Energy Conversion and Management 89 (2015) 127–136

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Short-term economic environmental hydrothermal scheduling using improved multi-objective gravitational search algorithm

Chunlong Li, Jianzhong Zhou *, Peng Lu, Chao Wang

School of Hydropower and Information Engineering, Huazhong University of Science and Technology, Wuhan 430074, PR China
Hubei Key Laboratory of Digital Valley Science and Technology, Huazhong University of Science and Technology, PR China

ARTICLE INFO

Article history:
Received 3 July 2014
Accepted 21 September 2014

Keywords:
Economic environmental hydrothermal scheduling
Multi-objective optimization
Gravitational search algorithm
Elite archive set
Neighborhood searching mechanism
Constraint handling method

ABSTRACT

With growing concerns about energy and environment, short-term economic environmental hydrothermal scheduling (SEEHS) plays a more and more important role in power system. Because of the two objectives and various constraints, SEEHS is a complex multi-objective optimization problem (MOOP). In order to solve the problem, we propose an improved multi-objective gravitational search algorithm (IMOGSA) in this paper. In IMOGSA, the mass of the agent is redefined by multiple objectives to make it suitable for MOOP. An elite archive set is proposed to keep Pareto optimal solutions and guide evolutionary process. For balancing exploration and exploitation, a neighborhood searching mechanism is presented to cooperate with chaotic mutation. Moreover, a novel method based on feasible space is proposed to handle hydro plant constraints during SEEHS, and a violation adjustment method is adopted to handle power balance constraint. For verifying its effectiveness, the proposed IMOGSA is applied to a hydrothermal system in two different case studies. The simulation results show that IMOGSA has a competitive performance in SEEHS when compared with other established algorithms.

1. Introduction

For the increasing power demand, lots of thermal plants and hydro plants have been built in recent years. These plants not only bring abundant electricity, but also lead to energy scarcity and serious pollution. Given the attention to energy and environment, short-term economic environmental hydrothermal scheduling (SEEHS) plays a more and more important role in power system, and it has caught lots of attentions in recent years [1–4]. The main task of SEEHS is to determine the processes of hydro plants and thermal plants for minimizing fuel cost and emission while subjecting to various equality and inequality constraints. Because of multiple objectives and coupled constraints, SEEHS is a complex multi-objective optimization problem (MOOP).

Compared to the economy objective, the emission objective may be neglected sometimes, thus the SEEHS will be simplified to a single objective optimization. In this case, the single objective optimization problem can be solved by linear programming (LP) [5], nonlinear programming (NLP) [6] or dynamic programming (DP) [7,8]. Besides these mathematical methods, some heuristic algorithms including genetic algorithm (GA) [9,10], differential evolution (DE) [11,12] and particle swarm optimization (PSO) [13–15] are also applied to solve the problem. However, most of the time the emission objective cannot be neglected, SEEHS is a typical MOOP. If the above algorithms are still employed, SEEHS should be converted to a single objective optimization by weighting methods [16] or constraints conversion [17]. In such a way, we will not obtain Pareto optimal solutions unless lots of repeated calculations are executed, and the distribution of these solutions cannot be guaranteed.

In order to solve the problem, some multi-objective evolutionary algorithms (MOEAs) have been proposed in recent years. Inspired by the popular non-dominated sorting genetic algorithm-II (NSGA-II) [18] and strength Pareto evolutionary algorithm-II (SPEA-II) [19], some novel MOEAs, including multi-objective differential evolutionary (MODE) [20–22], multi-objective particle swarm optimization (MOPSO) [23–25] and multi-objective artificial bee colony (MOABC) [26], have been developed by introducing MOOP into heuristic algorithm. These MOEAs can obtain many Pareto optimal solutions instead of one solution in single calculation, and these solutions are distributed evenly.

Based on the Newtonian laws of gravity and motion, a novel heuristic algorithm called gravitational search algorithm (GSA) [27] was proposed by E. Rashedi in 2009. In GSA, the agents move towards the heavier agents because of the gravity forces from

* Corresponding author at: School of Hydropower and Information Engineering, Huazhong University of Science and Technology, Wuhan 430074, PR China. Tel.: +86 02787543127.
E-mail address: jz.zhou@hust.edu.cn (J. Zhou).

http://dx.doi.org/10.1016/j.enconman.2014.09.063
0196-8904/

other agents, and converge to the heaviest agent at last. Due to its powerful exploration ability, GSA has been widely utilized in some fields [28,29], such as power system [30–32]. However, the traditional GSA is not suitable for MOOP, and it still suffers from the premature convergence as well as other heuristic algorithms.

In this paper, we present an improved multi-objective gravitational search algorithm (IMOGSA) to solve SEEHS successfully. In IMOGSA, the mass of the agent is redefined to make it suitable for MOOP, an elite archive set is proposed to keep Pareto optimal solutions and guide evolutionary process. For balancing exploration and exploitation, a neighborhood searching mechanism is presented to cooperate with chaotic mutation. Considering the complex constraints during SEEHS, a novel method based on feasible space is proposed to handle hydro plant constraints, and a violation adjustment method is adopted to handle power balance constraint. Finally, the proposed IMOGSA is applied to a hydrothermal system for verifying its effectiveness. The results show that IMOGSA has a competitive performance in SEEHS.

The paper is organized as follows: The formulation of SEEHS is introduced in Section 2, and IMOGSA is proposed with a brief description of MOOP in Section 3. Section 4 presents novel constraint handling methods to solve SEEHS. The proposed IMOGSA is applied to a hydrothermal system and compared with other established algorithms in Section 5. Finally, conclusions followed by acknowledgements are summarized in Section 6.

2. Problem formulation

Because of the objectives, SEEHS which takes fuel cost and emission into account is a typical MOOP. In order to optimize these objectives, SEEHS has the task to determine the processes of thermal plants and hydro plants while subjecting to various equality and inequality constraints. In general, the formulation of SEEHS is expressed as follows:

2.1. Objective function

2.1.1. Economy objective

As a vital objective of SEEHS, the fuel cost of thermal system contains normal operation part and valve point effect part. The normal operation part will increase nonlinearly with the growth of output, and it can be represented as a quadratic function. The valve point effect part which depends on the condition of admission valve can be represented as a sinusoidal function. Therefore, the total fuel cost can be represented as formula (1):

$$\min F = \sum_{i=1}^{Ns}\sum_{t=1}^{T} f_{si,t} = \sum_{i=1}^{Ns}\sum_{t=1}^{T}\left\{a_i + b_i P_{si,t} + c_i (P_{si,t})^2 + d_i \left|\sin e_i (P_{si,t} - P_{si,\min})\right|\right\} \tag{1}$$

where F denotes the total fuel cost of thermal system; Ns is the number of thermal plants; T is the number of periods; a_i, b_i, c_i, d_i and e_i denote the cost coefficients of the i-th thermal plant; $P_{si,\min}$ denotes the minimum output limit of the i-th thermal plant; $f_{si,t}$ and $P_{si,t}$ denote the fuel cost and output of the i-th thermal plant in the t-th period, respectively.

2.1.2. Environment objective

With the increasing attention to environment, emission pollutants released by thermal plants has become an important objective. Among these pollutants, sulfur oxide (SOx) and nitrogen oxide (NOx) are particularly serious, thus the emission of nitrogen oxide (NOx) is considered in this paper. The emission can be represented as a summation of quadratic function and exponential function, which is shown as formula (2):

$$\min E = \sum_{i=1}^{Ns}\sum_{t=1}^{T} e_{si,t} = \sum_{i=1}^{Ns}\sum_{t=1}^{T}\left\{\alpha_i + \beta_i P_{si,t} + \gamma_i (P_{si,t})^2 + \eta_i \exp(\delta_i P_{si,t})\right\} \tag{2}$$

where E denotes the total emission of thermal system; α_i, β_i, γ_i, η_i and δ_i denote the emission coefficients of the i-th thermal plant; $e_{si,t}$ denotes the emission of the i-th thermal plant in the t-th period.

2.2. Constraints

During the process of SEEHS, various coupled constraints will bring us some difficulties, while they cannot be neglected to insure the feasibility of solutions. These equality and inequality constraints are described as follows:

2.2.1. Power balance constraint

$$\sum_{i=1}^{Ns} P_{si,t} + \sum_{j=1}^{Nh} P_{hj,t} = P_{D,t} + P_{L,t} \quad t \in [1, T] \tag{3}$$

where $P_{hj,t}$ denotes the output of the j-th hydro plant in the t-th period; $P_{D,t}$ denotes the system load demand in the t-th period; $P_{L,t}$ denotes the total power transmission loss in the t-th period; Nh is the number of hydro plants.

As to the power balance constraint, hydro plants and thermal plants are associated closely, thus hydro plants can influence the two objectives indirectly. With a certain load demand $P_{D,t}$, the more output of hydro plants, the less output of thermal plants, which leads to less fuel cost and lower emission. In other words, thermal plants and hydro plants both take part in optimization.

In general, the output of hydro plant depends on not only the water discharge, but also on the net water head which is correlated with water storage. Thus the output of hydro plant $P_{hj,t}$ can be described as formula (4):

$$P_{hj,t} = C_{1j}(V_{hj,t})^2 + C_{2j}(Q_{hj,t})^2 + C_{3j} V_{hj,t} Q_{hj,t} + C_{4j} V_{hj,t} + C_{5j} Q_{hj,t} + C_{6j} \tag{4}$$

where $V_{hj,t}$ and $Q_{hj,t}$ denote the water storage and water discharge of the j-th hydro plant in the t-th period; C_{1j}, C_{2j}, C_{3j}, C_{4j}, C_{5j} and C_{6j} denote the output coefficients of the j-th hydro plant.

Moreover, the power transmission loss is calculated by formula (5):

$$P_{L,t} = \sum_{i=1}^{Nh+Ns}\sum_{j=1}^{Nh+Ns} P_{i,t} B_{ij} P_{j,t} + \sum_{i=1}^{Nh+Ns} B_{0i} P_{i,t} + B_{00} \tag{5}$$

where $P_{i,t}$ denotes the output of hydro or thermal plant; B_{ij}, B_{0i} and B_{00} denote power transmission loss coefficients.

2.2.2. Output limit constraint

$$\begin{cases} P_{si,\min} \leqslant P_{si,t} \leqslant P_{si,\max} \\ P_{hj,\min} \leqslant P_{hj,t} \leqslant P_{hj,\max} \end{cases} \tag{6}$$

where $P_{si,\min}$ and $P_{si,\max}$ denote the minimum and maximum output limits of the i-th thermal plant; $P_{hj,\min}$ and $P_{hj,\max}$ denote the minimum and maximum output limits of the j-th hydro plant.