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Multi-objective optimization of short-term hydrothermal scheduling using non-dominated sorting gravitational search algorithm with chaotic mutation

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ABSTRACT

This paper proposes a non-dominated sorting gravitational search algorithm with chaotic mutation (NSGSA-CM) to solve short-term economic/environmental hydrothermal scheduling (SEEHTS) problem. The SEEHTS problem is formulated as a multi-objective optimization problem with many equality and inequality constraints. By introducing the concept of non-dominated sorting and crowding distance, NSGSA-CM can optimize two objectives of fuel cost and pollutant emission simultaneously and obtain a set of Pareto optimal solutions in one trial. In order to improve the performance of NSGSA-CM, the paper introduces particle memory character and population social information in velocity update process. And a chaotic mutation is adopted to prevent the premature convergence. Furthermore, NSGSA-CM utilizes an elitism strategy which selects better solutions in parent and offspring populations based on their non-domination rank and crowding distance to update new generations. When dealing with the constraints of the SEEHTS, new strategies without penalty factors are proposed. In order to handle the water dynamic balance and system load balance constraints, this paper uses a combined strategy which adjusts the violation averagely to each decision variable at first and adjusts the rest violation randomly later. Meanwhile, a new symmetrical adjustment strategy by modifying the discharges at current and later interval without breaking water dynamic balance is adopted to handle reservoir storage constraints. To test the performance of the proposed NSGSA-CM, simulation results are compared with other methods reported in literatures. The results verify that the proposed NSGSA-CM is feasible and efficient for solving SEEHTS problem.

1. Introduction

The short-term hydrothermal optimal scheduling is one of the most important optimization problems in electric power system operation [1–5]. The main goal of short-term hydrothermal scheduling is to minimize the total operation cost of hydrothermal system during whole schedule period with satisfying various non-linear and non-convex constraints. In general, the water resource is regarded as renewable so that the operation cost of hydro plants is insignificant. Thus, the objective of short-term hydrothermal scheduling reduces to make full use of the hydraulic resource and minimize the fuel cost of thermal plants.

Since the importance of hydrothermal scheduling is well recognized, many mathematical methods have been used to solve this problem, such as: linear programming (LP) [6], nonlinear programming (NLP) [7], dynamic programming (DP) [8], Lagrangian relaxation [9]. These traditional methods all suffer from curse of dimensionality when applied on a large hydrothermal system with various constraints. Therefore, in recent years, many stochastic search algorithms are developed for solving hydrothermal scheduling. Several famous evolutionary approaches including genetic algorithm (GA) [10,11], cultural algorithm (CA) [12], differential evolution (DE) [13,14], particle swarm optimization (PSO) [15,16] are applied and have obtained some success. However, these researches are only concerned about the economic benefit of electric power system, the environmental problem caused by pollution emission of the thermal plants are not taken into consideration.

As the increasing public awareness of environmental protection, the harmful pollution emission produced by thermal plants is noticed by society gradually. The traditional hydrothermal scheduling which only considering the fuel cost cannot satisfy the requirements of environmental protection because of huge emission amount. Thus, it is necessary to take the emission as one of the objectives of hydrothermal scheduling problem. Then the hydrothermal scheduling is extended to a multi-objective

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optimization problem (MOP) with considering fuel cost and emission simultaneously. Many approaches are proposed to solve short-term economic/environmental hydrothermal scheduling problems (SEEHTS), such as: fuzzy satisfying evolutionary programming [17], genetic algorithm [18], quadratic approximation based differential evolution [19], particle swarm optimization [20,21]. All the methods mentioned above convert the multi-objective optimization problem into single objective problem by using weights, price penalty factors or trade-offs. Although those approaches can obtain compromise solutions for SEEHTS problem, there are still some drawbacks of them: The weights or price penalty factors of the objectives are difficult to determine. Each optimization process can only obtain one best compromise solution, and if the objective functions are non-convex, they may not get the true Pareto fronts by changing the trade-offs.

Recently, some multi-objective evolutionary algorithms (MOEA) have been presented to solve the multi-objective optimization problem. Some classic and famous methods among the MOEAs are Deb's non-dominated sorting genetic algorithm (NSGA-II) [22], Zitzler's enhanced strength Pareto evolutionary algorithm (SPEA-II) [23], multi-objective particle swarm optimization (MOPSO) [24] and multi-objective differential evolutionary algorithm (MODE) [25]. Compared to the methods using weights or price penalty factors, the MOEAs are proved to be efficient in solving multi-objective optimization problem with optimize the conflict objectives simultaneously. MOEAs have no need to compute the trade-offs between the objectives of fuel cost and emission, and MOEAs can obtain a set of non-dominated solutions in a single run instead of only one optimal solution. Thus, researchers have tried to utilize MOEAs to deal with the multi-objective optimization problem in electric power system and obtained some achievements. In Ref. [26], the author applies NSGA-II to solve economic environmental dispatch of fixed head hydrothermal power systems. But due to NSGA-II is based on genetic algorithm, it suffers from the premature convergence. The paper [27] develops a multi-objective chaotic particle swarm optimization (MOCPSO) to solve the environmental/economic dispatch problems considering both economic and environmental issues. However, due to the fast convergence rate of PSO, the search may fall into local optimal without any improvement. In Ref. [28], a multi-objective differential evolution (MODE) is presented for economic environmental dispatch of hydrothermal power system. But in this paper the process of handling the constraints is not described clearly. From the descriptions above, it is significant to find methods obtaining better performance and more effective ways to deal with the constraints for solving SEEHTS problem.

Gravitational search algorithm [29] is a newly heuristic optimization algorithm based on Newton's law of gravity, which guides the evolution of populations through gravitation interactions between particles. Due to the flexibility and efficiency characters of GSA, researchers have used it for solving different optimization problems. Rashedi et al. [30] presents a new linear and nonlinear filter modeling based on GSA. Mohammad et al. [31] applies GSA to search for the minimum factor of safety and minimum reliability index in both deterministic and probabilistic slope stability analysis. Güvenç et al. [32] uses GSA to deal with the economic load dispatch problem of thermal plants successfully. But this paper just considers the load dispatch with only one time period. Duman et al. [33] employs GSA to find the optimal solution for optimal power flow problem in a power system. Furthermore, in order to solve the multi-objective optimization problem, many extension of GSA are presented. In Ref. [34], the first multi-objective variant of GSA called multi-objective GSA (MOGSA) is proposed by Hassanzadeh. MOGSA uses an external achieve to store non-dominated solutions as the same as Simple multi-objective PSO (SMOPSO) [35]. Nobahari et al. [36] apply a non-dominated sorting GSA by introducing both non-dominated sorting and external achieve for multi-objective problem. Ibrahim et al. [37] presents a novel Vector Evaluated Gravitational Search Algorithm (VEGSA) for multi-objective optimization problem. This technique uses a population of particles corresponds to one objective function to be minimized or maximized. And simultaneous minimization or maximization of every objective function is realized by exchanging a variable between populations. In Ref. [38], the author proposes MOGSA to optimize both objectives including execution time and cost of multi-objective grid scheduling. However, the application of GSA for SEEHTS problem is rarely reported in literatures so far.

In this paper, a new extension of GSA which is non-dominated sorting GSA with chaotic mutation (NSGSA-CM) is proposed to solve SEEHTS problem successfully. By introducing the fast non-dominated sort approach and the crowding distance concept of NSGA-II [22], NSGSA-CM can obtain a set of Pareto optimal solutions with diverse distribution in single trial. Differ from GSA, the mass of each particle is calculated by its non-dominated rank rather than the objective values in NSGSA-CM. In order to enhance the performance of this technique, particle memory character and population social information are added into new velocity update equation to accelerate the evolution process. To overcome the premature convergence, a mutation operator based on chaotic sequence is applied in NSGSA-CM to search in global region. Furthermore, NSGSA-CM adopts a selection operation based on elite preservation strategy in parent and offspring populations to update new generation according to the non-dominance relationship and crowding distance. When dealing with the various complicated constraints of SEEHTS problem, this paper adopts new adjustment strategies. To handle the equality constraints including water dynamic balance and system load balance, the combined strategy adjusts the violation averagely to each decision variable at first and then adjusts the rest of violation to the decision variable randomly selected. For handling the inequality constraints which are reservoir storage volumes limit, this paper proposes a new strategy which modifies the water discharge at current time interval in feasible region based on the violations of the reservoir storages. Meanwhile, it modifies the equal amount to the corresponding discharge at the later time intervals without breaking the water dynamic balance. Finally, in order to verify the performance of NSGSA-CM for solving SEEHTS problem, the proposed approach is tested on a sample system with four cascaded hydro plants and three thermal plants [17]. Simulation results obtained by the proposed NSGSA-CM are compared with those obtained by other methods in recent literatures applied on the same problem. The result analysis proves that NSGSA-CM is efficient in dealing with the constraints and obtaining Pareto optimal solutions for SEEHTS problem.

The rest of this paper is organized as follows: Section 2 provides the mathematical formulation of short-term economic/environmental hydrothermal scheduling problem. Section 3 presents some basic definitions about multi-objective optimization problem. Section 4 describes the standard GSA and the proposed NSGSA-CM. Section 5 presents the implementation of NSGSA-CM for solving short-term economic/environmental hydrothermal scheduling problem in details. Section 6 gives the numerical example. Section 7 outlines the conclusions. Acknowledgement is given in the end.

2. Problem formulation of SEEHTS

The SEEHTS problem is a bi-objective optimization problem. It is aimed to minimize both the fuel cost and emission of thermal plants while making full use of the availability of hydro resource