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An efficient chaos embedded hybrid approach for hydro-thermal unit commitment problem

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ABSTRACT

This paper establishes a model to deal with the short-term hydrothermal generation scheduling (SHTGS) problem. The problem is composed of three interconnected parts: short-term hydrothermal coordination, thermal unit commitment and economic load dispatch. An efficient hybrid method composed of chaotic backtracking search optimization algorithm and binary charged system search algorithm (CBSA–BCSS) is proposed to solve this problem. In order to analyze the effect of the chaotic map on the performance of the method, three different chaotic maps are adopted to integrate into the proposed method and the corresponding consequences are achieved. Furthermore, efficient heuristic search strategies are adopted to handle with the complicated constraints of the SHTGS system. Finally, a hydrothermal unit commitment system is utilized to verify the feasibility and effectiveness of the proposed method. The results demonstrate the efficiency of the hybrid optimization method and the appropriation of the constraint handling strategies. The comparison of the solutions achieved by different methods shows that the proposed method has higher efficiency in terms of solving SHTGS problem.

1. Introduction

Short-term hydrothermal generation scheduling (SHTGS) is one of the most important optimization problems in power system. It aims at finding the optimal amount of the water release for the hydro plants and generation output for thermal units in the system to meet the load demands as well as other various constraints over a scheduling horizon [1]. Generally, the SHTGS can be divided into three sub-problems, short-term hydrothermal coordination (SHC), thermal unit commitment (TUC) and economic load dispatch (ELD), according to the solution mechanism [2]. The structure of the problem and the relationships among the sub-problems can be described as Fig. 1. In the problem, the solution space of the SHC and the ELD are continuous while the TUC is a discrete problem with its solution in binary encoding space. Mathematically, the SHTGS is a large-scale, dynamic and nonlinear constrained programming problem, which makes the optimization process intractable.

Many researches associated with SHTGS problem have been done [1–13]. In Refs. [3–7], authors established different models of short-term hydro generation scheduling problem and heuristic optimization methods are adopted to deal with the models presented. The objective was set to minimize the deviation between load demand and generation through hydro power plants for the schedule horizon in Refs. [3,4]. While in Refs. [5,6] the target was to maximum the expected profit of the hydropower generation in the day-ahead market. Authors in Ref. [7] established a short-term economic dispatch model to maximize the total hydroelectric generation. However, these studies only considered the hydroelectric in the power system and did not take the thermal power generation into account. Refs. [8–13] studied the short-term thermal generation scheduling problem, which is also known as thermal unit commitment (TUC). The TUC refers to the optimization problem in determining the start-up and shut-down schedule of thermal generating units over a scheduling period. Its objective is to minimize the total operation cost while satisfying various constraints, such as minimum up/down constraint and ramp-up/down capacity constraints. Many effective methods have been proposed to solve TUC and lots of satisfactory results have been achieved such as mixed-integer linear programming (MILP) [8], quantum-inspired binary gravitational search algorithm (QBGSA) [9], binary particle swarm optimization (BPSO) [10] and discrete differential evolution approach (DE) [11,12], second order cone programming (SOCP) [13] and so on. Whereas, in actual electric power system, the thermal-electric and hydro-electric are closely connected and

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hydro-thermal joint scheduling is studied extensively by researches. Refs. [14–19] established proper models for short-term hydro-thermal joint scheduling system and focused their studies on finding a fast and efficient method to deal with the problem. The methods presented in these literatures such as genetic algorithm (GA) [14], gravitational search algorithm (GSA) [15], cultural algorithm (CA) [16] and particle swarm optimization (PSO) [17,18], neural network [19] have been proved competitive for their robust searching capacity and simple operation. However, the models established in these literatures treated the thermal units as normal operation units during the whole scheduling period and none of them considered the problem of thermal unit commitment. In the hydrothermal generation scheduling system, the system load demand is provided by the hydro plants and the thermal plants together. And the load of thermal plants is decided by subtracting the output of hydro plants from the total system load demand. But we know that the start-up and shut-down operation of the thermal unit should satisfy the minimum up/down time constraints in normal situation. Therefore, to choose lower consumption thermal units for operation to meet the requirement of load demand affect the profitability of the power plant directly.

In order to overcome the deficiencies of these studies, this paper establishes a model of SHTGS which not only considers the coordination between hydro plant and thermal plant but also takes the problem of thermal unit commitment into account. In this model, the first sub-problem short-term hydrothermal coordination (SHC) is aimed at determining the water discharge rate of each hydro plant and the remaining load demand for thermal plant over the whole scheduling period. The second sub-problem TUC, on basis of the remaining load demand which determined by first sub-problem, is specific to thermal plant and the purpose is to find the best unit combination of thermal unit. The third sub-problem focuses its task on loading dispatch among the thermal units, which is based on the result of unit combination achieved in the second sub-problem. The objective of SHTGS is to minimize the total cost of the hydrothermal system over the whole scheduling period while satisfying all of the constraints in the hydrothermal system operation. The practical constraints need to be satisfied can be separated as equality constraints and inequality constraints. The equality constraints include system load balance constraint and terminal reservoir storage constraint. The inequality constraints contains system spinning reserve constraint, thermal units' minimum up/down constraint, thermal units' ramp-up/down capacity constraints, water release rate limit, reservoir storage limit and the operation limits of the hydro and thermal generators. As the cost of hydro plants is unconspicuous compared to the cost of thermal plants, the cost of hydro plant generation is unconsidered in this paper. Thus, the SHTGS optimization problem is aimed at finding the optimal water discharge rate of each hydro plant and the best thermal unit combination as well as the final outputs of each thermal unit over the scheduling period to minimize the fuel cost of thermal units, which contains the fuel consumed in the operation and the extra fuel consumption for start-up.

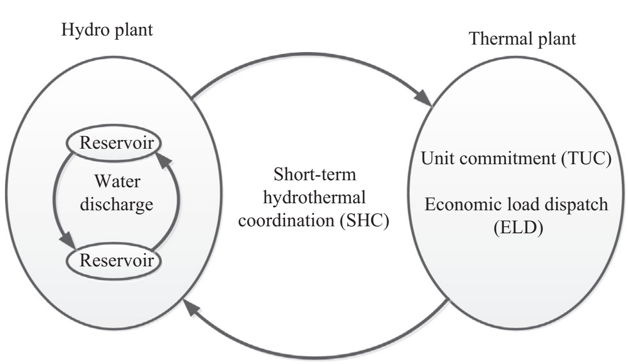

Fig. 1. The structure of the SHTGS problem.

Thus, in order to minimize the total cost of the power system, which not only include fuel cost but also start-up cost of thermal unit, the SHTGS optimization problem is aimed at finding the optimal water discharge rate of each hydro plant and the best thermal unit combination as well as the final outputs of each thermal unit over the scheduling period.

However, the SHTGS problem is more complex compared with the TUC and the hydrothermal optimal scheduling problem which does not consider the unit commitment of thermal unit (HTSPW). Instead of dealing with the real solution space problem such as HTSPW or the problem whose optimization object is binary coded such as TUC, the solution of SHTGS includes the coupled real part and binary coded part. As a result, the methods adopted for dealing with the TUC problem as QBGSA, BPSO, SOCP listed above as well as the algorithms presented for optimization the HTSPW (GSA, PSO, CA, etc.) cannot be used to solve the SHTGS directly. Fortunately, many feasible approaches have been proposed to solve the SHTGS problem. In Ref. [20], the SHTGS problem was decomposed into independent single-unit problems and a disaggregated Bundle method was utilized to deal with the corresponding dual problem. Authors in Refs. [21,22] have presented a two layer approach which combined genetic algorithm (GA) and Lagrangian relaxation (LR) to solve the SHTGS problem. The GA was used in the first layer as an optimization method to determine the units' on/off state and the LR was used in the second layer to perform the economic dispatch while meeting all of the constraints. Ref. [23] have applied the Benders decomposition (BD) approach to deal with the SHTGS problem, which decomposed the problem into a master problem and two set of sub-problems. The master problem applies integer programming as an optimization approach to solve unit commitment and the sub-problems apply nonlinear programming solution method to dispatch the system load over whole scheduling period. In addition, the authors in Ref. [24] presented a hybrid approach to deal with the SHTGS by using simulated annealing embedded evolutionary programming (SAEP). However, these methods have different drawbacks to some extent in terms of solving SHTGS problem. The efficiency of LR depends on the Lagrange multipliers updating strategy and the sensitivity problem may cause unnecessary commitments of some units [25]; GA suffers from premature convergence which will lead the optimization trap into local optimal when it is applied for high dimension large scale problem such as SHTGS; The convergence speed of BD is slow and it is very difficult to obtain the global optimal solution when handling the problems with non-convexity feasible solution space and multimodality objective function [26]; Though the SAEP proposed in Ref. [24] has been verified good merit, the approach only optimized the unit commitment of thermal unit and the outputs of hydro plants have not been optimized. Moreover, most of these references lacked an efficient mechanism to deal with the various constraints of SHTGS.

Backtracking search optimization algorithm (BSA) and charged system search algorithm (CSS) as two newly proposed methods have become a candidate for optimization application due to their flexibility and efficiency. Unlike many heuristic stochastic algorithms, BSA as a new evolutionary algorithm has a single control parameter which makes the algorithm easier to be controlled. And the performance of this algorithm is not over sensitive to the initial value of this parameter. Moreover, BSA has a simple structure that is effective, fast and capable in solving multimodal problems, which enables it to easily adapt to different optimization problems [27]. BSA has been verified good quality performance in solving different numerical optimization problems but it has not been applied for dealing with hydrothermal generation scheduling