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A robust TLBO algorithm for solving the ELD problem

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Abstract: This work focuses a teaching learning-based optimization (TLBO) algorithm for solving economic load dispatch (ELD) problem. The TLBO technique is a recently developed optimization algorithm based on the influence of teaching-learning process. Best possible dispatches scheduled of thermal generator are finding using TLBO algorithm that minimization of fuel cost of a given system. To test the effectiveness of the TLBO algorithm, the proposed algorithm has been applied to three and six generating unit systems for fuel cost minimization. The simulation results achieved by proposed method are better-optimized solutions for fuel cost minimization.

Keywords*—Economic load dispatch, Evolutionary Computing, Fuel Cost Minimization, TLBO*

1. INTRODUCTION

Nowadays, ELD problem are gaining popularity because of reduction in consumption of fossil fuels and high demand in power sector [1, 2]. Cost-effective operation of power system is the major concerns of power engineer and system operator. The TLBO algorithm has been used for minimizing cost at the same time take care of power balance equality constraint and inequality constraints imposed due to generator operating limits. The ramp rate limits of the generating units are not considered in this work. The ELD problem is a well-known optimization problem in the domain of power system. It is highly non-linear and constrained optimization problem. There are number of conventional method successfully solved the ELD problem, but most of the time convention problem is stuck in local optimal solution therefore in this paper authors are proposed the TLBO algorithm to solved ELD problem. The proposed TLBO algorithm relies on the behavior of teacher and students. The performance of the proposed algorithm is examined by implementing it on various three and six generating unit system for fuel cost minimization [3-6].

2. PROBLEM FORMULATION

The optimization problem for fuel cost minimization is subjected to some existing constraints associated with ELD problem which are as follows [7-8]:

2.1 Objective Function

The fuel cost can be representing as fellow [9]:

$$\text{Min } F_T(x,u) = \sum_{i=1}^{NG} f_i\,(P_{G_i})(\$/h) \tag{1}$$

$$f_i(P_{G_i}) = R_i + S_i P_{G_i} + T_i P_{G_i}^2 (\$/h) \tag{2}$$

Where R_i, S_i,and T_i are the *i*th generating unit cost coefficients [10].

2.2 System Constraints

The ELD problem consists of two types of constraint namely equality and inequality, which are as fellow [11-12]:

2.2.1 Equality constraints:

$$P_d + P_L = \sum_{i=1}^{NG} P_{G_i} \tag{3}$$

Where, P_L and P_d are the system active power losses and system load demand respectively.

The active power loss of transmission lines can be calculated as:

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_{gi} B_{ij} P_{gj} + \sum_{i=1}^{N} P_{gi} B_{0i} + B_{00} \quad (4)$$

Where B_{00}, B_{0i} and B_{ij} are are the B-coefficients of the transmission line's losses.

2.2.2 Inequality constraints:

- Generator constraints:

$$V_{G_i}^{min} \le V_{G_i} \le V_{G_i}^{max} \quad i = 1 \ldots\ldots NG \quad (5)$$

$$P_{G_i}^{min} \le P_{G_i} \le P_{G_i}^{max} \quad i = 1 \ldots\ldots NG \quad (6)$$

$$Q_{G_i}^{min} \le Q_{G_i} \le Q_{G_i}^{max} \quad i = 1 \ldots\ldots \mathrm{NG} \quad (7)$$

- Transformer Constraints

$$T_i^{min} \le T_i \le T_{G_i}^{max} \quad i = 1 \ldots\ldots NT \quad (8)$$

- Security Constraints

$$V_{L_i}^{min} \le V_{L_i} \le V_{L_i}^{max} \quad i = 1 \ldots\ldots NL \quad (9)$$

$$S_{l_i} \le S_{l_i}^{max} \quad i = 1 \ldots\ldots nl \quad (10)$$

3. TEACHING LEARNING BASED OPTIMIZATION (TLBO)

Rao and colleagues [43] in 2014 proposed a novel meta-heuristic based named as TLBO algorithm. The TLBO algorithm is parameters less optimization algorithm, this property marks it special to other meta-heuristic algorithm. The algorithm dependent parameters tuning are very tedious task. Brief descriptions of these steps of TLBO algorithm are given below [13, 14]:

3.1 Teaching phase

The teaching phase of TLBO algorithm is represented in equations (12-14)

Using the above concept, the grade point of subject j of student i may be modified as follows

$$G_{i,j}^{k+1} = G_{i,j}^{k} + \lambda_j^k \quad (11)$$

where λ_j^k is the difference between the existing and new mean of subject *j* at iteration *k* which may be formulated as

$$\lambda_j^k = rand \text{ x } (M_{new_j}^k - \mathrm{t_f} M_j^k) \quad (12)$$

Where $M_{new_j}^k$ is the mean grade point of subject j at iteration k; $\mathrm{t_f}$ is the teaching factor which is evaluated randomly using (14):

$$\mathrm{t_f} = \mathrm{round}[1 + \mathrm{rand}(0,1)] \quad (13)$$

3.2 Learner phase

The main motive of the learning phase is performed local search of the algorithm. It may mathematically be expressed as follows:

$$G_{i,j}^{k+1} = G_{i,j}^{k} + \text{rand x} \left(G_{i,j}^{k} - G_{l,j}^{k}\right) \text{ if } \quad \mathrm{f(OG_i) < f(OG_l)} \quad (14)$$

$$G_{i,j}^{k+1} = G_{i,j}^{k} + \text{rand x} \left(G_{l,j}^{k} - G_{i,j}^{k}\right) \text{ if } \quad \mathrm{f(OG_i) > f(OG_l)} \quad (15)$$

Where, $\mathrm{OG_l = G_{l,1}, G_{l,2}, \ldots\ldots, G_{l,j}, \ldots. G_{l,d}}$ and $\mathrm{f(OG_l)}$ is the overall grade point of student l.

4. NUMERICAL RESULTS

There are two different test systems that use the TLBO algorithm to determine the lowest fuel cost for any given power demand.

1. Three generating units
2. Six generating units.

4.1 Test system 1: Three generating units

To test the effectiveness of the proposed TLBO algorithm and examine superiority of the TLBO algorithm, it has been applied for 3 generating unit system. The system data along with B- coefficient are given in Appendix A.

Table 1: Input parameters of TLBO Algorithm

S.no	Parameter	Quantity
1	Population size	20
2	Number of generations	100

Table 2: The results of three-unit system using TLBO algorithm

S. No	PD (MW)	P1 (MW)	P2 (MW)	P3 (MW)	Fuel Cost($/h)	Time in (Sec)
1	50	11.5549	20.2146	18.6076	861.9374	1.25
2	100	20.3115	43.3603	37.5891	1221.10	1.31
3	150	33.1173	63.6858	55.8577	1599.9	1.22

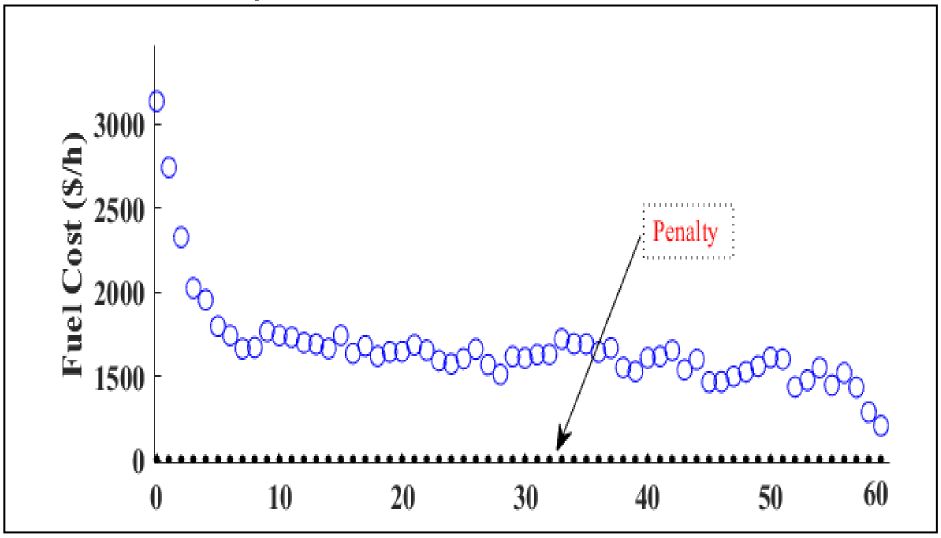

Fig 1: Convergence curve of TLBO algorithm (50 MW demand)

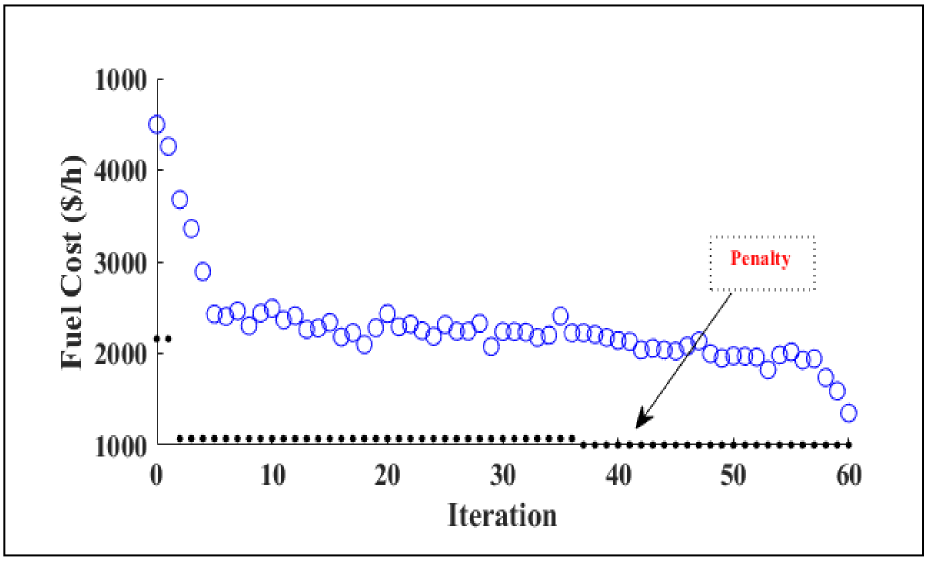

Fig 2: Convergence curve of TLBO algorithm (100 MW demand)

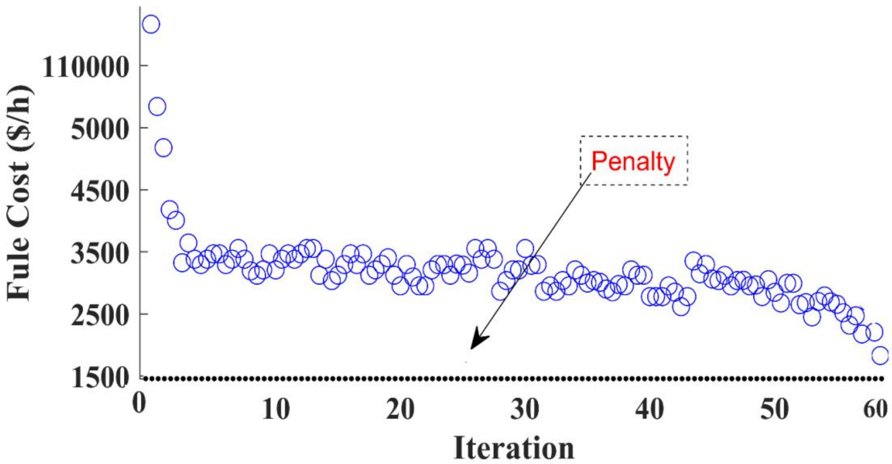

Fig 3: Convergence curve of TLBO algorithm (150 MW demand)

4.2 Test system 2:Six generating units

To test the effectiveness of the proposed TLBO algorithm and examine superiority of the TLBO algorithm, it has been applied for 6 generating unit system. The system data along with B- coefficient are given in Appendix B.

Table 3: The results of six-unit system using TLBO algorithm

S. No	PD (MW)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	Fuel Cost ($/h)	Time in Sec
1	600	22.8198	15.1190	120.4108	131.5686	226.0575	203.0992	36851	5.41
2	700	18.2261	13.5004	79.1425	105.7893	325.0000	179.2549	37106	5.60
3	800	21.9822	11.6438	102.2957	69.9772	325.0	190.00	37122	5.42

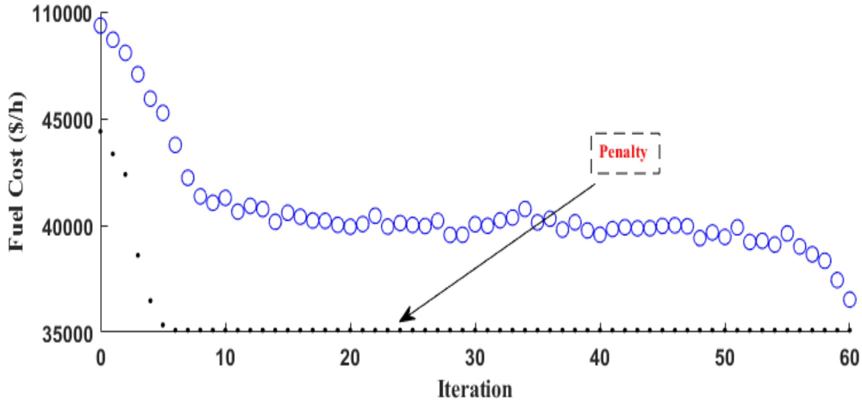

Fig 4: Convergence curve of TLBO algorithm (600 MW demand)

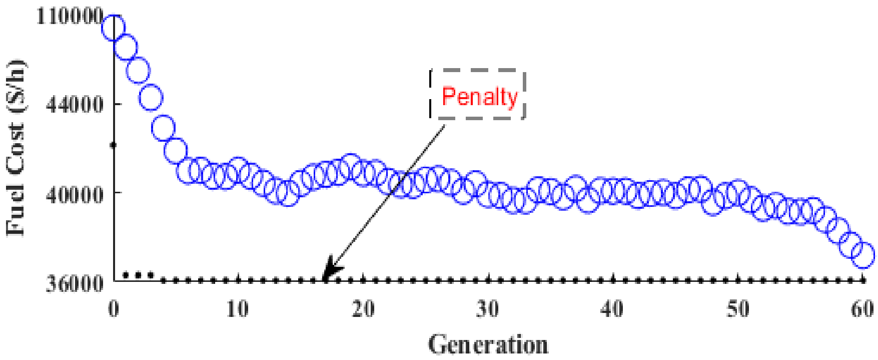

Fig 5: Convergence curve of TLBO algorithm (700 MW demand)

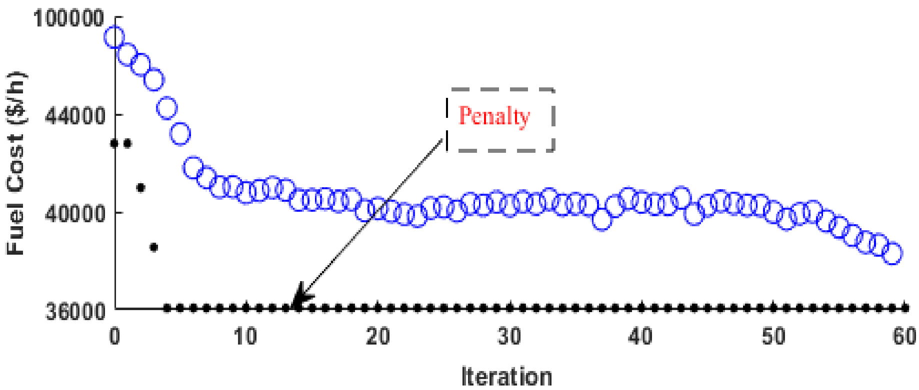

Fig 6: Convergence curve of TLBO algorithm (800 MW demand)

5. CONCLUSION

This work focuses a teaching learning based optimization (TLBO) algorithm for solving economic load dispatch (ELD) problem. The TLBO technique is a recently developed optimization algorithm based on the influence of teaching-learning process. Best possible dispatches scheduled of thermal generator are finding using TLBO algorithm that minimization of fuel cost of a given system. To test the effectiveness of the TLBO algorithm, the proposed algorithm has been applied to three and six generating unit systems for fuel cost minimization. The result shows that the applied method provides better-optimized solutions for three and six generating unit systems for fuel cost minimization.

5.1 Future Scope

The scope of work is identified as:

- In this paper only generator fuel cost is optimized. In future work other objective function namely emission, power loss are also consider for the same
- The formulation can be extended for multiple objectives ELD problem.
- Other methods such as Jaya, PSO, BAT search and Rao algorithm can also use for the same.
- In future work, binary version of TLBO algorithm has been developed to solve the ELD problem

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Appendix A: Three unit system

The generator unit cost characteristics are shown as follows:

$$F_1 = 0.008\,6P_{G1}^2 + 7\,P_{G1} + 200\;Rs/hr \quad (1)$$

$$F_2 = 0.009\,P_{G2}^2 + 6.3P_{G2} + 180\;\;Rs/hr \quad (2)$$

$$F_3 = 0.007\,P_{G3}^2 + 6.8\,P_{G3} + 140\;\;Rs/hr \quad (3)$$

The unit operating ranges are:

$$10\text{ MW} \leq P_1 \leq 85\text{ MW} \quad (4)$$

$$10\text{ MW} \leq P_2 \leq 80\text{ MW} \quad (5)$$

$$10\text{ MW} \leq P_3 \leq 70\text{ MW} \quad (6)$$

B-coefficient are shown as follows:

$$B_{mn} \;=\; 0.01 * \begin{bmatrix} 0.0218 & 0.0093 & 0.0028 \\ 0.0093 & 0.0228 & 0.0017 \\ 0.0028 & 0.0017 & 0.0179 \end{bmatrix} \quad (7)$$

$$B_{mo} \;=\; 10^{-3}\;\;[0.3\;\;3.1\;\;1.5] \quad (8)$$

$$B_{oo} \;=\;\; [0.030523] \quad (9)$$

Appendix B: Six unit system

The cost function of the six units are given as follows

$$F_1 = 0.15240P_{G1}^2 + 38.53973\,P_{G1} + 756.79886\,Rs/hr \quad (10)$$

$$F_2 = 0.10587\,6P_{G2}^2 + 46.15916\,P_{G2} + 451.32513\,Rs/hr \quad (11)$$

$$F_3 = 0.02803\,P_{G3}^2 + 40.30965\,P_{G3} + 1049.9977\,Rs/hr \quad (12)$$

$$F_4 = 0.03546\,P_{G4}^2 + 38.30553\,P_{G4} + 1243.5311\;\;Rs/hr \quad (13)$$

$$F_5 = 0.02111\,P_{G5}^2 + 36.03278\,P_{G5} + 1658.5596\;\;Rs/hr \quad (14)$$

$$F_6 = 0.01799\,P_{G6}^2 + 38.27041\,P_{G6} + 1356.6592\,Rs/hr \quad (15)$$

The unit operating ranges are

$$10\text{ MW} \leq P_1 \leq 125\text{ MW} \quad (16)$$

$$10\text{ MW} \leq P_2 \leq 150\text{ MW} \quad (17)$$

$$10\text{ MW} \leq P_3 \leq 225\text{ MW} \quad (18)$$

$$35\text{ MW} \leq P_4 \leq 210\text{ MW} \quad (19)$$

$$130\text{ MW} \leq P_5 \leq 325\text{ MW} \quad (20)$$

$$125\text{ MW} \leq P_6 \leq 315\text{ MW} \quad (21)$$

B_{mn} coefficient matrix is given as

$$B_{mn} = \begin{bmatrix} 0.00014 & 0.000017 & 0.000015 & 0.000019 & 0.000026 & 0.000022 \\ 0.000017 & 0.000060 & 0.000013 & 0.000016 & 0.000015 & 0.000020 \\ 0.000015 & 0.000013 & 0.000065 & 0.000017 & 0.000024 & 0.000019 \\ 0.000019 & 0.000016 & 0.000017 & 0.000071 & 0.000030 & 0.000025 \\ 0.000026 & 0.000015 & 0.000024 & 0.000030 & 0.000069 & 0.000032 \\ 0.000022 & 0.000020 & 0.000019 & 0.000025 & 0.000032 & 0.000085 \end{bmatrix} \quad (22)$$

$$B_{mo} = 10^{-3} \; [-0.3908 \; -0.1297 \; 0.7047 \; 0.0591 \; 0.2161 \; -0.6635] \quad (23)$$

$$B_{oo} = [0.056] \quad (24)$$

