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Krill herd algorithm applied to short-term hydrothermal scheduling problem

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Abstract In this paper, krill herd algorithm (KHA) technique is employed to solve the short-term hydrothermal scheduling (HTS) problem. In this article, the potentialities of DE are used in KHA technique to improve the convergence speed and robustness. The practical short-term HTS problem is solved here using KHA technique in which the crossover and mutation operation of differential evolution algorithm (DEA) is employed to efficiently control the local and global search, so that premature convergence may be avoided and global solutions can be achieved. The quality and usefulness of the proposed algorithm is demonstrated through its application to two standard test systems. The simulation results reveal that the current proposal is better in comparison with the other existing techniques in terms of computational time and the quality of the solutions obtained.

1. Introduction

Hydrothermal scheduling (HTS) plays an important role for the economic operation and control of the interconnected multi-reservoir system. In hydrothermal scheduling process, the water availability should be maintained in such a way that the overall thermal generation cost should be reduced as much as possible, while satisfying all the equality and inequality constraints. The prime constraints of short-term HTS problem are supply balance, continuity equations, water discharge limits, water storage and the spillage that put the limit on the initial and the final water storage volumes. Cascaded hydroelectric plants are related to each other in both power and hydraulic aspects, so the short-term optimal dispatch of cascaded hydrothermal plants is a large-scale, dynamic with time delay and complicated constrained nonlinear optimization problem. Generally, most of the hydroplants are used for multipurpose, so it is necessary to meet the certain restriction other than the power generation. Some of the general problems associated with the hydroplants are their location and their operating characteristics. Other problems associated with such kind of hydroplants are the location of the same stream or on the different stream. The operation of the downstream depends on the immediate upstream plants. But the downstream plant

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influences the immediate upstream plant by its effect on tail water elevation and the effective head. Therefore, the optimal scheduling of hydrothermal power system is usually more complex than that for all-thermal systems. It is basically a non-linear problem involving non-linear objective function and a mixture of linear and nonlinear constraints. Various mathematical models had been presented to solve the HTS problems. Some of the classical methods employed to solve the HTS problems are dynamic programming (DP) [1,2], Bender decomposition techniques [3], Lagrangian relaxation (LR) [4], mixed-integer linear programming (MILP) [5], bundle method [6], and augmented Lagrangian approach [7]. The major disadvantages of these techniques are that these methods take huge computational time, need large memory space and also have poor convergence rate. But with the development of new heuristic methods in last decade such as genetic algorithm (GA) [8], particle swarm optimization (PSO) [9,10], evolutionary programming (EP) [11], and simulated annealing (SA) [12] the drawbacks of classical techniques are mostly eliminated and nonlinear HTS problems are solved effectively. Mahor and Rangnekar [13] presented a novel self adaptive PSO (APSO) technique to solve the optimal generation schedule of real time based operated cascaded hydroelectric system located at Narmada river in Madhya Pradesh, India. Zhang et al. [14] introduced an algorithm named as multi-objective cultural algorithm (MOCA) in which the cultural algorithm framework is integrated with PSO. Moreover, an effective constraint handling technique was adopted so that the various constraints applicable to the HTS can be carried out effectively. Liao et al. [15] presented adaptive artificial bee-colony (ABC) algorithm to solve the HTS problem. To improve the operation process, the authors made change in the employed bee phase, onlooker bee phase and the scout bee phase of the conventional ABC algorithm. Wang et al. [16] combined the Cauchy mutation process with clonal real-coded quantum-inspired evolutionary algorithm to avoid premature convergence of HTS problems. Moreover, heuristic strategies are designed for dealing all kinds of constraints effectively. Zhang et al. [17] introduced chaotic sequences based multi-objective differential evolution (CSMODE) to solve the HTS problem. The presented algorithm also improved the convergence ability of basic differential evolution (DE) algorithm and a heuristic two-step constraint-handling technique was utilized to handle the complex equality and inequality constraints. Moreover, in order to avoid premature convergence, the presented CSMODE integrated three chaotic mappings into DE to enlarge the search space and increase the diversity of population in evolution process. Selvakumar [18] presented civilized PSO which combined the society–civilization algorithm (SCA) and PSO to provide global optimal solution. In the presented method, the central and non-central society communication mechanisms of SCA were embedded into the food-searching strategy of PSO. Hinojosa and Leyton [19] developed mixed-binary evolutionary PSO in which water discharge and thermal states were made as the continuous and binary decision variable. The constraint handling technique used in this evolutionary algorithm was based on a strategy to generate and keep the decision variables in feasible space through the correction operators. Xu et al. [20] introduced ε-domination and orthogonal design method (ε-ODEMO) based DE algorithm to obtain a good distribution of Pareto-optimal solutions in a small computational time and the orthogonal design method generated an initial population of points that were scattered uniformly over the feasible solution space. This modified DE algorithm was implemented to make it suit for multi-objective optimization problems and improved its performance. Wang et al. [21] introduced an improved self-adaptive PSO algorithm (ISAPSO) to solve HTS problem. To avoid the premature convergence of PSO, the evolution direction of each particle was shifted dynamically by adjusting the two sensitive parameters of PSO in the evolution process. Zhang et al. [22] developed small population-based PSO (SPPSO) to solve the HTS problem. In the presented algorithm, a novel mutation operation was used to give the flying guides for each individual to enhance the diversity of the small population. Moreover, DE algorithm was also employed as an acceleration operator to improve the convergence speed of the approach if optimal result had no significant improvements after several iterations. Moreover, a migration operation was adopted to keep the swarm's crowding diversity above a desired level. Also, a special repair procedure was developed, instead of the penalty function approach, to handle the complex equality constraints of short-term HTS scheduling problem. Hota et al. [23] presented improved PSO (IPSO) for solving short-term HTS problems. This technique worked with an inequality constraint treatment mechanism called as dynamic search-space squeezing strategy. To accelerate the optimization process, the inherent basics of conventional PSO algorithm was preserved. Kumar and Mohan [24] introduced GA to solve HTS problems. In this algorithm hydel problems were solved by using GA whereas the thermal problems were solved by using the lambda iteration method (LIM). Mandal and Chakraborty [25] presented DE technique to solve the HTS problems. Here, a multi-reservoir cascaded hydrothermal system with non-linear relationship between water discharge rate, power generation and net head was considered. Also, water transport delay between the connected reservoirs was also taken into account. Several equality and non-equality constraints on thermal units as well as hydrounits and the effect of valve point loading were also included in the problem formulation. Liao [26] introduced improved immune algorithm (IIA) by combining the fuzzy system (FS), the annealing immune (AI) method and the immune algorithm (IA) for solving HTS problem. The presented algorithm differed from its counter parts by the following ways: (1) changing the crossover and mutation ratios from a fixed value to a variable value determined by the fuzzy system method, (2) using the memory cell and (3) adding the annealing immune operator. Yu et al. [27] applied PSO technique to solve the STHTS problem. Lakshminarasimman and Subramanian [28] introduced modified DE (MDE) to solve the short-term HTS problem. In the presented algorithm authors checked that the classical DE did not give the proper idea about the constraints handling mechanism of the hydel discharges. Amjady and Soleymanpour [29] introduced modified adaptive PSO to deal the HTS problems having non-linear, non-convex and non-smooth optimization. Yuan et al. [30] used HTS based DE algorithm in which chaos theory is applied to achieve the self-adaptive parameter settings in differential DE. In order to prevent the premature convergence, Yuan et al. [31] introduced hybrid chaotic GA for solving the short-term HTS problem. Swain et al. [32] presented clonal selection algorithm (CSA) to solve short-term HTS problem in less computational time. Sasikala and Ramaswamy [33] presented optimal gamma