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Modified cuckoo search algorithm for short-term hydrothermal scheduling

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ABSTRACT

This paper proposes a modified cuckoo search algorithm (MCSA) for solving short-term hydrothermal scheduling (HTS) problem. The considered HTS problem in this paper is to minimize total cost of thermal generators with valve point loading effects satisfying power balance constraint, water availability, and generator operating limits. The MCSA method is based on the conventional CSA method with modifications to enhance its search ability. In the MCSA, the eggs are first sorted in the descending order of their fitness function value and then classified in two groups where the eggs with low fitness function value are put in the top egg group and the other ones are put in the abandoned one. The abandoned group, the step size of the Lévy flight in CSA will change with the number of iterations to promote more localized searching when the eggs are getting closer to the optimal solution. On the other hand, there will be an information exchange between two eggs in the top egg group to speed up the search process of the eggs. The proposed MCSA method has been tested on different systems and the obtained results are compared to those from other methods available in the literature. The result comparison has indicated that the proposed method can obtain higher quality solutions than many other methods. Therefore, the proposed MCSA can be a new efficient method for solving short-term fixed-head hydrothermal scheduling problems.

Introduction

A modern power system consists of a large number of thermal and hydro plants connected at various load centers through a transmission network. An important objective in the operation of such a power system is to generate and transmit power to meet the system load demand at minimum fuel cost by an optimal mix of various types of plants. However, the hydro resources being limited, thus the worth of water is greatly increased [1]. Therefore, an optimal operation of a hydrothermal system will lead to a huge saving in fuel cost of thermal power plants. The objective of the hydrothermal scheduling problem is to find the optimum allocation of hydro energy so that the annual operating cost of a mixed hydrothermal system is minimized [1]. Several conventional methods have been implemented for solving the hydrothermal scheduling problem such as gradient search techniques (GS) [2], lambda-gamma iteration method, dynamic programming (DP) [2], Lagrange relaxation (LR) [3], decomposition and coordination method [4], mixed integer programming (MIP) [5], and Newton's method [6]. The GS method has been applied to the problem where the hydro generation models were represented as piecewise linear functions or polynomial approximation with a monotonically increasing nature. However, such an approximation may be too rough and seems impractical. In the lambda-gamma method, the gamma values associated with different hydro plants are initially chosen and then the lambda iterations are invoked for the given power demand at each interval of the schedule time horizon. The DP method is another popular optimization method implemented for solving the hydrothermal scheduling problems. However, computational and dimensional requirements in the DP method will drastically increase for large-scale systems [7]. On the contrary to the DP method, the LR method is more reliable and efficient for dealing with large-scale problems. However, the LR method may suffer to the duality gap oscillation during the convergence process due to the dual problem formulation, leading to divergence for some problems with non-convexity of incremental heat rate curves of thermal generators. In the decomposition and coordination method, the problem is decomposed into thermal and hydro sub-problems and they are solved by network flow programming and

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Nomenclature

a_{hj}, b_{hj}, c_{hj}	water discharge coefficients of hydro plant j
a_{sik}, b_{si}, c_{si}	fuel cost coefficients of thermal plant i
d_{si} e_{si}	fuel cost coefficients of thermal plant i with valve-point effects
B_{ij}, B_{0i}, B_{00}	B-matrix coefficients for transmission power loss
$P_{D,m}$	total system load demand at subinterval m
$P_{hj,m}$	power output of hydro plant j in subinterval m
$P_{hj,max}$	maximum power output of hydro plant j
$P_{hj,min}$	minimum power output of hydro plant j
$P_{L,m}$	total transmission loss at subinterval m
$P_{si,m}$	power output of thermal plant i in subinterval m
$P_{si,max}$	maximum power output of thermal plant i
$P_{si,min}$	minimum power output of thermal plant i
$q_{j,m}$	rate of water flow from hydro plant j in subinterval m
W_j	volume of water available for hydro unit j during the scheduled period

priority list based dynamic programming methods. In order to solve the HTS problem, the MIP method requires a linearization of equations whereas the decomposition and coordination method may encounter the difficulties when dealing with the non-linearity of objective function and/or constraints. The Newton's method is computationally stable, effective, and fast for solving a set of non-linear equations. Therefore, it has a high potential for implementation on optimization problems such as economic load dispatch in hydrothermal power systems. However, a drawback of the Newton's method is the dependence on the formulation and inversion of Jacobian matrix, leading to its restriction of applicability on large-scale problems. Generally, these conventional methods can be efficiently applicable for the HTS problems with differentiable fuel cost function and constraints. A multistage Benders decomposition method has been presented in [8,9] for solving a short-term hydrothermal scheduling problem. In this method, an alternative strategy is proposed to decompose the HTS problem into many stages with each stage comprising variables and constraints of several time-steps. The advantage of this approach is that it allows exploring the best trade-off between solving a "larger number of shorter stages" and solving a "shorter number of larger stages". As a result, the multistage Benders decomposition method in [8] can reduce the number of iterations for convergence. However, the computational time for the subproblem in each stage is increased. For enhancing the efficiency of the method, there is an additionally optimal aggregation factor suggested in [9] that yields the least computational time for the overall problem.

Recently, several novel methods based on artificial intelligence techniques have been implemented for solving the HTS problems such as simulated annealing approach (SA) [10], evolutionary programming (EP) [11–14], genetic algorithm (GA) [15–18], differential evolution (DE) [19], artificial immune system (AIS) [20], and Hopfield neural network (HNN) [21]. In the SA technique, the appropriate setting of the relevant control parameters is a difficult task and it usually suffers slow speed of convergence when dealing with practical sized power systems. Both the GA and EP algorithms are evolutionary based methods for solving optimization problems. However, the essential encoding and decoding schemes in the both methods are different. In the GA method, the required crossover and mutation operations to diversify the offspring may be detrimental to actually reaching an optimal solution. In this regard, the EP technique is more likely better when overcoming these disadvantages where the mutation is a key search operator which generates new solutions from the current ones [17]. However, one disadvantage of the EP method in solving some multimodal optimization problems is its slow convergence to a near optimum. Another evolutionary based method for solving optimization problems is DE method which has the ability to search in very large spaces of candidate solutions with few or no assumptions about the considered problem. However, the DE method is slow or no convergence to the near optimum solution when dealing with large-scale problems. The AIS method is one of the efficient metaheuristic search methods for solving optimization problems. In the AIS method, the most important step is the application of the aging operator to eliminate the old antibodies to maintain the diversity of the population and avoid a premature convergence. The advantages of the AIS method are few control parameters and small number of iterations. However, the AIS method also suffers a difficulty when dealing with large-scale problems like other metaheuristic search methods. The HNN method is an efficient neural network for dealing with optimization problems. However, it encounters a difficulty of predetermining the synaptic interconnections among neurons which may lead to constraint mismatch if the weighting coefficients associated with constraints in its energy function are not carefully selected. In addition, the HNN method also suffers slow convergence to an optimal solution and the constraints of the problems must be linearized when applying in HNN [22]. In general, most of the artificial intelligence based techniques are efficient for finding near optimum solution for complex problems but they also usually suffer slow convergence, especially for large-scale problems.

Cuckoo search algorithm (CSA) is a new metaheuristic algorithm for solving optimization problems developed by Yang and Deb in 2009 [23]. This algorithm is inspired from the reproduction strategy of cuckoo species in the nature. At the most basic level, cuckoos lay their eggs in the nests of other host birds which may be of different species. The host bird may discover strange eggs in its nest and it either destroys the eggs or abandons the nest to build a new one. The effectiveness of the CSA method over other methods such as GA and particle swarm optimization (PSO) has been validated on benchmarked functions [23]. Moreover, CSA has been also successfully applied for solving non-convex economic dispatch (ED) problems [24,25] and micro grid power dispatch problem [25]. However, the conventional CSA still suffers slow convergence for complex and large-scale problems. Therefore, a new modified CSA (MCSA) has been proposed by Walton et al. [26] to speed up its convergence to the optimal solution. The efficiency of the MCSA method over other methods such as conventional CSA, DE and PSO has been given in [26].

This paper proposes MCSA method for solving short-term hydrothermal scheduling (HTS) problem. The considered HTS problem in this paper is to minimize total cost of thermal generators with valve point loading effects satisfying power balance constraint, water availability, and generator operating limits. The MCSA method is based on the conventional CSA method with modifications to enhance its search ability. In the MCSA, the eggs are first sorted in the descending order of their fitness function value and then classified in two groups where the eggs with low fitness function value are put in the top egg group and the other ones are put in the abandoned one. The abandoned group, the step size of the Lévy flight in CSA will change with the number of iterations to promote more localized searching when the eggs are getting closer to the optimal solution. On the other hand, there will be an information exchange between two eggs in the top egg group to