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Teaching–learning-based optimization algorithm for multi-area economic dispatch

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ABSTRACT

This paper presents teaching–learning-based optimization algorithm for solving MAED (multi-area economic dispatch) problem with tie line constraints considering transmission losses, multiple fuels, valve-point loading and prohibited operating zones. TLBO (teaching–learning-based optimization) is one of the recently proposed population based algorithms which simulates the teaching–learning process of the class room. It is a very simple and robust global optimization technique. The effectiveness of the proposed algorithm has been verified on three different test systems, both small and large, involving varying degree of complexity. Compared with differential evolution, evolutionary programming and real coded genetic algorithm, considering the quality of the solution obtained, the proposed algorithm seems to be a promising alternative approach for solving the MAED problems in practical power system.

1. Introduction

ED (economic dispatch) [1] is one of the important optimization problems in power system operation. ED allocates the load demand among the committed generators most economically while satisfying the physical and operational constraints in a single area. Generally, the generators are divided into several generation areas interconnected by tie-lines. MAED (multi-area economic dispatch) is an extension of economic dispatch. MAED determines the generation level and interchange power between areas such that total fuel cost in all areas is minimized while satisfying power balance constraints, generating limits constraints and tie-line capacity constraints.

The economic dispatch problem is frequently solved without considering transmission constraints. However, some researchers have taken transmission capacity constraints into account. Shoults et al. [2] solved economic dispatch problem considering import and export constraints between areas. This study provides a complete formulation of multi-area generation scheduling, and a framework for multi-area studies. Romano et al. [3] presented the Dantzig–Wolfe decomposition principle to the constrained economic dispatch of multi-area systems. Doty and McEntire [4] solved a multi-area economic dispatch problem by using spatial dynamic programming and the result obtained was a global optimum. An application of linear programming to transmission constrained production cost analysis was proposed in Ref. [5]. Helmick et al. [6] solved multi-area economic dispatch with area control error. Ouyang et al. [7] proposed heuristic multi-area unit commitment with economic dispatch. Wang and Shahidehpour [8] proposed a decomposition approach for solving multi-area generation scheduling with tie-line constraints using expert systems. Network flow models for solving the multi-area economic dispatch problem with transmission constraints have been proposed by Streiffert [9]. An algorithm for multi-area economic dispatch and calculation of short range margin cost based prices has been presented by Wernerus and Soder [10], where the multi-area economic dispatch problem was solved via Newton–Raphson's method. Yalcinoz and Short [11] solved multi-area economic dispatch problems by using Hopfield neural network approach. Jayabarathi et al. [12] solved multi-area economic dispatch problems with tie line constraints using evolutionary programming. The direct search method for solving economic dispatch problem considering transmission capacity constraints was presented in Ref. [13]. Manoharan et al. [14] explored the performance of the various evolutionary algorithms on multi-area economic dispatch (MAED) problems.

Here, evolutionary algorithms such as the RCGA (Real-Coded Genetic Algorithm), PSO (Particle Swarm Optimization), DE (Differential Evolution) and CMAES (Covariance Matrix Adapted Evolution Strategy) are considered. MAEED (multi-area economic environmental dispatch) problem is proposed in Ref. [15]. Here, MAEED problem is handled by an improved MOPSO (multi-objective particle swarm optimization) algorithm for searching out the

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Pareto-optimal solutions. Sharma et al. [16] have presented a close comparison of classic PSO and DE strategies and their variants for solving the reserve constrained multi-area economic dispatch problem with power balance constraint, upper/lower generation limits, ramp rate limits, transmission constraints and other practical constraints. In Ref. [17] a discussion of "Reserve constrained multi-area economic dispatch employing differential evolution with time-varying mutation" has been presented.

TLBO(teaching–learning-basedoptimization),ateaching–learning processinspiredalgorithmrecentlyproposedbyRaoetal.[18,19]andRao andPatel[20]isbasedontheeffectofinfluenceofateacherontheoutputof learnersinaclass.Itisapopulation-basedmethodanddoesnotrequireany algorithm-specificcontrolparameters.ThemainadvantageofTLBOisthat itrequiresonlycommoncontrollingparameterslikepopulationsizeand numberofiterationsforitsworking.TLBOhasbeenappliedsuccessfullyto parameteroptimizationproblemofmodernmachiningprocesses[21].

In this paper, TLBO has been applied to solve MAED problem. Here, three types of MAED problems have been considered. These are A) MAEDQCPOZTL (multi-area economic dispatch with quadratic cost function, prohibited operating zones and transmission losses), B) MAEDVPL (multi-area economic dispatch with valve point loading), C) MAEDVPLMFTL (multi-area economic dispatch with valve point loading multiple fuel sources and transmission losses).

The proposed TLBO approach has been validated by applying it to three different test systems. The performance of the proposed TLBO in terms of solution quality has been compared with differential evolution (DE), EP (evolutionary programming) and real coded genetic algorithm (RCGA).

2. Problem formulation

The objective of MAED is to minimize the total production cost of supplying loads to all areas while satisfying power balance constraints, generating limits constraints and tie-line capacity constraints.

Three different types of MAED problems have been considered.

2.1. Multi-area economic dispatch with quadratic cost function, prohibited operating zones and transmission losses (MAEDQCPOZTL)

The objective function F_t, total cost of committed generators of all areas, of MAED problem may be written as

$$F_t = \sum_{i=1}^{N}\sum_{j=1}^{M_i} F_{ij}(P_{ij}) = \sum_{i=1}^{N}\sum_{j=1}^{M_i}\left(a_{ij} + b_{ij}P_{ij} + c_{ij}P_{ij}^2\right) \quad (1)$$

where $F_{ij}(P_{ij})$ is the cost function of jth generator in area i and is usually expressed as a quadratic polynomial; a_{ij}, b_{ij} and c_{ij} are the cost coefficients of jth generator in area i; N is the number of areas, M_i is the number of committed generators in area i; P_{ij} is the real power output of jth generator in area i. The MAED problem minimizes F_t subject to the following constraints.

2.1.1. Real power balance constraint

$$\sum_{j=1}^{M_i} P_{ij} = P_{Di} + P_{Li} + \sum_{k,k\neq i} T_{ik} \quad i \in N \quad (2)$$

The transmission loss P_{Li} of area i may be expressed by using B-coefficients as

$$P_{Li} = \sum_{l=1}^{M_i}\sum_{j=1}^{M_i} P_{ij}B_{ilj}P_{il} + \sum_{j=1}^{M_i} B_{0ij}P_{ij} + B_{00i} \quad (3)$$

where P_{Di} real power demand of area i; T_{ik} is the tie line real power transfer from area i to area k. T_{ik} is positive when power flows from area i to area k and T_{ik} is negative when power flows from area k to area i.

2.1.2. Tie line capacity constraints

The tie line real power transfer T_{ik} from area i to area k should not exceed the tie line transfer capacity for security consideration.

$$-T_{ik}^{\max} \le T_{ik} \le T_{ik}^{\max} \quad (4)$$

where $T_{ik}^{\max}$ is the power flow limit from area i to area k and $-T_{ik}^{\max}$ is the power flow limit from area k to area i.

2.1.3. Real power generation capacity constraints

The real power generated by each generator should be within its lower limit $P_{ij}^{\min}$ and upper limit $P_{ij}^{\max}$, so that

$$P_{ij}^{\min} \le P_{ij} \le P_{ij}^{\max} \quad i \in N \text{ and } j \in M_i \quad (5)$$

2.1.4. Prohibited operating zone

The prohibited operating zones in the input–output performance curve for a typical thermal unit can be due to vibration in a shaft bearing caused by a steam valve or can be due to faults in the machines themselves or the associated auxiliary equipment, such as boilers, feed pumps etc. In practice, the shape of the input–output curve in the neighborhood of a prohibited zone is difficult to determine by actual performance testing. In actual operation, the best economy is achieved by avoiding operation in these areas. Cost function that takes into account prohibited operating zones, can be represented as in Fig. 1.

The feasible operating zones of unit can be described as follows:

$$\begin{aligned} &P_{ij}^{\min} \le P_{ij} \le P_{ij,1}^{l} \\ &P_{ij,m-1}^{u} \le P_{ij} \le P_{ij,m}^{l}; \quad m = 2,3\ldots,n_{ij} \\ &P_{ij,n_{ij}}^{u} \le P_{ij} \le P_{ij}^{\max} \end{aligned} \quad (6)$$

where m represents the number of prohibited operating zones of j the generator in area i. $P_{ij,m-1}^{u}$ is the upper limit of $(m-1)$th prohibited operating zone of j the generator in area i. $P_{ij,m}^{l}$ is the lower

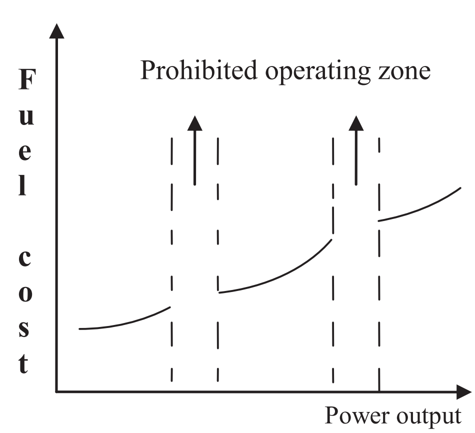

Fig. 1. Input–output curve with prohibited operating zones.