

Combined Dynamic Economic Emission Dispatch using Teaching Learning Based Optimization

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ABSTRACT: Dynamic Economic Emission Dispatch (DEED) is a computational process of allocating generations to various generation plants so as to simultaneously minimize both fuel cost and emissions subject to load and operational constraints over a scheduling period. This paper proposes a method involving teaching-learning based optimization (TLO), for solving DEED to overcome the drawbacks of classical methods. TLO is inspired from the behavior of the students in improving their performance through gaining the knowledge from the teacher and interacting with other students. The proposed method partitions the DEED problem into as many as the number of sub-problems, and employs TLO in solving each sub-problem. The simulation results on standard test problem demonstrates that the proposed method is able to provide the global best solution.

KEYWORDS: dynamic economic emission dispatch; economic load dispatch; teaching-learning based optimization

NOMENCLATURE

a_i, b_i, c_i	fuel cost coefficients of the i^{th} generator
B, B_o, B_{oo}	loss coefficients
DEED	dynamic economic emission dispatch
DR_i	down-ramp limits of i^{th} generator
d_i, e_i	coefficients of valve point effects of the i^{th} generator
ED	emission dispatch
EED	economic emission dispatch
$E_i(P_{Gi})$	emission function of the i^{th} generator
$F_i(P_{Gi})$	fuel cost function of the i^{th} generator
nt	number of intervals
ng	number of generators
PM	proposed method
$P_{G_{it}}$	real power generation at i^{th} generator at interval- t
P_{Gi}^{\min} & P_{Gi}^{\max}	minimum and maximum generation limits of i^{th} generator respectively
P_{Dt}	total power demand at interval- t
P_{Lt}	net transmission loss at interval- t
UR_i	up-ramp limits of i^{th} generator in MW/h
$\Phi(P_G)$	objective function to be minimized
$\alpha_i, \beta_i, \gamma_i, \xi_i$ and δ_i	emission coefficients of i^{th} generator

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I. INTRODUCTION

Dynamic Economic Load Dispatch performs computation of the most economical generations so as to supply the forecasted power demand over a scheduling period at lowered operating cost, while satisfying several operational constraints that includes the ramp-rate limits of the generators. Operating at minimum fuel cost is not the only criterion for dispatching electric power, as the public are more concerned about environmental pollutions. Besides the enactment of the 'Clean Air Act Amendment of 1990' force the utilities to change their operating methodologies to meet environmental standards. The power plants using coal, oil and gas, releases pollutions such as sulphur oxides (SO_x), nitrogen oxides (NO_x) and carbon dioxide into the atmosphere. In the light of the fact that the economic load dispatch leads a large fuel cost savings, it causes large emissions. One of the simplest methodology in reducing the pollutions while at the same time lowering the fuel cost is the Dynamic Economic Emission Dispatch (DEED). Several researchers have considered emissions either in the objective function or treated emissions as additional constraints. Emission function, which is similar to fuel cost function, is the sum of all types of emissions, whose characteristic is sometimes non linear and the slope of the curve is not always positive [1].

Over the years, many methods were suggested in the literature for solving the DEED problems. At earlier stages, mathematical or heuristically-based approaches, such as gradient projection method [2], linear programming [3], interior point methods [4], etc. were developed. Though they have several advantages such as mathematically proven, suitable for large-scale problems and not requiring any problem-specific parameters, they may land at sub-optimal traps, be sensitive to the initial guess, require functions to be differential, not handle non-convex objective function, etc. To overcome these drawbacks, methods involving artificial intelligence, such as neural networks, fuzzy logic, genetic algorithm, differential evolution and particle swarm optimization were employed for solving the DEED problems [5-7]. Besides hybrid algorithms combining two or more approaches such as evolutionary programming with sequential quadratic programming [8], and Hopfield neural network with quadratic programming [9] were suggested for better results of DEED problems.

Recently, teaching learning based optimization (TLO), inspired from teaching-learning process in class rooms, was suggested for solving optimization problems by Rao et al. [10]. It mimics the behaviour of the students in improving their performance through gaining the knowledge from the teacher and interacting with other students. This paper attempts to apply TLO in solving the DEED problem by dividing the problem into several sub-problems for reducing the computational burden and improving the robustness.

II. PROBLEM FORMULATION

The DEED problem can be formulated as an optimization problem with an objective of lowering the total emissions of all ng generating units over the given dispatch period of nt intervals while satisfying several constraints.

$$\text{Minimize } \Phi(P_G) = \sum_{t=1}^{nt} \left\{ w \sum_{i=1}^{ng} F_i(P_{G_{it}}) + (1-w) \sum_{i=1}^{ng} E_i(P_{G_{it}}) \right\} \quad (1)$$

Subject to

$$\sum_{i=1}^{ng} P_{G_{it}} - P_{Dt} - P_{Lt} = 0 \quad t \in nt \quad (2)$$

$$P_{Gi}^{\min} \leq P_{G_{it}} \leq P_{Gi}^{\max} \quad i \in ng, t \in nt \quad (3)$$

$$\begin{aligned} P_{G_{it}} - P_{G_{it-1}} &\leq UR_i \quad i \in ng \quad t = 2, \dots, nt \\ P_{G_{it-1}} - P_{G_{it}} &\leq DR_i \quad i \in ng \quad t = 2, \dots, nt \end{aligned} \quad (4)$$

Where

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$$F_i(P_{G_{it}}) = a_i P_{G_{it}}^2 + b_i P_{G_{it}} + c_i + \left| d_i \sin \left\{ e_i (P_{G_{it}}^{\min} - P_{G_{it}}) \right\} \right| \quad (5)$$

$$E_i(P_{G_{it}}) = \alpha_i P_{G_{it}}^2 + \beta_i P_{G_{it}} + \gamma_i + \xi_i \exp(\delta_i P_{G_{it}}) \quad (5)$$

$$P_{Lt} = \sum_{i=1}^{ng} \sum_{j=1}^{ng} P_{G_{it}} B_{ij} P_{G_{jt}} + \sum_{k=1}^{ng} B_{0k} P_{G_{kt}} + B_{00} \quad (6)$$

III. PROPOSED METHOD

The number of decision variables in DEED problem equals the product of the number of generating plants and the number of intervals over the scheduling horizon, thereby making the solution process very complex involving large computational burden. The proposed method (PM) divides the DEED problem into a number of sub-problems, each representing an economic emission dispatch (EED) of interval- t and then employs TLO for solving each sub-problem, while at the same time accounting the ramp-rate limits. Each student [10] in the DEED is denoted to represent the real power generations of each sub-problem as

$$S_i = [P_{G1t}, P_{G2t}, \dots, P_{Gngt}] \quad (7)$$

The TLO explores the solution space for optimal solution by maximizing a performance function (F), which is formed as

$$\text{Maximize} \quad F = \frac{1}{1 + \sum_{i=1}^{ng} E_i(P_{G_{it}}) + K_1 \sum_{i=1}^{ng} (P_{G_{it}} - P_{Dt} - P_{Lt})^2} \quad (8)$$

At a random initial interval $t = t^0$, the lower and upper bounds of the student is set as

$$\begin{aligned} S^{\min} &= [P_{G1}^{\min}, P_{G2}^{\min}, \dots, P_{Gng}^{\min}] \\ S^{\max} &= [P_{G1}^{\max}, P_{G2}^{\max}, \dots, P_{Gng}^{\max}] \end{aligned} \quad (9)$$

The TLO is then applied for solving the EED problem of the initial interval- t . Then the same solution process is continues for the subsequent intervals $t = t + 1$, with the lower and upper limits for the students, set by accounting the ramp rate limits of Eq. (4) and solved using TLO.

$$\begin{aligned} S^{\min} &= [S_1^{\min}, S_2^{\min}, \dots, S_{ng}^{\min}] \\ S^{\max} &= [S_1^{\max}, S_2^{\max}, \dots, S_{ng}^{\max}] \end{aligned} \quad (10)$$

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Where

$$S_j^{\min} = \begin{cases} P_{Git-1} - DR_i & \text{if } (P_{Git-1} - DR_i) \geq P_{Gj}^{\min} \\ P_{Gj}^{\min} & \text{else} \end{cases}$$

$$S_j^{\max} = \begin{cases} P_{Git-1} + UR_i & \text{if } (P_{Git-1} + UR_i) \leq P_{Gj}^{\max} \\ P_{Gj}^{\max} & \text{else} \end{cases} \quad (11)$$

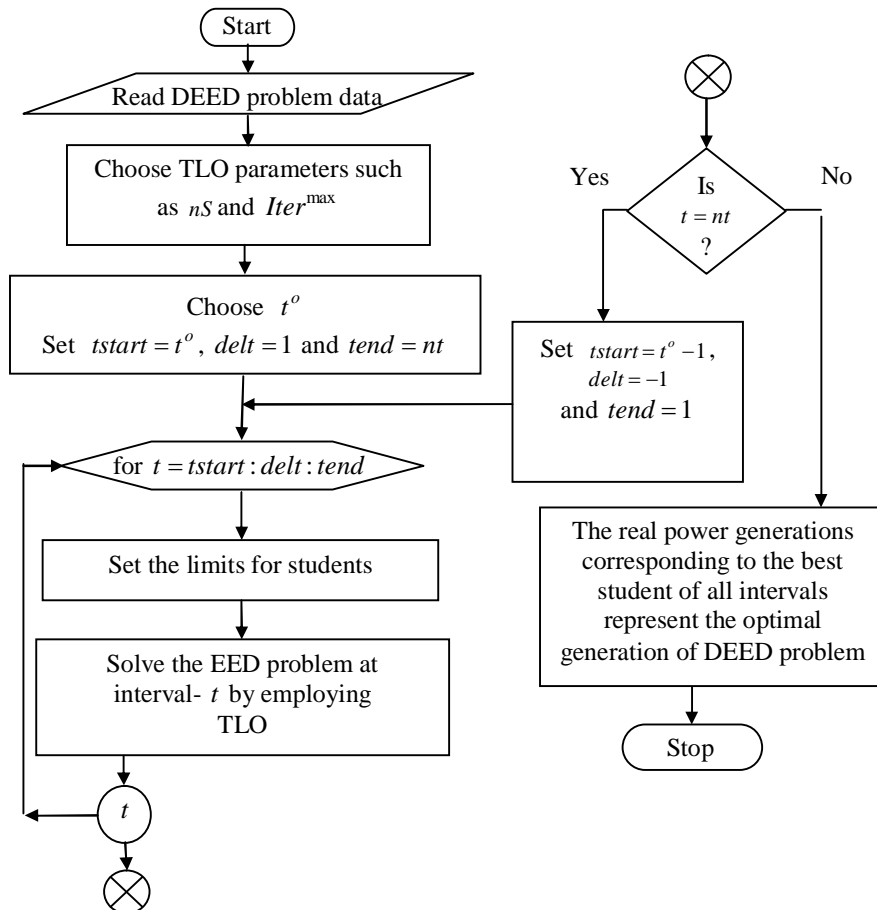


Fig 1 Outline of the PM

The above TLO based solution process is repeated by incrementing the interval - t till the last interval- nt of the scheduling horizon. Similarly the preceding sub-problems of the initial interval $t = t^o$ is obtained by decrementing the interval as $t = t - 1$ and solved using the TLO till the solution for the first interval is obtained. The limits of the students during this phase are modified as

$$h_j^{\min} = \begin{cases} P_{Git+1} - UR_i & \text{if } (P_{Git+1} - UR_i) \geq P_{Gj}^{\min} \\ P_{Gj}^{\min} & \text{else} \end{cases}$$

$$h_j^{\max} = \begin{cases} P_{Git+1} + DR_i & \text{if } (P_{Git+1} + DR_i) \leq P_{Gj}^{\max} \\ P_{Gj}^{\max} & \text{else} \end{cases} \quad (12)$$

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The real power generations obtained for each interval over the scheduling horizon represent the optimal solution of the DED problem. The solution process, requiring TLO [10], of the PM is explained through the flow chart of Fig .1.

IV. SIMULATION RESULTS

The PM is applied on a test system possessing 10 generating units. The real power generations of DEED, obtained by the PM with w as 0.5 in the objective function, for the test system are furnished in Table 1. The net fuel cost and emissions of the PM is also included in the same table. The solution offered by the PM is the compromised solution.

Table 1 Real power generations of DEED

Hour	P_D (MW)	Generations (MW)									
		P_{G1}	P_{G2}	P_{G3}	P_{G4}	P_{G5}	P_{G6}	P_{G7}	P_{G8}	P_{G9}	P_{G10}
1	1036	150	136.26	106.45	116.62	80.57	125.84	126.63	109.73	58.52	45.19
2	1110	150.57	135.07	173.54	96.29	117.34	135.43	127.12	85.71	63.63	47.94
3	1258	155.33	174.63	190.65	117.56	166.47	159.15	100.51	112.94	54.73	54.93
4	1406	199.71	156.94	237.03	157.82	187.63	135.03	125.57	107.64	80	54.96
5	1480	201.36	138.34	291.40	166.35	220.33	159.45	129.54	94.27	64.18	54.93
6	1628	183.57	217.84	292.29	205.36	233	160	129.95	119.93	80	54.95
7	1702	261.53	157.33	331.59	218.15	243	160	129.97	119.94	79.92	55
8	1776	273.55	226	295.76	253.14	242.15	160	129.94	119.94	79.93	55
9	1924	293.57	286.04	328.65	298.55	243	160	130	119.93	80	55
10	2022	317.92	358.82	337.33	299.68	243	160	130	120	80	55
11	2106	379.17	386.82	340	300	243	160	130	120	80	55
12	2150	394.35	420.18	340	300	243	160	130	120	80	55
13	2072	354.76	376.63	337.34	300	243	160	130	120	79.96	55
14	1924	289.18	305.03	320.47	292.36	242.85	160	130	120	80	55
15	1776	251.89	235.16	274.89	292.64	235.73	160	130	120	79.94	55
16	1554	181.14	215.94	210.89	244.57	225.43	157.87	129.80	119.92	58.64	54.93
17	1480	150.35	206.21	247.56	228.23	225.75	119.22	129.43	90.93	68.04	54.91
18	1628	161.72	249.63	285.47	246.29	228.47	143.26	129.73	119.32	58.12	54.93
19	1776	213.74	272.61	302.53	279.77	229.62	160	129.71	120	71.93	54.94
20	1972	291.84	328.81	338.12	300	242.93	160	130	120	80	55
21	1924	273.43	308.32	327.45	297.78	242.97	160	130	120	80	55
22	1628	211.43	229.52	252.57	256.15	222.49	136.35	129.94	119.92	63.87	55
23	1332	150.31	176.43	180.77	209.13	173.33	123.35	129.77	119.68	49.32	52.34
24	1184	150.23	135	135.36	178.97	151.92	131.11	129.84	118.27	24	54.65
Net Fuel Cost over 24 hours, \$/day							2522298.28				
Net Emissions over 24 hours, lb/day							285807.53				

V. CONCLUSION AND FUTURE WORK

DEED is a computational process of allocating generations to various generation plants so as to lower the net fuel cost and net emissions while satisfying various load and operational constraints over a scheduling period. The TLO, inspired from the pollination process of plants, searches for optimal solution for multimodal optimization problems. A novel methodology using TLO was developed for solving DEED problem, which is a complex non-linear optimization problem involving large number of decision variables and the ramp rate constraints. The problem is split into a number of sub-problems and each sub-problem is solved using TLO. The simulation results on a standard test system clearly

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exhibits the robustness and computational efficiency of the proposed method. The method can be extended to include adaptive techniques for tuning the parameters.

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