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Teaching-Learning Based Optimization for Economic Emission Dispatch

P. Aravindhababu

Professor, Department of Electrical Engineering, Annamalai University, Annamalainagar, Tamilnadu, India

ABSTRACT: Economic Emission Dispatch (EED) 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. This paper proposes a method involving teaching-learning based optimization (TLO), for solving EED 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 learner in the proposed method is modeled to denote the real power generations, and the performance function is tailored involving the objective function along with power balance constraint. The simulation results of a test system with 40 generating plants are presented to exhibit the superior performance of the proposed method.

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

I. INTRODUCTION

Today's power systems have the requirement of operating the system in an economical and reliable manner under changing load conditions. Economic dispatch (ELD), an opt methodology in operating the system economically, is a computational process whereby the total required generation is distributed among the generating units in operation so as to lower the total generation cost, subject to load and operational constraints. Recently, 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 (SOx), nitrogen oxides (NOx) and carbon dioxide into the atmosphere. In the light of the fact that the ELD leads a large fuel cost savings, it causes large emissions. One of the simplest methodology in reducing the pollutions is the Economic Emission Dispatch (EED), which simultaneously minimises both fuel cost and emissions [1].

In recent years, several classical methods such as lambda iteration, gradient search, linear programming, dynamic programming, quadratic programming and so on [2] were outlined in the literature for solving the EED problems. A few of these methods have drawbacks involving natural complexity and convergence issues. For example, the classical lambda-iteration method has convergence problems which depends on the initial choice of lambda values, leading to oscillatory issues and larger computation time. Another family of algorithms, called bio-inspired optimization algorithms, such as have been suggested for solving genetic algorithms (GA) [3], particle swarm optimization (PSO) [4], evolutionary programming (EP) [5], differential evolution (DE) [6], ant colony optimization (ACO) [7] etc. were applied for solving EED problems. These algorithms differ from one another only by the way of representing the problem variables, formation of fitness/cost functions and the mechanism adapted for creating new off-springs. These algorithms have been considered as a robust method, as they do not require derivatives of the functions.

Recently, teaching learning based optimization (TLO), inspired from teaching-learning process in class rooms, was suggested for solving optimization problems by Rao et al. [8,9]. 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 proposes a method involving TLO for solving EED problem to overcome the drawbacks of classical methods.

II. PROBLEM FORMULATION

The EED problem may be developed by defining an objective function involving both minimization of net fuel costs and emissions of real power generations while satisfying several equality and inequality constraints as Minimize

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$$\Phi(P_G) = w\sum_{i=1}^{ng} a_i\, P_{Gi}{}^2 + b_i\, P_{Gi} + c_i + \left| d_i \sin\left\{e_i (P_{Gi}^{\min} - P_{Gi})\right\}\right| + (1-w)\sum_{i=1}^{ng}\alpha_i\, P_{Gi}{}^2 + \beta_i\, P_{Gi} + \gamma_i + \xi_i \exp(\delta_i\, P_{Gi}) \tag{1}$$

Subject to

$$\sum_{i=1}^{ng} P_{Gi} - P_D - P_L = 0 \tag{2}$$

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \qquad i = 1, 2, \cdots, ng \tag{3}$$

Where

$$P_L = \sum_{i=1}^{ng}\sum_{j=1}^{ng} P_{Gi} B_{ij} P_{Gj} + \sum_{i=1}^{ng} B_{oi} P_{Gi} + B_{oo} \tag{4}$$

$a_i\ b_i\ c_i$ represent fuel cost coefficients of the i^{th} generator
$\alpha_i, \beta_i, \gamma_i,\ \xi_i$ and δ_i are the emission cost coefficients.
$B\ B_o\ B_{oo}$ indicates loss coefficients
$\Phi(P_G)$ denotes net fuel cost and emissions
ng represents number of generators
P_D denotes the total power demand
P_L indicates the net transmission loss
P_{Gi} represents real power generation at i^{th} generator
w indicates the weight factor

III. PROPOSED METHOD

The proposed method (PM) employs TLO for solving EED problem. In this approach, each student represents a solution point and his performance is analogous to fitness value of the problem. The best student in the population is considered as the teacher. A group of students comprising a teacher forms the population and the solution process is governed by two basic operations, namely teaching and learning phases. The procedure involves representation of problem variables and the formation of a performance function (B). Each student (S) in the TLO is defined to indicate the real power generations of all generating plants as

$$S = [P_{G1}, P_{G2}, P_{G3}, \cdots, P_{Gng}] \tag{5}$$

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

$$Maximize \quad F = \frac{1}{1 + \Phi(P_G) + \lambda\left(\sum_{i=1}^{ng} P_{Gi} - P_D - P_L\right)^2} \tag{6}$$

In teaching phase, the students gain knowledge from the teaching delivered by a teacher in the class. The mean grade point of the subject increases and the difference between the grade point of the teacher and the mean grade point of the subject is expressed as

$$\Delta S^{jk} = rand(0,1) \times \left(S_{teacher}^{jk} - t_f\ S^{jk\,ave}\right) \tag{7}$$

Where

$S^{jk\ ave}$ is the mean grade of the j-th subject at k-th iteration and computed by

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$$S^{j\,k\,ave} = \frac{1}{nS}\sum_{i=1}^{nS} S_i^{j\,k} \tag{8}$$

$S_{teacher}^{j\,k}$ is the grade point of the j-th subject of the teacher at k-th iteration

t_f is the teaching factor

The new grade point of the j-th subject of the i-th student, as a result of teaching, is mathematically modeled by

$$S_i^{j\,k+1} = S_i^{j\,k} + \Delta S^j \tag{9}$$

The grade points of all the students at the teachers phase are further improved by the learner phase.

In the learning phase, the students enrich their knowledge by interaction among themselves for improving their performances. The influence on the grade points due to the interaction of p-th student with q-th student may be mathematically expressed as follows:

$$S_p^{j\,k+1} = \begin{cases} S_p^{j\,k} + rand \times \left(S_p^{j\,k} - S_q^{j\,k}\right) & if\ F_p > F_q \\ S_p^{j\,k} + rand \times \left(S_q^{j\,k} - S_p^{j\,k}\right) & otherwise \end{cases} \tag{10}$$

Where F_p and F_q is the performance, indicating the fitness, of the p-th and q-th student respectively.

An initial population of students is obtained by generating random values within their respective limits to every individual in the population. The fitness F is calculated by considering the grade points of each student; and the teaching and learning phases are performed for all the students in the population with a view of maximizing their performances. The iterative procedure is continued until the number of iterations reaches the specified maximum number of iterations. The real power generations obtained from best student in the population is EED solutuion.

IV. SIMULATION RESULTS

The PM is applied on a test system comprising 40 generating units. The fuel cost coefficients, emission coefficients and generation limits of the test system are available in [10]. The ELD generations are obtained by setting w as one, and the ELD solution, fuel cost and emissions are compared with the results of two existing methods [11,12] for a power demand of 10500 MW in Table 1. It can be observed that the PM offers the lowest fuel cost of 121414.537 S/h

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Table 1 Comparison of ELD, ED and EED solutions for a demand of 10500 MW

Gen. No	ELD			ED	EED
	PM	Ref. [11]	Ref. [12]	PM	PM
1	110.8076	110.8016	114.0000	114.0000	114.0000
2	110.8083	110.8068	114.0000	114.0000	113.9997
3	97.4007	97.4007	120.0000	116.1197	120.0001
4	179.7333	179.7333	179.8000	158.4350	166.6002
5	87.8034	87.8180	97.0000	97.0000	97.0001
6	140.0000	139.9997	140.0000	116.1143	120.4104
7	259.6001	259.6010	300.0000	280.8852	290.0563
8	284.6014	284.6000	300.0000	280.8545	286.7944
9	284.6025	284.6005	300.0000	280.8448	286.7622
10	130.0000	130.0003	130.0000	279.4383	281.2525
11	168.7997	168.7999	94.0000	280.8620	289.7792
12	168.7997	168.7999	94.0000	280.8562	289.6513
13	214.7593	214.7599	125.0000	413.0693	416.0094
14	394.2792	394.2794	304.6000	412.9083	417.0163
15	304.5194	304.5196	394.3000	412.9205	417.0718
16	394.2791	394.2794	304.6000	412.9198	417.1295
17	489.2790	489.2796	489.3000	413.1603	421.4272
18	489.2790	489.2795	489.3000	413.1621	421.3039
19	511.2791	511.2794	511.3000	413.1607	421.5196
20	511.2792	511.2796	511.3000	413.1582	421.5195
21	523.2795	523.2797	550.0000	413.1606	433.5196
22	523.2793	523.2798	525.8909	413.1612	433.5195
23	523.2795	523.2801	549.9211	413.1653	433.5196
24	523.2795	523.2795	550.0000	413.1675	433.5196
25	523.2795	523.2797	523.3333	413.1712	433.5199
26	523.2796	523.2799	550.0000	413.1738	433.5196
27	10.0000	10.0004	10.0000	150.0000	63.6298
28	10.0000	10.0004	10.0000	150.0000	63.2638
29	10.0000	10.0003	10.0000	150.0000	64.1013
30	92.7134	92.7158	97.0000	97.0000	97.0000
31	190.0000	189.9998	190.0000	158.4840	162.8196
32	190.0000	189.9998	190.0000	158.4825	162.7895
33	190.0000	189.9998	190.0000	158.4831	162.9171
34	164.8021	164.8014	200.0000	200.0000	200.0000
35	164.8041	164.8015	200.0000	200.0000	200.0000
36	164.8022	164.8051	200.0000	200.0000	200.0000
37	110.0000	109.9998	110.0000	93.8352	97.0940
38	110.0000	109.9998	110.0000	93.8363	97.1930
39	110.0000	109.9996	110.0000	93.8342	97.2408
40	511.2793	511.2797	511.3547	413.1594	421.5196
Net Fuel Cost	121414.537	121414.6978	122186.9048	161371.692	133218.179
Emissions	285835.7467	---	---	66663.583	81163.561

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while the existing methods leads to 121414.6978 $/h and 122186.9048 $/h, thereby exhibiting that the proposed method is robust in obtaining the global best solution. The results comprising real power generations, the fuel cost and emissions for ED, obtained by setting w as zero, are also included in the same table. It is seen that the emissions are lower value of 66663.583 kg/h and fuel cost is much higher value of 161371.692 $/h in this case. The table also includes the results of EED solution, obtained by setting w as 0.5. It is seen from the results of EED that the EED solution lies in between the best fuel cost and best emissions. The PM attempts to lower the fuel cost, minimizes emissions and extracts satisfactory results in relation to those obtained by ELD and ED.

V. CONCLUSION AND FUTURE WORK

EED is a computational process of economically allocating generations to various generation plants subject to load and operational constraints. A TLO based method for solving EED problem was proposed in this paper. The firefly was represented to denote the real power generations and the brightness function was built comprising objective function and power balance constraint. The method has been run for 100 iterations and the obtained results were compared with those of existing methods for a system with 13 generating units. The results have illustrated the effectiveness of the algorithm in finding the global best solution.. The proposed method involving TLO will culminate itself as a powerful tool in solving EED problem at energy control centers. The objective function can be modified to include emissions and the method can be extended to obtain a compromised solution.

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