^g = pP_{1,j} + (1-p)P_{2,j}$
```

Step 3: Performing migration operation

Migration operation will be performed. The value of λ and μ for each habitat are calculated using (24) and (25). It was discussed in ***Segment IV***. The pseudo code of migration operation is given below.

1) For habitat selection who is selected for migration operation

```
for i=1 to No of habitats
if  fitness value< infinite
Species Count i=N-i ;
Otherwise,
Species Count i=0
```

Step 4: Mutation operation

In this step mutation operation will be performed. The detailed of this process was discussed elaborately in ***Segment IV***. The pseudo code of mutation operation is as follows.

1) First checking whether habitat is suitable for mutation then mutation operation

```
for k=1:No. of habitats
If
randomly generated number < modification probability
$\lambda_{Scale} = \lambda_{Lower} + \left( \lambda_{Upper} - \lambda_{Lower} \right) * \left( \lambda(k) - \lambda_{\min} \right) / \left( \lambda_{\max} - \lambda_{\min} \right)$

    if rand(1)<lamda_scale(k)
       while (random_num>select)&&(selectindex<n)
          population(q,j)=after initialization population (selectindex,j);
    otherwise
          population (q,j)= after initialization population q,j);
```

Step 5: Termination

When maximum number of iteration is reached, the optimum value is obtained.

VI. RESULTS AND DISCUSSION

Proposed hybridization of TLBO and BBO (HTLBBO) algorithm has been applied on four different test systems; ***case I [14]: thirteen unit system, case II [15]: fifteen unit system, case III [14]: forty generator system*** and ***case IV [16]: one forty generator systems.*** Linear constraints as well as non-linear constraints like losses due to transmission, forbidden zone, effect of uneven power generation are undertaken.

The software MATLAB 7.01 in Pentium IV processor with 3.2 GHz speed and 1 GB RAM is used for writing the coding for getting solution of loading economically problem.

Selection of HTLBBO parameter

Following parameters are most fit for the HTLBBO algorithm.

No of habitats: 1000; No. of iteration: 1000/500; Probability Modification = 1; Probability limits of Immigration = [0, 1]; Mutation Probability = 0.005; Elitism Parameter = 1

Case I: Thirteen unit systems

Proposed hybridization algorithm has been implemented on thirteen unit systems [14]. Here the loading effects due to opening and closing of valves and generation of power within limits are considered. Best optimum fuel cost obtained using applied algorithm shown in Table 1 with load demand of 2520MW. From Table 1, it is evident that, HTLBBO is suitable method for getting lesser fuel cost than SA [14], GA [14], GA-SA [14], EP-SQP[14], PSO-SQP [14], EP-EPSO[14]. Figure 3 shows fuel cost vs. number of iteration for 2520 MW considering mentioned non-linear constraints using HTLBBO.

Table 1: Optimal power output for *case I* using HTLBBO $\left(P_D = 2520MW\right)$

Unit Power Output	**HTLBBO (Proposed)**	**TLBO [12]**	**BBO [13]**	**SA [14]**	**GA [14]**	**GA-SA [14]**	**EP-SQP [14]**	**PSO-SQP [14]**	**EP-EPSO [14]**
$P_1(MW)$	623.1378	623.5641	629.0384	668.40	628.32	628.23	628.3136	628.3205	680.0000
$P_2(MW)$	299.5761	299.2522	299.4	359.78	356.49	299.22	299.1715	299.0524	360.0000
$P_3(MW)$	297.316	299.2019	300.9	358.20	359.43	299.17	299.0474	298.9681	360.0000
$P_4(MW)$	160.2723	159.7330	160.0331	104.28	159.73	159.12	159.6399	159.4680	180.0000
$P_5(MW)$	161.055	159.7350	158.5731	60.36	109.86	159.95	159.6560	159.1429	150.3476
$P_6(MW)$	160.0431	159.7242	158.7641	110.64	159.73	158.85	158.4831	159.2724	151.2105
$P_7(MW)$	159.9812	160.3826	160.8360	162.12	159.63	157.26	159.6749	159.5371	149.6332
$P_8(MW)$	150.6738	159.4098	158.8546	163.03	159.73	159.93	159.7265	158.8522	149.8140
$P_9(MW)$	159.495	159.3962	158.3287	161.52	159.73	159.86	159.6653	159.7845	148.9940
$P_{10}(MW)$	77.6662	77.3997	75.3916	117.09	77.31	110.78	114.0334	110.9618	40.0000
$P_{11}(MW)$	77.5397	77.4040	76.3812	75.00	75.00	75.00	75.0000	75.0000	40.0000
$P_{12}(MW)$	100.9581	92.3988	92.5633	60.00	60.00	60.00	60.0000	60.0000	55.0000
$P_{13}(MW)$	92.2858	92.3985	90.8731	119.58	55.00	92.62	87.5884	91.6401	55.0004
Total Generation Cost($/h)	**22172**	24197	24249	24970.91	24398.23	24275.71	24266.44	24261.05	24050.1519

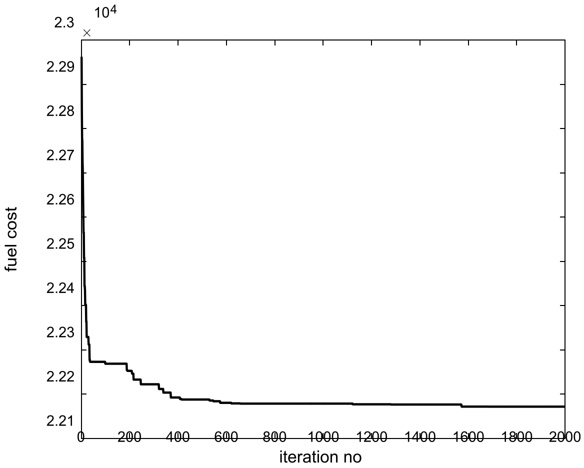

Fig 3: Fuel cost vs. Number of iterations for *case I* using HTLBBO

Case II: Fifteen unit system

Proposed hybridization algorithm has been applied on fifteen unit systems [15]. Here non-linear constraints like loading effect, uneven generation effects, forbidden zone effect is considered. Best optimum power output using proposed algorithm is shown in Table 2. Figure 4 shows fuel cost vs. number of iteration for 2630 MW considering mentioned non-linear constraints using HTLBBO.

Table 2: Optimal power output for *case II* using HTLBBO compared with MBA and MBBO $\left(P_D = 2630\,MW\right)$

Unit Power Output	**HTLBBO**	**MBA**	**MBBO**
$P_1(MW)$	391.9340	439.2187	435.3057
$P_2(MW)$	342.9497	369.1925	381.9302
$P_3(MW)$	110.1228	117.2403	104.8925
$P_4(MW)$	117.3033	128.5349	117.3242
$P_5(MW)$	152.4142	167.8495	167.2076
$P_6(MW)$	435.0065	432.3532	415.0628
$P_7(MW)$	433.7791	426.1817	393.2798
$P_8(MW)$	143.2036	73.1450	145.5716
$P_9(MW)$	116.8440	100.7468	136.6732
$P_{10}(MW)$	156.5951	144.6919	138.4706
$P_{11}(MW)$	76.5059	56.9502	55.1802
$P_{12}(MW)$	79.9344	77.0818	69.8113
$P_{13}(MW)$	26.1275	28.4953	25.5375
$P_{14}(MW)$	31.9407	52.2035	28.4664
$P_{15}(MW)$	15.3392	16.1149	15.2863
Total Generation Cost($/h)	**27131**	32509	32589

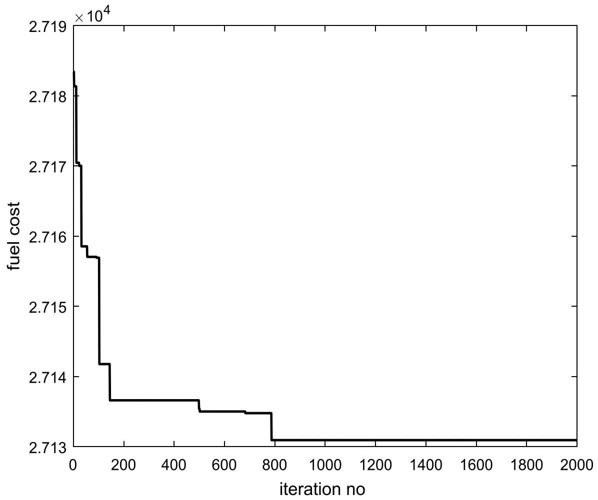

Fig 4: Fuel cost vs. Number of iterations for *case II* using HTLBBO

Case III: Forty unit system

The proposed hybridization algorithm has been tested on forty generator system [14]. Here loading effect due to opening and closing of valve is included. Table 3 shows optimum power output using HTLBO. Figure 5 shows corresponding cost characteristic for 10500 MW with using HTLBBO.

Table 3: Optimal power output for *case III* using HTLBBO compared with TLBO and NN-EPSO $\left(P_D = 10500\,MW\right)$

Unit Power Output	HTLBBO	TLBO [12]	NN-EPSO [14]
$P_1(MW)$	107.0574	36.1161	114.0
$P_2(MW)$	102.8018	37.9455	114.0000
$P_3(MW)$	108.4643	61.8403	120.0000
$P_4(MW)$	177.0816	93.4369	190.0000
$P_5(MW)$	88.7029	83.3052	97.0000
$P_6(MW)$	130.9500	120.2602	140.0000
$P_7(MW)$	123.4782	290.4140	300.0000
$P_8(MW)$	251.9316	200.0000	300.0000
$P_9(MW)$	281.2815	293.7905	300.0000
$P_{10}(MW)$	207.5061	210.5287	300.0000
$P_{11}(MW)$	310.7095	337.4764	375.0000
$P_{12}(MW)$	327.3047	249.7551	375.0000
$P_{13}(MW)$	276.7387	380.7705	500.0000
$P_{14}(MW)$	299.4366	125.2402	500.0000

$P_{15}(MW)$	490.9080	487.4984	500.0000
$P_{16}(MW)$	450.7941	500.0000	500.0000
$P_{17}(MW)$	463.4512	319.7599	402.6000
$P_{18}(MW)$	362.9663	237.2392	225.0000
$P_{19}(MW)$	506.7022	516.5296	508.0000
$P_{20}(MW)$	333.6245	524.5736	458.0000
$P_{21}(MW)$	540.1114	540.1990	356.0000
$P_{22}(MW)$	523.4259	549.3921	394.0000
$P_{23}(MW)$	524.0476	550.0000	355.0000
$P_{24}(MW)$	533.7611	522.9545	525.0000
$P_{25}(MW)$	525.4183	532.1005	310.0000
$P_{26}(MW)$	539.0340	542.7990	448.0000
$P_{27}(MW)$	12.6646	56.7790	72.0000
$P_{28}(MW)$	22.2864	23.8696	131.0000
$P_{29}(MW)$	23.0989	12.7165	75.0000
$P_{30}(MW)$	48.8835	86.0264	67.0000
$P_{31}(MW)$	188.5997	190.0000	151.0000
$P_{32}(MW)$	178.7404	190.0000	112.0000
$P_{33}(MW)$	167.9294	190.0000	139.0000
$P_{34}(MW)$	196.5109	192.4549	90.0000
$P_{35}(MW)$	180.0013	189.1622	129.0000
$P_{36}(MW)$	152.2610	195.0759	104.0000
$P_{37}(MW)$	63.2031	109.6457	36.0
$P_{38}(MW)$	62.6410	110.0000	89.0000
$P_{39}(MW)$	93.6882	109.3120	104.0000
$P_{40}(MW)$	521.8021	501.2304	550.0
Total Generation Cost($/h)	**128070**	129960	130328.325

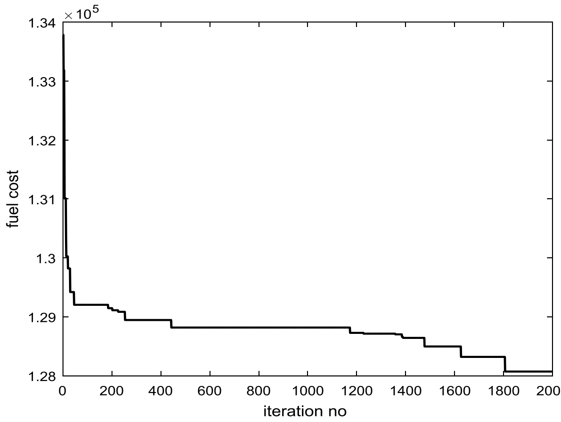

Fig 5: Fuel cost vs. Number of iterations for *case III* using HTLBBO

Case IV: One Forty unit system

In case IV, proposed hybridization algorithm has been implemented on one forty generator systems [16]. In this case losses are not undertaken and upper and lower power limits of generation are considered. Loading effects due to opening and closing of valves is also included. Table 4 shows the optimum power output using HTLBBO. Figure 6 show corresponding convergence characteristic for 49342 MW with mentioned non-linear constraints using HTLBBO.

Table 4: Optimal power output for *case IV* using HTLBBO $\left(P_D = 49342\,MW\right)$

Unit Power Output **1.0e+03 ***	HTLBBO	Unit Power Output	HTLBBO
$P_1(MW)$	0.0812	$P_{71}(MW)$	0.3071
$P_2(MW)$	0.1322	$P_{72}(MW)$	0.4510
$P_3(MW)$	0.1854	$P_{73}(MW)$	0.3611
$P_4(MW)$	0.1837	$P_{74}(MW)$	0.2597
$P_5(MW)$	0.1597	$P_{75}(MW)$	0.2542
$P_6(MW)$	0.1818	$P_{76}(MW)$	0.2222
$P_7(MW)$	0.4322	$P_{77}(MW)$	0.3580
$P_8(MW)$	0.4774	$P_{78}(MW)$	0.3701
$P_9(MW)$	0.4477	$P_{79}(MW)$	0.5267
$P_{10}(MW)$	0.4706	$P_{80}(MW)$	0.4417
$P_{11}(MW)$	0.4626	$P_{81}(MW)$	0.2986
$P_{12}(MW)$	0.4020	$P_{82}(MW)$	0.0715
$P_{13}(MW)$	0.4984	$P_{83}(MW)$	0.1400
$P_{14}(MW)$	0.4583	$P_{84}(MW)$	0.1164
$P_{15}(MW)$	0.4675	$P_{85}(MW)$	0.1209
$P_{16}(MW)$	0.3991	$P_{86}(MW)$	0.2384
$P_{17}(MW)$	0.4459	$P_{87}(MW)$	0.2577
$P_{18}(MW)$	0.4934	$P_{88}(MW)$	0.1991
$P_{19}(MW)$	0.4979	$P_{89}(MW)$	0.2177
$P_{20}(MW)$	0.4628	$P_{90}(MW)$	0.2090
$P_{21}(MW)$	0.4950	$P_{91}(MW)$	0.2153
$P_{22}(MW)$	0.4495	$P_{92}(MW)$	0.5641
$P_{23}(MW)$	0.4964	$P_{93}(MW)$	0.6163
$P_{24}(MW)$	0.4837	$P_{94}(MW)$	0.9727
$P_{25}(MW)$	0.5327	$P_{95}(MW)$	0.9708
$P_{26}(MW)$	0.4343	$P_{96}(MW)$	0.6640
$P_{27}(MW)$	0.5175	$P_{97}(MW)$	0.7185

$P_{28}(MW)$	0.5067	$P_{98}(MW)$	0.7062
$P_{29}(MW)$	0.4796	$P_{99}(MW)$	0.7028
$P_{30}(MW)$	0.3545	$P_{100}(MW)$	0.9407
$P_{31}(MW)$	0.5005	$P_{101}(MW)$	0.9519
$P_{32}(MW)$	0.4973	$P_{102}(MW)$	0.9418
$P_{33}(MW)$	0.4966	$P_{103}(MW)$	0.9806
$P_{34}(MW)$	0.4743	$P_{104}(MW)$	0.9662
$P_{35}(MW)$	0.4964	$P_{105}(MW)$	1.0122
$P_{36}(MW)$	0.4721	$P_{106}(MW)$	0.9420
$P_{37}(MW)$	0.2342	$P_{107}(MW)$	0.9254
$P_{38}(MW)$	0.2084	$P_{108}(MW)$	0.9975
$P_{39}(MW)$	0.7243	$P_{109}(MW)$	1.0072
$P_{40}(MW)$	0.7666	$P_{110}(MW)$	0.9981
$P_{41}(MW)$	0.0052	$P_{111}(MW)$	0.8128
$P_{42}(MW)$	0.0129	$P_{112}(MW)$	0.1089
$P_{43}(MW)$	0.2100	$P_{113}(MW)$	0.0951
$P_{44}(MW)$	0.1803	$P_{114}(MW)$	0.1283
$P_{45}(MW)$	0.2292	$P_{115}(MW)$	0.2540
$P_{46}(MW)$	0.2038	$P_{116}(MW)$	0.3429
$P_{47}(MW)$	0.1894	$P_{117}(MW)$	0.2720
$P_{48}(MW)$	0.2161	$P_{118}(MW)$	0.1282
$P_{49}(MW)$	0.1920	$P_{119}(MW)$	0.1385
$P_{50}(MW)$	0.2055	$P_{120}(MW)$	0.1618
$P_{51}(MW)$	0.3049	$P_{121}(MW)$	0.2017
$P_{52}(MW)$	0.3215	$P_{122}(MW)$	0.0059
$P_{53}(MW)$	0.4254	$P_{123}(MW)$	0.0172
$P_{54}(MW)$	0.3012	$P_{124}(MW)$	0.0245
$P_{55}(MW)$	0.3032	$P_{125}(MW)$	0.0095
$P_{56}(MW)$	0.2161	$P_{126}(MW)$	0.0182
$P_{57}(MW)$	0.1037	$P_{127}(MW)$	0.0109
$P_{58}(MW)$	0.4256	$P_{128}(MW)$	0.1379
$P_{59}(MW)$	0.2017	$P_{129}(MW)$	0.0118
$P_{60}(MW)$	0.4633	$P_{130}(MW)$	0.0058
$P_{61}(MW)$	0.2913	$P_{131}(MW)$	0.0074
$P_{62}(MW)$	0.1020	$P_{132}(MW)$	0.0774
$P_{63}(MW)$	0.1843	$P_{133}(MW)$	0.0091
$P_{64}(MW)$	0.1999	$P_{134}(MW)$	0.0485
$P_{65}(MW)$	0.2931	$P_{135}(MW)$	0.0511
$P_{66}(MW)$	0.2241	$P_{136}(MW)$	0.0471
$P_{67}(MW)$	0.2405	$P_{137}(MW)$	0.0246
$P_{68}(MW)$	0.4086	$P_{138}(MW)$	0.0078
$P_{69}(MW)$	0.1598	$P_{139}(MW)$	0.0119
$P_{70}(MW)$	0.1508	$P_{140}(MW)$	0.0301
Cost from HTLBBO=520970000 $/hr.			

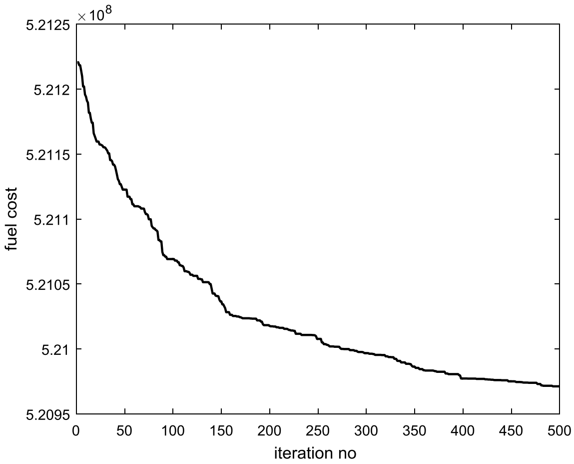

Fig 6: Fuel cost vs. Number of iterations for *case IV* using HTLBBO

VII. CONCLUSION

In this article, a hybridization of TLBO and BBO has been implemented successfully for getting solution of load scheduling problem meeting load demand. Here linear constraints like meeting load demand, generation of power within limits and non-linear constraint like loading effect, uneven generation effect and forbidden zone of operation are considered. Fuel cost obtained from hybridization algorithm proves its superiority property by comparing fuel cost compared to recent optimization algorithm by avoiding premature solution.

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