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Quasi-oppositional group search optimization for hydrothermal power system

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ABSTRACT

This paper presents quasi-oppositional group search optimization to determine the optimal schedule of power generation in a hydrothermal system. Group search optimization inspired by the animal searching behavior is a biologically realistic algorithm. Quasi-oppositional group search optimization (QOGSO) has been used here to improve the effectiveness and quality of the solution. The proposed QOGSO employs quasi-oppositional based learning (QOBL) for population initialization and also for generation jumping. The effectiveness of the proposed method has been verified on two test problems, two fixed head hydrothermal test systems and three hydrothermal multi-reservoir cascaded hydroelectric test systems having prohibited operating zones and thermal units with valve point loading. The ramp-rate limits of thermal generators are taken into consideration. The transmission losses are also accounted for through the use of loss coefficients. Test results of the proposed QOGSO approach are compared with those obtained by other evolutionary methods. It is found that the proposed QOGSO based approach is able to provide better solution.

Introduction

Optimum scheduling of generation in a hydrothermal system is of great importance to electric utility systems. With the insignificant marginal cost of hydroelectric operational cost of a hydrothermal system essentially reduces to that of minimizing the fuel cost for thermal plants under the various constraints on the hydraulic, thermal and power system network.

The main constraints include: the time coupling effect of the hydro sub problem, where the water flow in an earlier time interval affects the discharge capability at a later period of time, the cascaded nature of the hydraulic network, the varying hourly reservoir inflows, the physical limitations on the reservoir storage and turbine flow rate, prohibited operating zones of hydroelectric system, ramp-rate limits of thermal generators, the varying system load demand and the loading limits of both thermal and hydro plants.

The hydrothermal scheduling problem has been the subject of investigation for several decades. Most of the methods that have been used to solve the hydrothermal co-ordination problem make a number of simplifying assumptions in order to make the optimization problem more tractable. Some of these solution methods are Newton's method [1], mathematical decomposition [3], network flow [4], dynamic programming [5], deterministic optimization algorithm [6], Lagrangian relaxation [7], and Benders decomposition [8].

Since the mid 1990s, many techniques originated from Darwin's natural evolution theory have emerged. These techniques are usually termed by "evolutionary computation methods" including evolutionary algorithms (EAs), swarm intelligence and artificial immune system.

With the emergence of evolutionary computation methods, attention has been gradually shifted to application of such technology-based approaches to handle the complexity involved in real world problems. Stochastic search algorithms such as simulated annealing technique [9], evolutionary programming technique [10,13], genetic algorithm [11,12], differential evolution [14–16], and particle swarm optimization [17], clonal selection algorithm [18], artificial immune system [19] and teaching learning based optimization [20] have been applied for optimal hydrothermal scheduling problem and circumvented the above mentioned weakness.

Group search optimization (GSO) is a biologically realistic algorithm which is inspired by the animal (such as lions and wolves) searching behavior. He et al. [21] proposed GSO in 2006, and discussed the effects of designed parameters on the performance of GSO in 2009 [22]. GSO employs a special framework, under which

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Nomenclature

a_{si}, b_{si}, c_{si}, d_{si}, e_{si} cost curve coefficients of ith thermal unit
P_{sim} power output of ith thermal generator during subinterval m
P_{si}^{min}, P_{si}^{max} lower and upper generation limits for ith thermal unit
t_m duration of subinterval m.
P_{hjm} power output of jth hydro unit during subinterval m
P_{Dm} load demand during subinterval m
P_{Lm} transmission loss during subinterval m
B_{lr} loss formula coefficients.
a_{0hj}, a_{1hj}, and a_{2hj} coefficients for water discharge rate function of jth hydro generator
W_{hj} prespecified volume of water available for generation by jth hydro unit during the scheduling period.
P_{hj}^{min}, P_{hj}^{max} lower and upper generation limits for jth hydro unit
P_{sit} output power of ith thermal unit at time t
P_{Dt} load demand at time t
P_{Lt} transmission loss at time t
P_{hjt} output power of jth hydro unit at time t
C_{1j}, C_{2j}, C_{3j}, C_{4j}, C_{5j}, C_{6j} power generation coefficients of jth hydro unit
Q_{hjt} water discharge rate of jth reservoir at time t
V_{hjt} storage volume of jth reservoir at time t
Q_{hj}^{min}, Q_{hj}^{max} minimum and maximum water discharge rate of jth reservoir
$Q_{hj,k}^{L}$, $Q_{hj,k}^{U}$ lower and upper bounds of kth prohibited zones of hydro unit j
V_{hj}^{min}, V_{hj}^{max} minimum and maximum storage volume of jth reservoir
I_{hjt} inflow rate of jth reservoir at time t
R_{uj} number of upstream units directly above jth hydro plant
S_{hjt} spillage of jth reservoir at time t
τ_{lj} water transport delay from reservoir l to j
t, T time index and scheduling period
N_s number of thermal generating units
N_h number of hydro generating units
n_j number of prohibited zones for hydro unit j
k index of prohibited zones of a hydro unit

individuals are divided into three classes and evolve separately. This framework is proved to be effective and robust on solving multimodal problems [22]. Shen et al. [23] investigated the performance of GSO and concluded that GSO is an alternative for constrained optimization.

Due to its high efficiency, GSO has been applied in many fields. Moreover, some papers also indicate GSO as solutions to some discrete optimization problems, such as optimal design plate structures with discrete variables [24] and optimal design of spatial grid structure [25]. Continuous quick group search optimizer [26] has been applied to solve non-convex economic dispatch problems.

The basic concept of opposition-based learning (OBL) [29–31] was originally introduced by Tizhoosh. The main idea behind OBL is for finding a better candidate solution and the simultaneous consideration of an estimate and its corresponding opposite estimate (i.e., guess and opposite guess) which is closer to the global optimum. OBL was first utilized to improve learning and back propagation in neural networks by Ventresca and Tizhoosh [32], and since then, it has been applied to many EAs, such as differential evolution [33], particle swarm optimization [34] and ant colony optimization [35]. In [36] quasi oppositional based differential evolution has been discussed.

Here, quasi-oppositional based learning (QOBL) is implemented on group search optimization. The proposed quasi-oppositional group search optimization (QOGSO) along with basic group search optimization (GSO) is applied for optimal scheduling of generation in a hydrothermal system. This paper considers fixed head as well as variable head hydrothermal system. In case of fixed head hydro plants, water discharge rate curves are modeled as a quadratic function of the hydropower generation and thermal units with nonsmooth fuel cost function. Here, scheduling period is divided into a number of subintervals each having a constant load demand. In case of variable head hydrothermal system, multi-reservoir cascaded hydro plants having prohibited operating zones and thermal units with valve point loading and ramp rate limits are used. The proposed method is validated by applying it to two test problems, two fixed head hydrothermal test systems and three hydrothermal multi-reservoir cascaded hydroelectric test systems having prohibited operating zones and thermal units with valve point loading and ramp rate limits. Test results are compared with those obtained by other population-based evolutionary methods. From numerical results, it is found that the proposed QOGSO based approach provides better solution.

Problem formulation

Fixed head hydrothermal system

Fixed head hydrothermal scheduling problem with N_h hydro units and N_s thermal units over M time subintervals is described as follows:

Objective function

The fuel cost function of each thermal generator, considering valve-point effect, is expressed as a sum of quadratic and sinusoidal function. The superimposed sine components represent rippling effect produced by steam admission valve opening. The problem minimizes following total fuel cost

$$f_{FH}=\sum_{m=1}^{M}\sum_{i=1}^{N_s}t_m\left[a_{si}+b_{si}P_{sim}+c_{si}P_{sim}^2+\ d_{si}\times\sin\left\{e_{si}\times\left(P_{si}^{min}-P_{sim}\right)\right\}\right] \quad (1)$$

Constraints

(i) Power balance constraints:

$$\sum_{i=1}^{N_s}P_{sim}+\sum_{j=1}^{N_h}P_{hjm}-P_{Dm}-P_{Lm}=0 \quad m\in M \quad (2)$$

and

$$P_{Lm}=\sum_{l=1}^{N_h+N_s}\sum_{r=1}^{N_h+N_s}P_{lm}B_{lr}P_{rm} \quad m\in M \quad (3)$$

(ii) Water availability constraints:

$$\sum_{m=1}^{M}\left[t_m\left(a_{0hj}+a_{1hj}P_{hjm}+a_{2hj}P_{hjm}^2\right)\right]-W_{hj}=0 \quad j\in N_h \quad (4)$$

(iii) Generation limits:

$$P_{hj}^{min}\leqslant P_{hjm}\leqslant P_{hj}^{max} \quad j\in N_h,\quad m\in M \quad (5)$$