Electrical Power and Energy Systems 65 (2015) 159–168

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A modified chaotic differential evolution algorithm for short-term optimal hydrothermal scheduling

Jingrui Zhang [a,b,*], Shuang Lin [a], Weixia Qiu [a]

[a] *Department of Mechanical and Electrical Engineering, Xiamen University, Xiamen 361005, China*
[b] *Shenzhen Research Institute of Xiamen University, Shenzhen 518057, China*

ARTICLE INFO

Article history:
Received 11 November 2013
Received in revised form 17 September 2014
Accepted 22 September 2014

Keywords:
Short-term hydrothermal scheduling
Differential evolution
Regeneration
Chaotic local search

ABSTRACT

The short-term optimal hydrothermal scheduling (STOHS) plays one of the most important roles in power systems operation. The STOHS problem involves the solution of difficult constrained optimization problems that require good computational techniques. This paper proposes a modified chaotic differential evolution (MCDE) approach for the solution of this difficult optimization problem. A repair strategy and a novel selection operation are simultaneously introduced into the MCDE approach for handling constraints of the problem. The repair strategy preserves the feasibility of solutions generated and avoids the use of penalty factors as much as possible. The introduced selection operation makes a not clearly distinction between feasible solutions and infeasible ones at early stage of the algorithm and makes a clearly distinction at the later stage. Additionally, an adaptive regeneration operation is proposed to enhance population diversity and to avoid local optimums. Moreover, a chaotic local search technique is introduced also to accelerate the searching process of the algorithm. The proposed MCDE approach is applied to three well-known hydrothermal test systems in order to verify its feasibility and efficiency. The obtained results are compared with those obtained by other population-based heuristic approaches reported in literature. It is observed from the comparisons that the proposed MCDE approach performs effectively and can yield competitive solutions.

Introduction

The short-term optimal hydrothermal scheduling (STOHS) problem is one of the most important issues in the optimal operation of interconnected power systems [1,2]. The problem refers to determine the optimal hydro discharges of hydro plants and the optimal power generation from thermal plants over a schedule horizon so as to minimize the total thermal cost. It is very difficult to solve this complicate optimization problem within the consideration of various hydraulic and operational constraints.

Several heuristic methods have been proposed aiming at the solution of this STOHS issue due to their nature of neglecting non-linear, differentiable and even the convex of the optimization problem. Orero and Irving [3] introduced a genetic algorithm modeling framework and solution technique for the short-term optimal scheduling of hydrothermal system. The desired final reservoir levels were treated as soft constraints that can be either violated or relaxed in their work. Sinha et al. [4] employed an improved fast evolutionary programming technique for the STOHS. The final reservoir levels were satisfied by calculating the hydro discharges of a dependent time interval randomly chosen in their work. However, the calculated discharges may not satisfy their limits and a penalty function approach had to be employed for constraint violations. Genetic algorithm (GA) [5–9], simulated annealing (SA) [10–11], evolutionary programming (EP) [12], neural network [13–15], particle swarm optimization (PSO) [16–20], etc. have been introduced in succession to solve various STOHS problems in recent years.

Differential evolution (DE), as a heuristic method for minimizing continuous space functions, was proposed by Storn and Price [21] in 1995. It is found to be quite simple and efficient for those non-linear, non-differentiable continuous optimization problems. DE has been successfully applied to various power system optimizations and proved to have competitive performance compared with other stochastic evolutionary techniques published in literature. To our best knowledge, Lakshminarasimman and Subramanian [22] first proposed to adopt differential evolution algorithm to solve the STOHS problem. In their work, the dependent hydro discharges are used to satisfy the constraints of initial and final reservoir volumes but it still lacks handling technique for the constraint of power load balance. Immediately following,

* Corresponding author at: Department of Mechanical and Electrical Engineering, Xiamen University, Xiamen 361005, China.
E-mail address: zjrhust@gmail.com (J. Zhang).

http://dx.doi.org/10.1016/j.ijepes.2014.09.041
0142-0615/

they proposed a modified hybrid differential evolution [23] for the solution of the STOHS problem. The emphasis in their modification work was given to the handling technique for the equality constraints of the STOHS problem, i.e., the initial and final reservoir volumes for hydro reservoirs and the power load balance. However, penalty factors were still adopted to handle the other constraint violations such as the reservoir storage volumes and power generation of hydro plants. In the DE approach of Mandal and Chakraborty [24] for the STOHS problem, a strategy generating and keeping variables in feasible regions is adopted but just for control variables. The handling technique for equality constraints of the initial and final reservoir volumes and power system load balance were not reported clearly either.

Recently, hybrid methods were proposed to solve the STOHS problem in order to overcome the drawback of single intelligent method. Generally speaking, hybrid methods can yield a better solution with good efficiency compared with a single algorithm. Yuan et al [25] proposed a self-adaptive parameter setting hybrid DE approach to solve the STOHS problem. Chaotic sequences based on logistic map instead of random sequences were adopted in their approach to diversify the population and improve its performance to find the optimal solution. Moreover, three simple feasibility-based selection comparison rules were adopted in their work to avoid the use of penalty factors. However, their approach was just verified through a simple hydrothermal system with four interconnected cascade hydro plants and an equivalent thermal plant. Lu et al [26] proposed an adaptive chaotic differential evolution for the STOHS problem. An adaptive dynamic parameter adjusting strategy and a chaotic local search operation were integrated with DE to avoid premature convergence effectively in their approach. However, the handling technique to the equality constraints of the problem was too complicate and more parameters should be set in advance in their two stage constraint handling technique, which meant coarse adjusting and fine adjusting. Moreover, selection operation based on feasibility of solutions was not favor for enhancing the searching space at the early evolution stages because those solutions near the global optimum but not feasible will be drawn out compared with those ones feasible but far away from the global optimum. Sivasubramani and Shanti Swarup [27] proposed a hybrid method combining DE and sequential quadratic programming (SQP) for solving the STOHS problem. DE was used as a base level search and SQP was used to fine tune the solutions to reach the global optimum or near global optimum in their approach. However, the penalty factors were not avoided in their base level search. Wang et al [28,29] proposed a differential real-coded quantum-inspired evolutionary algorithm combined with quantum-inspired evolutionary algorithm. In their approach, the two stage equality constraint handling technique, one coarse search and the other fine search were still used. The constraints handling technique was too complicate to some extent and the constraint violations may occur yet within this handling method. But how to handle this type of violation was not reported in their work.

The main contribution of this paper aims at proposing a novel modified chaotic differential evolution (MCDE) approach for solving the STOHS problem. A repair strategy and a novel selection operation were employed for constraint handling instead of using penalty factors in the MCDE approach. The repair strategy maintained the feasibility of solutions generated by the algorithm. At the early stage of the evolution, the novel selection operation makes a not clear distinction between feasible solutions and infeasible solutions, and at the later stage, it makes a clear distinction. Additionally, an adaptive regeneration operation is proposed in order to enhance the population diversity and avoid local optimums. Moreover, a chaotic local search technique is introduced also to accelerate the searching process of the algorithm. The rest of this paper is organized as follows. The STOHS problem is formulated in Section 'Problem formulation'. Section 'Overview of differential evolution algorithm' is an overview of the par DE algorithm. Then in Section 'Modified chaotic DE for STOHS problem', the proposed MCDE algorithm is described in detail. The effectiveness of the proposed MCDE approach for the STOHS problem is verified through three well-known hydrothermal test systems in Section 'Simulation and discussions'. At last, the conclusions are outlined in Section 'Conclusions'.

Problem formulation

The scheduling horizon of the STOHS problem in this study is 1 day and is divided into T time intervals with each planning interval as 1 h. The problem aims at obtaining the minimum fuel cost of all thermal plants over the entire scheduling horizon by utilizing the water resources as much as possible while satisfying the various constraints. The objective function and various constraints are formulated as follows.

Objective function

The objective function for the STOHS problem is expressed mathematically, as

$$\text{minimize } F = \sum_{i=1}^{N_s}\sum_{t=1}^{T} f_i(P_{sit}) = \sum_{i=1}^{N_s}\sum_{t=1}^{T}(a_i + b_i * P_{sit} + c_i P_{sit}^2) \tag{1}$$

where F is the total fuel cost from all thermal plants over the entire scheduling horizon; N_s is the number of thermal plants; P_{sit} is the power generation from thermal plant i at time interval t; $f_i(P_{sit})$ is the fuel cost function of the ith thermal plant, and it is usually represented as follows with consideration of valve loading point effect.

$$f_i(P_{sit}) = a_i + b_i * P_{sit} + c_i P_{sit}^2 + \left| d_i * \sin(e_i * (P_{si}^{\min} - P_{sit})) \right| \tag{2}$$

where a_i, b_i, c_i, d_i and e_i are constant coefficients and $P_{si}^{\min}$ is the minimum generation of thermal plant i.

Constraints

(1) Power load balance

$$\sum_{i=1}^{N_s} P_{sit} + \sum_{i=1}^{N_h} P_{hit} = P_d(t) + P_l(t) \quad t = 1, 2, \ldots, T \tag{3}$$

where N_h is the number of hydro plants; P_{hit} is the power generation from hydro plant i at time interval t; $P_d(t)$ is the power demand of the system at time interval t; $P_l(t)$ is the total transmission loss of the system at time interval t and it can be calculated using the ***B*** matrix loss formula [2] as follows.

$$P_l(t) = \sum_{i=1}^{g}\sum_{j=1}^{g} P_{sit} B_{ij} P_{sjt} + \sum_{i=1}^{g} B_{0i} P_{sit} + B_{00} \tag{4}$$

where B, $B0$ and B_{00} are the coefficients of the corresponding power system. The power generation from hydro plant i at time interval t is calculated using a quadric function of the initial reservoir volume and the hydro discharge at the time interval as follows.

$$P_{hit} = c_{1i} V_{hit-1}^2 + c_{2i} Q_{hit}^2 + c_{3i} V_{hit-1} Q_{hit} + c_{4i} V_{hit-1} + c_{5i} Q_{hit} + c_{6i} \tag{5}$$

where V_{hit} is the final storage volume of reservoir i at time interval t and V_{hit-1} is the initial reservoir volume at time interval t; Q_{hit} is the discharge of reservoir i at time interval t; c_{1i}, c_{2i}, c_{3i}, c_{4i}, c_{5i} and c_{6i} are the constant coefficients.