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Short term hydrothermal scheduling using multi-objective differential evolution with three chaotic sequences

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ABSTRACT

Short-term hydrothermal optimal scheduling with economic emission (SHOSEE) is a multi-objective and complex constrained optimization problem. In this paper, three chaotic sequences based multi-objective differential evolution (CS-MODE) is proposed to solve this SHOSEE problem, and it utilizes elitist archive mechanism to retain the non-dominated individuals, which improves the convergence ability in the differential evolution, and a heuristic two-step constraint-handling technique is utilized to handle those complex equality and inequality constraints in SHOSEE problem. Furthermore, in order to avoid premature convergence, the proposed CS-MODEs have integrated three chaotic mappings into differential evolution to implement population space search, it enlarges search space and enriches the diversity of individuals generated in evolution process. The compromise scheme is selected from the non-dominated set to represent the average efficiency level on the hydrothermal system, and the obtained simulation result also reveals the feasibility and effectiveness of proposed CS-MODEs in comparison to other methods established recently.

1. Introduction

Short-term hydrothermal optimal scheduling (SHOS) has been one of the most important optimization problems for utilizing hydropower to achieve maximum economy in power system recently. Generally, the main objective of SHOS is to minimize the production cost of thermal plants by planning the generation scheme of hydro power and thermal power for each power plant. There are operational costs in SHOS compound by two parts, the water value and the maintenance cost. The first one is indirect, associated with thermal generation saved in the planning horizon. The second one is associated mainly with the on/off of hydro units and the forbidden zones, which can be neglected due the model used in this paper. The scheduling problem is simplified to minimize the fuel cost while satisfying generation limits, water balance constraint, load balance constraint over a scheduling horizon. Furthermore, SHOS is a large scale, dynamic and constrained nonlinear programming problem, and then it becomes a big challenge when time delay is considered.

Several researchers have proposed many optimization methods for solving this problem such as dynamic programming (DP) [1,2], progressive optimization algorithm (POA) [3], and network flow programming (NFP) [4], Lagrangian relaxation (LR) [5,6]. However, these methods have different drawbacks to some extent, DP suffers from 'curse of the dimensionality' [7], POA has great calculated capacity, and NFP is always trapped in local optimal value.

Afterwards, heuristic optimization techniques have aroused intense interest due to their flexibility, versatility and robustness in seeking global optimal solution, evolutionary algorithm (EA) is used to avoid these drawbacks and has fewer requirements in differentiability, continuity and concavity [8–11]. In the past decades, EA has been widely used in SHOS for their powerful optimization ability based on the principle of natural selection, and achieves some degrees of success.

Recently, due to the increasing concern of environmental requirement, the cheapest price of thermal power cannot meet the demand of society, and the harmful emission production of thermal unit must also be satisfied simultaneously [12]. As a new alternative choice, the emission rate of thermal system must also be taken into consideration as an objective, and a new strategy of short-term hydrothermal optimal scheduling with economic emission (SHOSEE) has become desirable and widely used.

Obviously, SHOSEE is a multi-objective optimization problem (MOP) with two conflicting objectives. For switching to low gaseous pollutants, several measures can be taken to reduce the pollutant emission, such as the replacement of pollutant cleaning equipment, and these measures are generally expensive or will scarify low emission fuel. Thus, a compromise between thermal cost and emission effect should be taken into consideration. Afterwards, some new optimization technologies based on the tradeoffs have been proposed to tackle with this problem, the objectives

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are incorporated into single one objective by multiplying the trade-off weight for each objective, i.e., interactive fuzzy satisfying method [9], goal-attainment method [13] and quantum-behaved particle swarm optimization method [14]. Though these methods make the optimization process simple and easy to operate, it lacks of flexibility and engineering practicability. Once the weight or price penalty factor changes, the whole optimization process will be started up again, which is quite time consuming to some extent.

Fortunately, some efficient multi-objective evolutionary algorithms (MOEA) have been proposed in recent years, such as Deb's non-dominated sorting genetic algorithm (NSGA-II) [15], Zitzler's enhanced strength pareto evolutionary algorithm (SPEA-II) [16], multi-objective particle swarm optimization (MOPSO) [17–19] and multi-objective differential evolutionary algorithm (MODE) [20–22]. Those methods optimize the MOPs in single simulation run, and those objectives are optimized simultaneously, finally a set of pareto solutions are produced as candidate schemes for decision makers. Furthermore, since MOEA provides a global search method and is available for a variety of objective functions, no matter whether they are differentiable, continuous or convex. This paper mainly proposes three new MOEAs named chaotic sequence based multi-objective differential evolutionary algorithm (CS-MODE).

Differential evolution (DE) [23] is a simple but powerful evolutionary strategy, DE has less parameters and is easy to implement and relative stable. This method is a promising alternative for solving real-valued optimization problems, especially for those operation scheduling problems, DE has gotten some success in past decades. Generally population size of DE is 5–10 times more than the number of decision variables in optimization process, which can avoid premature to some extend.

Recently, many chaotic differential evolutions (CDEs) have been proposed with integrated chaotic sequences in the evolutionary process [24–26], and satisfactory results also have been obtained in applications due to its enhanced exploitation capability of evolutionary search. In this paper, the proposed CS-MODEs adopt elitist archive retention mechanism to reserve the pareto solutions in the evolutionary process, and improves convergence efficiently in the population evolution. Furthermore, it modifies MODE with three chaotic mappings and some adaptive parameters, those parameters enlarge the search space when it converges to optima, while the chaotic factor makes the search trajectory jump out from the local optimal when it is trapped in local optima. And the simulation result proves that the proposed CS-MODEs act better and has more desirable results in comparison to the MODE.

The paper is organized as follows: the problem formulation of SHOSEE is introduced in Section 2, and in Sections 3 and 4 some basic definitions of MOP and overview of DE are presented, then the modified evolutionary strategy, constraint-handling technology and the corresponding case studies are described in Sections 5 and 6, ultimately conclusions is outlined in Section 7.

2. Problem formulation

SHOSEE is formulated as a multi-objective problem which is described by the combination of fuel cost and emission issue, the problem is mainly concerned with attempting to minimize these two objectives simultaneously, and some equality and inequality constraints must also be satisfied.

2.1. Objectives

2.1.1. Fuel cost

The economic scheduling is one of major problems in hydrothermal optimal scheduling, for a given hydrothermal system, hydrothermal scheduling can be described as attempting to minimize the total fuel cost of thermal units, which is subjected to various equality and inequality constraints, the fuel cost of each thermal generating unit is presented as follows:

$$f_{it}(P_{si,t}) = a_i + b_i \cdot P_{si,t} + c_i \cdot P_{si,t}^2 \tag{1}$$

where a_i, b_i, c_i are the fuel cost coefficients of the ith thermal unit, $P_{si,t}$ is the generated power of the ith thermal unit at tth time period. In the thermal power system, a sharp increase in fuel loss will be added into the fuel cost curve due to the wire drawing effects when steam admission valve starts to open, and this sharp fuel loss increase is denoted as valve point effects.

Traditionally, sinusoidal function is not taken into consideration, valve-point effects of sharp increase in fuel loss also has great effect on the total fuel cost. After practical simulation of the relationship between power generation of thermal plant and the sharp increase produced along with the power generation, sinusoidal function is a better fit curve line. Hence, the fuel cost of thermal unit can be modified as:

$$f'_{it}(P_{si,t}) = (a_i + b_i \cdot P_{si,t} + c_i \cdot (P_{si,t})^2 + |d_i \cdot \sin(e_i \cdot (P_{si,\min} - P_{si,t}))| \tag{2}$$

where a_i, b_i, c_i, d_i, e_i are the coefficients of thermal cost in the ith thermal unit, $P_{si,\min}$ is the minimum power limit of the ith thermal unit, and the total fuel cost of thermal system can be expressed as the summation of formulation (2) according to the thermal units, which is described as:

$$\min f_1 = \min \sum_{t=1}^{T} \sum_{i=1}^{N_s} f'_{it}(P_{si,t}) \tag{3}$$

where f_1 is the total fuel cost, T is the total number of operation periods, N_s is the number of thermal units.

2.1.2. Emission issue

The emission pollutant discharged by thermal unit is mainly composed of sulfur oxide and nitric oxide, for simplicity, only nitric oxide is considered from the viewpoint of environment conservation, the amount of nitric oxide emission in each thermal unit at each time interval is given as the function of thermal power. Generally, the emission amount is expressed as the summation of a quadratic function and an exponential function, and then the total emission cost can be described as follows:

$$\min f_2 = \sum_{t=1}^{T} \sum_{i=1}^{N_s} e_i(P_{si,t}) = \sum_{t=1}^{T} \sum_{i=1}^{N_s} \left(\alpha_i + \beta_i P_{si,t} + \gamma_i P_{si,t}^2 + \eta_i \cdot \exp(\delta_i \cdot P_{si,t}) \right) \tag{4}$$

where f_2 is the total emission rate, α_i, β_i, γ_i, η_i, δ_i are emission coefficients of ith thermal unit.

2.2. Constraints

(1) System load balance

$$\sum_{i=1}^{N_s} P_{si,t} + \sum_{j=1}^{N_h} P_{hj,t} = P_{L,t} + P_{D,t} \quad (t = 1, 2, \ldots, T) \tag{5}$$

where $P_{hj,t}$ is output of the jth thermal unit at tth time period, N_h is total number of hydro plant, $P_{D,t}$ is system load requirement at tth time period, $P_{L,t}$ is transmission loss at tth time period.

The transmission loss is calculated in the form of quadratic function with B loss coefficients as follows:

$$P_{L,t} = \sum_{i=1}^{N_s} \sum_{j=1}^{N_s} P_{si,t} B_{ij} P_{sj,t} + \sum_{i=1}^{N_s} B_{0i} P_{si,t} + B_{00} \tag{6}$$