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A hybrid of real coded genetic algorithm and artificial fish swarm algorithm for short-term optimal hydrothermal scheduling

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ABSTRACT

The short-term hydrothermal scheduling (SHS) is a complicated nonlinear optimization problem with a series of hydraulic and electric system constraints. This paper presents a hybrid algorithm for solving SHS problem by combining real coded genetic algorithm and artificial fish swarm algorithm (RCGA–AFSA), which takes advantage of their complementary ability of global and local search for optimal solution. Real coded genetic algorithm (RCGA) is applied as global search, which can explore more promising solution spaces and give a good direction to the global optimal region. Artificial fish swarm algorithm (AFSA) is used as local search to obtain the final optimal solution for improving the exploitation capability of algorithm. The water transport delay between connected reservoirs is taken into account in this paper. Moreover, new coarse and fine adjustment methods without any penalty factors and extra parameters are proposed to deal with all equality and inequality constraints. To verify the feasibility and effectiveness of RCGA–AFSA, the proposed method is tested on two hydrothermal systems. Compared with other methods reported in the literature, the simulation results obtained by hybrid RCGA–AFSA are superior in fuel cost and computation time.

Introduction

Short-term hydrothermal scheduling (SHS) is one of the most important issues in the economic operation of power system. The objective of SHS is to determine the optimal amount of water discharges of hydro plants and power generations of thermal plants over a scheduling horizon so as to minimize the total fuel cost of thermal plants while satisfying various hydraulic and electric system constraints. Among these constraints, equality constraints include system load balance, water dynamic balance, and initial and terminal reservoir storage volumes. Inequality constraints are hydrothermal generation limits, ramp rate limits of thermal units, reservoir storage volumes limits, water discharge rate limits and prohibited discharge zones of hydro units. Furthermore, the valve-point effects of thermal units intensify non-linearity and non-convexity of SHS problem [1,2]. Therefore, SHS is a large-scale, dynamic, non-linear, non-convex and complicated constrained optimization problem.

Various methods have been proposed to solve SHS problem in the past several decades. The major methods include dynamic programming (DP) [3,4], linear programming (LP) [5], network flow programming (NFP) [6,7], mixed-integer programming (MIP) [8,9], non-linear programming (NLP) [10] and Lagrangian relaxation (LR) [11]. These methods are not able to give optimal solution due to their drawbacks. DP can overcome the difficulty of non-linearity and non-convexity of SHS problem. However, it suffers from the curse of dimensionality which leads to long computation time and large memory storage. LP is applicable only to problems with linear objective function and constraints. SHS is solved by linear approximation, which would lead to errors of scheduling result. Although NFP is more efficient than LP in terms of computation time and space resources, the network flow model of SHS is often simplified to a linear or piecewise linear one. For MIP, poor calculating efficiency is widely recognized especially when applied to large-scale optimization problem such as SHS problem. NLP can accurately express the characteristics of SHS problem, while it also has some weaknesses of slow convergence, large memory requirement and inability to deal with constraints. Compared with other methods, LR is more flexible for handling different constraints. However, LR leads to the oscillation of solutions, and the convergence and accuracy of LR depend on the Lagrange multipliers updating methods.

In recent years, heuristic methods such as artificial neural network (ANN) [12,13], genetic algorithm (GA) [1], simulated annealing (SA) [14], tabu search (TS) [15], ant colony optimization (ACO)

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[16], particle swarm optimization (PSO) [17–22], differential evolution (DE) [23], quantum-inspired evolutionary algorithm (QEA) [24,25] and artificial bee colony (ABC) [26,27] have been employed for solving SHS problem. Moreover, some combinatorial methods such as fuzzy satisfying method based on evolutionary programming technique [28] and hybrid differential evolution and sequential quadratic programming (DE–SQP) algorithms [29] have been successfully applied to this problem. These methods are able to provide good solution and deal with complicated nonlinear constraints more simply and effectively. However, the above mentioned methods require a large amount of computation time especially for large-scale SHS problems. Besides, they are inclined to trap into the local optimum in the later evolution period and sensitive to initial points.

In order to overcome the drawbacks of heuristic optimization methods, a hybrid method that combines real coded genetic algorithm (RCGA) with artificial fish swarm algorithm (AFSA) is proposed to accelerate convergence and enhance the performance of searching global optimal solution. RCGA is one of the most popular stochastic search algorithms. It is very suitable for solving continuous optimization problems because of its real-number representation. RCGA is able to promote the calculation efficiency and improve the hill-climbing ability of binary coded genetic algorithm (BCGA). It has been widely and successfully applied to many optimization problems [30–32]. However, the basic RCGA also has disadvantages such as premature convergence and poor local search ability, because it cannot exploit local information of individual in the population. AFSA is a population-based intelligent algorithm, which was inspired by the various social behaviors of fish. Each fish search its own local optimum and pass on information in its self-organized system and finally obtain the global optimum [33]. AFSA can enhance the searching ability and avoid being trapped into local optimum. It has been proved effective in many engineering problems [33–35]. The combination of RCGA and AFSA make full use of their advantages. RCGA is capable of exploring new and more promising solution spaces and give a good direction to the global optimal region; AFSA is able to fine tune the solution to reach the global optimal solution. Thus, this hybrid algorithm has good global exploration capability of RCGA, as well as the local exploitation capability of AFSA. It can obtain better solution with faster convergence speed. What's more, the constraints handling methods, which require neither penalty factors nor any extra parameters, are provided to deal with complicated constraints of SHS problem. Hybrid RCGA–AFSA is applied to two test systems for solving SHS problem. The simulation results demonstrate the feasibility and effectiveness of the proposed method.

The rest of paper is organized as follow. Section 'Problem formulation' provides the mathematical formulation of SHS problem. The proposed algorithm is introduced in Section 'A hybrid algorithm combining RCGA with AFSA'. Section 'Application of the proposed algorithm to solve SHS problem' describes the application of hybrid RCGA–AFSA to solve SHS problem. Simulation results are presented and analyzed in Section 'Simulation results'. In the last section, conclusions and future research are given.

Problem formulation

Since the operation cost of hydropower is almost negligible, the SHS problem is aimed to minimize the thermal cost when making full use of hydro resources as much as possible. Typically, the total scheduling period is 1 day and each scheduling time interval is 1 h. The objective function and associated constraints of SHS problem are formulated as follows.

Objective function

The fuel cost function of thermal plant considering valve-point effects is expressed as the sum of a quadratic and a sinusoidal function. The superimposed sine component represents the rippling effects produced by the opening of each steam admission valve in a turbine [36]. For a given hydrothermal system, the total fuel cost function can be described as follows

$$\begin{aligned}\min\ F &= \sum_{t=1}^{T}\sum_{i=1}^{N_s} f_i(P_s(i,t)) \\ &= \sum_{t=1}^{T}\sum_{i=1}^{N_s}\Big[\left(a_{si}+b_{si}P_s(i,t)+c_{si}(P_s(i,t))^2\right) \\ &\quad +\left|d_{si}\sin\left(e_{si}\left(P_s(i)^{\min}-P_s(i,t)\right)\right)\right|\Big]\end{aligned} \quad (1)$$

where $f_i(P_s(i,t))$ is fuel cost of the ith thermal plant at time interval t, $P_s(i,t)$ is power generation of the ith thermal plant at time interval t, a_{si}, b_{si} and c_{si} are cost coefficients of the ith thermal plant, d_{si} and e_{si} are valve-point effects coefficients of the ith thermal unit, $P_s(i)^{\min}$, $P_s(i)^{\max}$ are the lower and upper generation limits of the ith thermal plant, N_s is the number of thermal plants, i is thermal plant index, T is the number of total intervals over a scheduling horizon, t is time interval index.

Constraints

(1) System power balance

$$\sum_{i=1}^{N_s}P_s(i,t)+\sum_{j=1}^{N_h}P_{h(j,t)} = P_{D(t)}+P_{L(t)} \quad (2)$$

where $P_h(j, t)$ is power generation of the jth hydro plant at time interval t, N_h and j are the number of hydro plants and hydro plant index, $P_D(t)$ is load demand at time interval t and $P_L(t)$ is transmission loss at the corresponding time.

The power generated from a hydro plant is related to the reservoir characteristics as well as the water discharge rate. In general, hydropower generation is a function of net head and turbine discharge. The model can be written in terms of reservoir volume instead of the reservoir net head, and a frequently used expression [37] is

$$\begin{aligned}P_h(j,t) &= C_{1j}(V_h(j,t))^2 + C_{2j}(Q_h(j,t))^2 + C_{3j}V_h(j,t)Q_h(j,t) \\ &\quad + C_{4j}V_h(j,t) + C_{5j}Q_h(j,t) + C_{6j}\end{aligned} \quad (3)$$

where C_{1j}, C_{2j}, C_{3j}, C_{4j}, C_{5j}, and C_{6j} are generation coefficients of the jth hydro plant, $V_h(j, t)$ is storage volume of the jth reservoir at the end of time interval t, $Q_h(j, t)$ is water discharge rate of the jth reservoir at time interval t.

(2) Generation limits

$$P_s(i)^{\min} \leqslant P_s(i,t) \leqslant P_s(i)^{\max} \quad (4)$$

$$P_h(j)^{\min} \leqslant P_h(j,t) \leqslant P_h(j)^{\max} \quad (5)$$

where $P_h(j)^{\min}$ and $P_h(j)^{\max}$ are the minimum and maximum generation of the jth hydro plant, respectively.

(3) Ramp rate limits

$$P_s(i,t) - P_s(i,t-1) \leqslant UR_s(i) \quad (6)$$

$$P_s(i,t-1) - P_s(i,t) \leqslant DR_s(i) \quad (7)$$

where $UR_s(i)$ and $DR_s(i)$ are the ramp-up and ramp-down rate limit of the ith thermal unit, respectively.