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A HYBRID TEACHING LEARNING BASED OPTIMIZATION ALGORITHM INTEGRATED WITH LINEAR REGRESSION

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A B S T R A C T :

The Economic Load Dispatch (ELD) problem plays a pivotal role in optimizing power system operations by determining the most cost-effective distribution of generation across available units. This study presents a new hybrid optimization strategy that integrates the Teaching-Learning-Based Optimization (TLBO) algorithm with adaptive parameter tuning and linear regression techniques. The objective is to improve the convergence behavior and solution accuracy when addressing the dynamic and complex nature of power systems. To validate the proposed methodology, simulations are conducted on two benchmark systems: the IEEE 30-bus and IEEE 14-bus networks. These standard test cases offer a comprehensive platform to evaluate the algorithm's performance across various operating conditions. The adaptive parameter tuning mechanism enables the algorithm to modify its parameters in real-time, enhancing responsiveness to evolving problem characteristics. Additionally, linear regression is utilized to uncover hidden relationships among variables, thereby strengthening the algorithm's modeling and prediction capabilities in the ELD context.

Keywords: Adaptive Parameter Control, Economic Load Dispatch, Linear Regression, TLBO.

1. Introduction

In modern power systems, the economic operation of electricity generation plays a vital role in meeting the ever-increasing demand for electricity while ensuring cost-effective and efficient power production. Economic load dispatch (ELD) is a fundamental optimization problem that aims to allocate the power output of various generators in a power system to meet the load demand while minimizing the total generation cost. It is a critical task for power system operators and energy planners to achieve an optimal balance between electricity supply and demand, considering economic factors. The objective of ELD is to determine the optimal power output for each generator in the system, taking into account several constraints and factors. These include the physical and operational constraints of generators, transmission line capacities, system stability, and most importantly, the cost of fuel or energy consumed by each generator. The goal is to minimize the total fuel cost or the overall operating cost of the system, which has a direct impact on the electricity tariffs for consumers and the profitability of power generation companies. ELD is a complex optimization problem due to the large number of variables involved, the nonlinear characteristics of the generation cost curves, and the constraints imposed by the system. Traditionally, mathematical programming techniques such as linear programming, nonlinear programming, and dynamic programming have been used to solve ELD problems. However, these techniques often suffer from high computational complexity, especially for large-scale power systems with diverse generator types and complicated constraints.

The sole objective of classical ED is to minimize the total fuel cost based on the following assumptions:

I. The cost function is smooth
II. Economic Dispatch is a static problem
III. Environmental pollutant emissions of thermal power plants are not considered.
IV. The startup and shut down costs are also neglected.

With these assumptions ED problem can be solved by using the traditional methods such as gradient search method, lambda iteration, Lagrange multiplier method, dynamic programming, linear programming etc. [4] However, these assumptions are impractical in the real world and do not give accurate results.

In recent years, various optimization algorithms and meta-heuristic techniques have gained significant attention for solving ELD problems more efficiently and effectively. These approaches include evolutionary algorithms, particle swarm optimization, genetic algorithms, simulated annealing, and ant colony optimization, among others. These techniques offer innovative and adaptive search mechanisms that can explore the solution space and find near-optimal solutions for ELD problems.

2. Illustrations

The theoretical review on Hybrid TLBO linear regression Algorithm is described, and the empirical review on previous research work performed for purpose of reviewing the achievements attained by the previous researchers and the current research gap in a concerned area. Economic dispatch is the way of determining the power output of each generation station in a power system aimed at reducing the fuel cost while satisfying the equality and inequality constraints of the system. This is done so as to meet the system load at a minimum possible cost of fuel with the main intention of reducing the operation cost [3]. Generally, each generating unit has its own characteristic depending on its efficiency and the type of fuel used which determine the relationship between the cost of fuel and power generated. The relationship function which relates fuel cost and generated power is normally termed cost function, depending on the type of the system this function can be a quadratic function or a quadratic function with ripples.
In [3], it is stated that;

$$L = F + \lambda(P_D - \sum_{i=1}^{N} P_{Gi}) \quad (1)$$

Where L stands for Lagrage equation and F for cost functions while PD is the power demand and PGi represents the generation of ith .unit.

Considering two units in a system, equation (2.1) can be written as;

$$L = F_1(P_1) + F_2(P_2) + \lambda(P_{load} - P_1 - P_2) \quad (2)$$

Considering the two generator cost functions gives the following equations:

$$F_1(P_1) = a_1 + b_1P_1 + c_1P_1^2 \quad (3)$$
$$F_2(P_2) = a_2 + b_2P_2 + c_2P_2^2 \quad (4)$$
$$F_3(P_3) = a_3 + b_3P_3 + c_3P_3^2 \quad (5)$$
$$F_4(P_4) = a_4 + b_4P_4 + c_4P_4^2 \quad (6)$$
$$F_5(P_5) = a_5 + b_5P_5 + c_5P_5^2 \quad (7)$$
$$F_6(P_6) = a_6 + b_6P_6 + c_6P_6^2 \quad (8)$$

Where a, b, and c are fuel cost coefficients of generator units.

$$L = a_1 + b_1P_1 + c_1P_1^2 + a_2 + b_2P_2 + c_2P_2^2 + a_3 + b_3P_3 + c_3P_3^2 + a_4 + b_4P_4 + c_4P_4^2 + a_5 + b_5P_5 + c_5P_5^2 + a_6 + b_6P_6 + c_6P_6^2 + \lambda(P_{load} - P_1 - P_{2\_}P_3 - P_4 - P_5 - P_6) \quad (9)$$

Lagrange differentiation of (9) with respect to P1, P2 and λ gives;

$$\frac{\partial L}{\partial P_1} = b_1 + 2c_1P_1 - \lambda \quad (10)$$
$$\frac{\partial L}{\partial P_2} = b_2 + 2c_2P_2 - \lambda \quad (11)$$
$$\frac{\partial L}{\partial P_3} = b_3 + 2c_3P_3 - \lambda \quad (12)$$
$$\frac{\partial L}{\partial P_4} = b_4 + 2c_4P_4 - \lambda \quad (13)$$
$$\frac{\partial L}{\partial P_5} = b_5 + 2c_5P_5 - \lambda \quad (14)$$
$$\frac{\partial L}{\partial P_6} = b_6 + 2c_6P_6 - \lambda \quad (15)$$

By optimizing the system, derivatives must be equal to zero (0), thus;

$$\frac{\partial L}{\partial P_1} = \frac{\partial L}{\partial P_2} = \frac{\partial L}{\partial P_3} = \frac{\partial L}{\partial P_4} = \frac{\partial L}{\partial P_5} = \frac{\partial L}{\partial P_6} = \frac{\partial L}{\partial \lambda} = 0 \quad (16)$$
$$P_{load} - \frac{\lambda - b_1}{2c_1} - \frac{\lambda - b_2}{2c_2} - \frac{\lambda - b_3}{2c_3} - \frac{\lambda - b_4}{2c_4} - \frac{\lambda - b_5}{2c_5} - \frac{\lambda - b_6}{2c_6} = 0 \quad (17)$$
$$P_1 = \frac{\lambda - b_1}{2c_1} \quad (18)$$
$$P_2 = \frac{\lambda - b_2}{2c_2} \quad (19)$$
$$P_3 = \frac{\lambda - b_3}{2c_3} \quad (20)$$
$$P_4 = \frac{\lambda - b_4}{2c_4} \quad (21)$$

$P_5 = \frac{\lambda - b_5}{2c_5}$ (22)

$P_6 = \frac{\lambda - b_6}{2c_6}$ (23)

Whereby P1 and P2 are dispatched power at the incremental cost.

the cost function is expressed as;

$cost = \sum_{i=1}^{NG} a_i P_i^2 + b_i P_i + c_i$ (24)

Where ai, bi, ci are fuel cost coefficient of ith unit and Pi is generated power by ith unit.

In [23], the economic load dispatch objective function is given as;

$Minimise\ (cost) = \sum_{i=1}^{NG} a_i P_i^2 + b_i P_i + c_i$ (25)

Under the two categories of constraints;

i) Equality constraints;

Power balance

$P_i = \sum_{i=1}^{NG} P_D + P_L$ (26)

Where PD and PL are load demand and power transmission losses respectively.

ii) Inequality constraints;

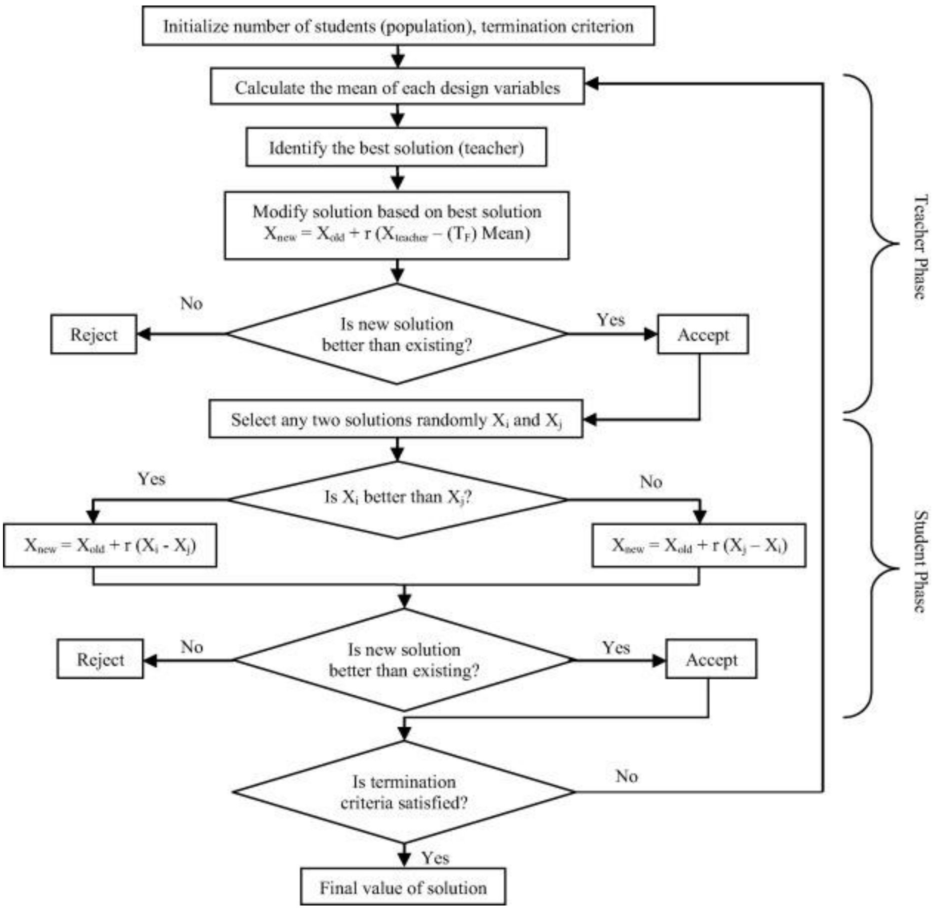
$P_{i(min)} \leq P_i \leq P_{i(max)}$ (27)

The economic dispatch objective function can be used for the bundled system in overall dispatch of power from power stations. For the case of unbundled system, the given objective function can be used for power dispatch of generators from the same power station.

3. Proposed Methodology

This paper evaluates the effectiveness of the hybrid algorithm using the test system "IEEE 30-bus system". These widely recognized test case provide diverse and realistic scenarios for assessing the proposed algorithm's performance under different operational conditions. The integration of adaptive parameter control allows the algorithm to dynamically adjust its parameters during optimization, ensuring adaptability to the changing characteristics of the ELD problem.

Figure 1: Flowchart of traditional TLBO algorithm.



IEEE 14-Bus System:

The IEEE 14-bus system [1] is a smaller test case, with three generator systems and with a load demand of 204.24 MW is a widely recognized benchmark system. The performance of the proposed Bat Algorithm integrated with linear regression is further analyzed through the results obtained for the IEEE 14-bus system across three different iterations: 50, 100, and 150.

Table 4.1: Power generation sharing in IEEE 14 bus system

Gen. No.	P_i^{Min} (MW)	P_i^{Max} (MW)	No. of Iterations		
			50	100	150
			P_i (MW)	P_i (MW)	P_i (MW)
G1	10	160	160.00	160.00	160.00
G2	20	80	24.20	24.23	24.24
G3	20	50	20.04	20.01	20.00
Total Cost (Rs./hr)			757.8920	757.8788	757.8780

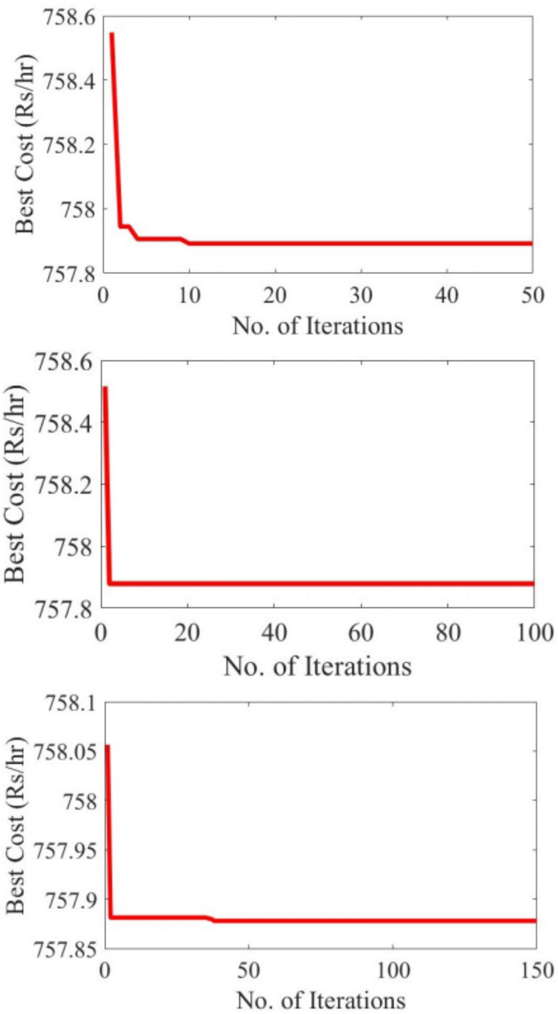


Figure 2: Cost minimization in power generation with different iterations.

The total operational cost reflects a minor improvement as the iterations increase, with costs of Rs. 757.8920/hr, Rs. 757.8788/hr, and Rs. 757.8780/hr for the respective iterations. This indicates that the proposed algorithm not only achieves optimal generation distribution among the generators but also contributes to cost efficiency. Moreover, Fig. 2 illustrates the convergence behaviour of the best cost over the iterations, highlighting the effectiveness of the TLBO Algorithm combined with linear regression in rapidly approaching an optimal solution. The graph depicts a steady decline in the best cost, demonstrating the algorithm's efficiency in refining the solution as more iterations are performed. Results indicate that the proposed hybrid approach effectively addresses the Economic Load Dispatch problem in the IEEE 14-bus system, resulting in optimal power generation sharing and cost minimization while ensuring adherence to operational constraints.

IEEE 30-Bus System:

The IEEE 30-bus system [12] provides a more complex scenario, reflecting a larger and more varied power network with load demand of 283.5 MW. These test systems serve as critical benchmarks for evaluating the performance and effectiveness of the proposed optimization methodology, offering varying levels of complexity and operational challenges. The **total cost** of power generation decreases with an increase in iterations, from Rs. 767.8724/hr for 50 iterations to Rs. 767.5896/hr for 150 iterations. This reduction in cost highlights the effectiveness of the proposed algorithm in minimizing the operational costs while ensuring an optimal power distribution.

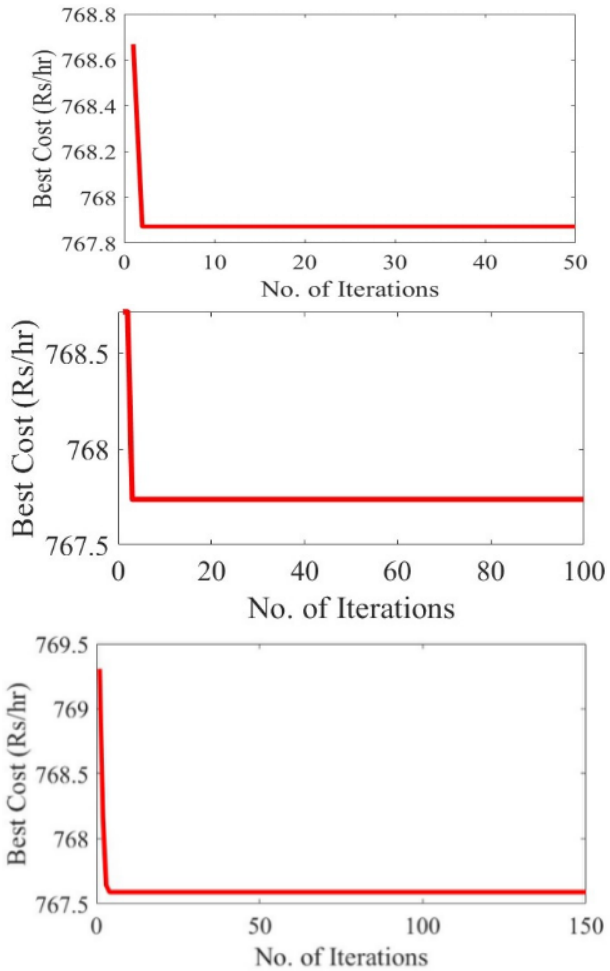


Figure 3: Cost minimization in power generation with different iterations.

Table 4: comparison with various algorithms.

Algorithms	Optimum Cost (Rs/hr) (100 iterations)	Optimum Cost (Rs/hr) (150 iterations)
Proposed TLBO algorithm with integration of linear regression	767.7368	767.5896
BAT [9]	768.8048	-
GA [13]	778.0762	-
CSA [14]	778.08	-
ADEEA [15]	773.4749	-

Linear regression plays a crucial role in enhancing the performance of the TLBO Algorithm by providing a statistical basis for predicting the relationship between variables and cost. By incorporating linear regression, the search process is more informed, allowing the algorithm to make more precise updates to the solution during iterations. This results in faster convergence and a lower overall cost, as evidenced by the results. The synergy between the heuristic nature of the Bat Algorithm and the analytical strength of linear regression provides a hybrid approach that effectively balances exploration and exploitation, leading to superior optimization for the economic load dispatch problem.

4. Conclusion

This work introduces an enhanced methodology for solving the Economic Load Dispatch (ELD) problem by combining the Teaching-Learning-Based Optimization (TLBO) algorithm with linear regression. The objective was to improve the efficiency and precision of determining an optimal generation schedule that minimizes fuel cost while adhering to operational constraints. The proposed approach was benchmarked against several well-established optimization techniques, including Genetic Algorithm (GA), Cuckoo Search Algorithm (CSA), and Adaptive Differential Evolution with External Archive (ADEEA). Results from this comparative study highlight the superior performance of the proposed hybrid method, particularly in terms of cost reduction. The integration of linear regression significantly contributes to this improvement by offering a predictive framework that guides the optimization process. By identifying patterns between decision variables and the objective function, linear regression enhances the update mechanism within TLBO, leading to faster and more accurate convergence. This synergy effectively combines TLBO's exploration capabilities with the predictive insight of linear regression, resulting in more efficient and reliable solutions for ELD problems. Overall, the hybrid TLBO approach consistently achieved lower operational costs compared to BAT and other traditional methods under identical system constraints.

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