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Teaching learning based optimization for short-term hydrothermal scheduling problem considering valve point effect and prohibited discharge constraint

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ABSTRACT

This article presents a novel teaching learning based optimization (TLBO) to solve short-term hydrothermal scheduling (HTS) problem considering nonlinearities like valve point loading effects of the thermal unit and prohibited discharge zone of water reservoir of the hydro plants. TLBO is a recently developed evolutionary algorithm based on two basic concept of education namely teaching phase and learning phase. In first phase, learners improve their knowledge or ability through the teaching methodology of teacher and in second part learners increase their knowledge by interactions among themselves. The algorithm does not require any algorithm-specific parameters which makes the algorithm robust. Numerical results for two sample test systems are presented to demonstrate the capabilities of the proposed TLBO approach to generate optimal solutions of HTS problem. To test the effectiveness, three different cases namely, quadratic cost without prohibited discharge zones; quadratic cost with prohibited discharge zones and valve point loading with prohibited discharge zones are considered. The comparison with other well established techniques demonstrates the superiority of the proposed algorithm.

1. Introduction

The hydro thermal generation scheduling problem is a complex nonlinear dynamic constrained optimization problem, which plays an important role for economic operation of electric power systems. As hydro-electric energy may be regarded as a renewable source of energy fueled by the sun, production of hydro-generation is essential for the welfare, development and the economic progress of the society. Furthermore, production of hydro-generation minimizes the use of costly and limited source of fossil fuels, which results in minimum environmental damage that produced by thermal, diesel and nuclear power plants. The objective of short-term HTS of power systems is to determine the optimal hydro and thermal generations in order to meet the load demands over a scheduled horizon of time while satisfying the various constraints on the hydraulic and thermal power system network. The optimal scheduling of hydrothermal power system is usually more complex than that for all-thermal system. It is basically a nonlinear problem involving nonlinear objective function and a mixture of linear and nonlinear constraints.

A number of researchers have been extensively investigating the HTS problems for last few decades. A bibliographical survey on HTS reveals that various numerical optimization techniques have been employed to resolve the HTS problem. HTS is solved raditionally using mathematical based optimization techniques such as variational calculus [1]; dynamic programming (DP) [2–4]; linear programming (LP) [5–7]; decomposition method (DM) [8–10]; progressive optimality algorithm [11] and quadratic programming [12]. Because of the highly nonlinear characteristics of the HTS problem with many local optimum solutions and a large number of constraints, these classical methods may not perform satisfactorily in solving HTS problems. Though DP [2,3] is not affected by the nonlinearity and discontinuity, it suffers from the "curse of dimensionality" and local optimality. The neural networks approach [13,14] may also be applied to solve the HTS problems. However, the neural network-based approaches may suffer from excessive numerical iterations, resulting in enormous calculations.

Over the past few years, the studies on population based techniques have shown that these methods can be efficiently used to eliminate most of the difficulties of classical methods. Evolutionary programming (EP) is probably the oldest meta heuristic optimization technique used to solve optimization problems. The EP emphasizes the relationship between parents and their offspring and it relies exclusively on a mutation operator to produce offspring. There is no recombination process in EP. Yang et al. proposed EP algorithm to solve the HTS problem [15]. Later on, Sinha et al. proposed fast evolutionary programming (FEP) and improved

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Nomenclature

$FC(PT)$	the total fuel cost of the thermal units
$PT_{i,j}$, $PH_{i,j}$	the power generation of the ith thermal and hydro unit, respectively, at the jth time interval
$PT_i^{\min}, PT_i^{\max}$	the minimum and maximum power generation, respectively, of the ith thermal plant
$PH_i^{\min}, PH_i^{\max}$	the minimum and maximum power generation, respectively, of the ith hydro plant
P_{L_j}	the transmission loss at the jth time interval. However, for simplicity, the transmission loss has not been taken into consideration in this article
P_{D_j}	the load demand at the jth time interval
a_i, b_i, c_i, d_i, e_i	the fuel cost coefficients of the ith thermal generating unit
$c_{1,i}$, $c_{2,i}$, $c_{3,i}$, $c_{4,i}$, $c_{5,i}$, $c_{6,i}$	the power generation coefficients of ith hydro generating unit
$Q_{i,j}$	the water discharge of the ith hydro plant during the jth time interval
$Q_i^{\min}, Q_i^{\max}$	the lower and upper limits of reservoir water discharge of the ith hydro plant
$V_{i,j}$	the water storage level in the ith hydro reservoir at the beginning of the jth time interval
V_i^{begin}, V_i^{end}	the initial and final storage volume of the ith reservoir
V_i^1, V_i^{25}	the volume of the ith reservoir at the beginning of 1st and 25th hour
$V_i^{\min}, V_i^{\max}$	the minimum and maximum water storage level limit, respectively, of the ith hydro reservoir
$D_{k,i}$	the water transport delay from kth to ith reservoir
u_i	the number of upstream hydro generating plants immediately above the ith reservoir
$I_{i,j}$	the natural inflow of the ith reservoir at the jth time interval
$S_{i,j}$	the spillage discharge rate of the ith reservoir at the jth time interval
n_h, n_t	the number of hydro and thermal generating units
NH	the number of time intervals
$rand$	random number between [0, 1]
$x_{i,j}^k, x_{i,j}^{k+1}$	the grade of the jth subject of the ith student at the kth and $(k+1)$ th iteration
$\mu_{diff_j}^k$	the difference between the mean of the jth control variable at the kth and $(k+1)$ th iteration
r_1	random number between [0, 1]

FEP (IFEP) techniques [16] to solve HTS problem. This paper claimed that IFEP was the best among the three EP techniques. Basu [17] reported a fuzzy based EP technique for the economic-environmental HTS problem. Simulated annealing (SA) is a powerful optimization technique but in practice, the annealing schedule of SA should be carefully tuned otherwise achieved solution will still be of locally optimal. Nevertheless, an appropriate annealing schedule often requires tremendous computation time. Wong et al. [18] implemented SA algorithm for solving the HTS problem. Genetic algorithm (GA) is another commonly used evolutionary technique and is based on selection, crossover and mutation operation. Orero et al. presented a GA approach to solve HTS problem [19]. Kumar et al. proposed GA [20] to solve the hydrothermal scheduling problem with optimal power flow (OPF). The proposed algorithm was implemented on 9 bus and 66 bus systems and its simulation results were compared with DA and LP. However, recent research has identified some deficiencies in GA performance. An efficient multi-objective based genetic algorithm for solving combined economic emission hydro-thermal scheduling was developed by Gjorgiev et al. [21]. However, the premature convergence of GA degrades its performance and reduces its search capability that may lead to obtain local optimum solutions. Particle swarm optimization (PSO), first introduced by Kennedy and Eberhart, is one of the most popular heuristic algorithms. The literature survey of PSO reveals that this technique is able to generate high-quality solutions with less computational time. It has also been found that PSO is robust and can produce stable convergence characteristics than most of the other stochastic methods. An improved PSO to solve a multi-reservoir cascaded hydro-electric system having prohibited discharge zones and a thermal unit with valve point loading is proposed by Hota et al. [22]. The simulation results showed its superiority over other techniques. Modified adaptive PSO (MAPSO) based HTS [23] was introduced by Amjady et al. and was implemented on six test systems. Mahor et al. [24] presented al self-adaptive inertia weight based PSO approach to determine the optimal generation scheduling of cascaded hydro-electric system. The differential evolution (DE) is another well popular, simple, versatile and robust algorithm, in which only few parameters of algorithm is required to be set. A short term HTS based DE algorithm was introduced by Mandal et al. [25]. However, it is difficult to properly choose the control parameters of DE and the faster convergence of DE results in a higher probability of searching toward a local optimum or getting premature convergence. A tabu search (TS) technique for finding the optimal scheduling of hydrothermal system was reported by Bai et al. [26]. The main advantage of the TS algorithm is its ability to escape from local optima and fast convergence to the global optimum. However, a conventional TS algorithm might have problems of reaching the global optimum solution in a reasonable computational time when the initial solution is far away from the region where the global optimum solution exists. The ant colony optimization (ACO) algorithm is inspired by the behaviors of real ant colonies. By analyzing the behaviors of real ants, it may be observed that the ants are capable of finding the shortest path from the nest to the food source without using cues. The ACO applied to solve HTS problems was reported by Huang [27]. Liao et al. [28] proposed adaptive artificial bee colony (AABC) algorithm to solve long-term dispatch of cascaded hydropower systems and compared its efficiency with other existing techniques. Matos et al. [29] developed stochastic dynamic dual programming for solving the long-term hydrothermal scheduling problems. Other recent computational intelligence tools are biogeography based optimization (BBO) [30], quasi oppositional BBO (QOBBO) [31] and gravitational search algorithm (GSA) [32]. However, these techniques have never been used to solve HTS problem.

Teaching learning based optimization (TLBO) [33] is a new optimization technique developed by Rao et al. and it has hardly been used to solve power system optimization problem. This article presents TLBO algorithm to solve short-term HTS problem having several equality and non-equality constraints on thermal plants as well as hydroelectric plants. The test system consists of a multi-chain cascade of four hydro units and one thermal unit. To demonstrate the effectiveness of the proposed TLBO algorithm, the three different cases namely quadratic cost without prohibited discharge zones; quadratic cost with prohibited discharge zones and valve point loading with prohibited discharge zones have been consid-