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A novel two-swarm based PSO search strategy for optimal short-term hydro-thermal generation scheduling

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ABSTRACT

The optimal power generation of hydro-thermal systems to minimize total operating costs is one of the most important targets in short-term hydro-thermal scheduling (STHS) and its evaluation is complicated by several complex and interconnected equality and inequality constraints.

To solve this type of problem, it is necessary to develop on one side a model of the system characterized by a fair and proper treatment of all the equality and inequality constraints and on the other a performing optimization algorithm simultaneously considering not only the minimization of the operating costs but also the feasibility of the proposed solution.

The paper presents a novel two-swarm based PSO (Particle Swarm Optimization) search strategy developed for solving these kinds of STHS problems. To exclude constraint violations as far as possible during the optimization process, first a complete inequality and equality constraints treatment of the hydrothermal systems was developed, combined with a fair spillage modelling. Then, a recent evolution of the particle swarm optimization algorithm ASD-PSO (Adaptive Search Diversification-Particle Swarm Optimization) was modified, introducing a secondary swarm able to exploit the potential contribution of the infeasible solutions. Within the context of this new strategy, two different swarms were designed, each characterized by a different treatment of the infeasible solutions, and each interacting properly with the other at every iteration.

The primary swarm dealt with feasible solutions, resulting from the manipulation of constraint repairing strategies, and with a limited number of infeasible solutions whose potential contribution in the search process was not wasted out but it was properly weighted on the basis of the violation degree. The secondary swarm involved less manipulated solutions that were subjected only to one repair strategy in order to foster the exploration capability of the swarm. At each iteration, the two swarms independently update their position and velocity but partially interact with each other to obtain mutual advantages from their different peculiarities.

This novel two-swarm based strategy for solving short-term hydro-thermal scheduling (STHS) problems was validated by comparing the achieved performance in terms of accuracy with those of several algorithms proposed in literature. Six different test cases, widely analysed in the literature and characterized by increasing complexity, were considered. In all the considered Test Cases, the algorithm performed very well with minimum total fuel costs that were still lower than all the feasible solutions proposed in the literature, and that satisfied all the equality and inequality constraints of the system.

1. Introduction

One of the most important targets in short-term hydro-thermal scheduling (STHS) is to evaluate the optimal power generation of both hydro and thermal plants in order to minimize the total operating cost of the power system under several complex and interconnected equality and inequality constraints.

The operating cost of hydro-power plants may be assumed to be negligible compared to thermal plants, so that only the operating cost of thermal plants can be assumed to be representative of the operating cost of the entire hydro-thermal power system. Therefore, minimizing the operating cost of the hydro-thermal power system also implies minimizing the fuel cost of the thermal plants, thereby reducing the environmental pollution associated with fossil fuel usage.

To solve this type of problem, it is necessary to develop on one side a model of the system characterized by a fair and proper treatment of all the equality and inequality constraints and on the other a performing optimization algorithm simultaneously considering not only

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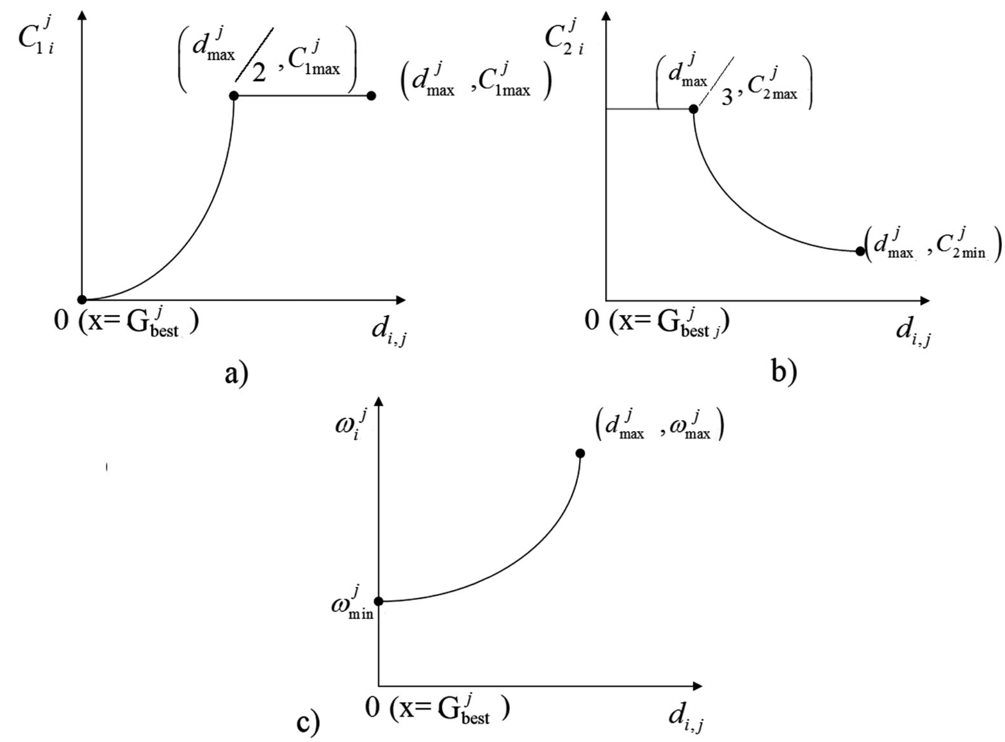

Fig. 1. Distribution of the acceleration coefficients $c_{1_i}^j$ (a) and $c_{2_i}^j$ (b) and of the inertial weight ω (c).

the minimization of the fuel cost but also the feasibility of the proposed solution.

In such a context, several optimization techniques have been proposed in the literature which may be classified into mathematical methods and heuristic algorithms [1].

Mathematical methods, such as linear programming, Lagrange relaxion-based and gradient-based techniques, present difficulties in solving non-linear STHS problems, thus requiring linearization procedures to obtain feasible solutions [2]. The dynamic programming methods overcome the non-linearity and non-convexity nature of STHS problems, but they show increasing programming complexity and computational time as the dimensionality of the STHS problem increases [2,3] even if a promising approach based on semidefinite programming has been recently proposed [2] to overcome such drawbacks connected with large-scale STHS problems.

In recent years, heuristic methods, such as the genetic algorithm, differential evolution, particle swarm optimization, teaching-learning based optimization and other heuristic population-based optimization algorithms, have gained increasing attention due to their capability of solving non-linear and non-convex problems subject to complex interconnected constraints such as those involved in STHS problems, without generating alterations in their mathematical formulation.

Many heuristic algorithms have been proposed, such as differential evolution (DE) [3,4], real-coded genetic algorithm (RCGE) [5], predator civilized swarm optimization (PCSO) [6], gravitational search algorithm (GSA) [7], teaching learning based optimization (TLBO) [8], particle swarm optimization (PSO) [9–12], ant lion optimization [13].

However, heuristic techniques presents some drawbacks, among which the actual probability of converging on a local rather than on a global minimum. So, to compare their performance to each standard algorithm approach or to acknowledge the novelties proposed, different hydrothermal test systems were proposed in the literature as test cases and the results were employed to validate and rank their performance.

Moreover, in the results of these comparisons many doubts have been also raised of late about the quality of the optimal solutions proposed for these test cases [14–17]. Many reservoir storage constraints and hourly power demand balance violations were found when the results of the optimal STHS solution of each test case were verified [18,19]. Such inconsistencies are often connected with the use of penalty functions in the total fuel cost objective function [3,5,13] or with the choice of reducing the use of repair strategies of the infeasible solutions, thereby favouring population diversity and the exploration capability of the optimization algorithm [3,4].

Furthermore, spillages are generally ignored in the reservoir dynamic balance [2–4,7,12,17,20]. Even when they were taken into account [21,22] their formulation and implementation were incomplete. As a result, optimal solutions of STHS problems often appear to have contradictory outcomes like hourly turbine discharge rates greater than zero and the corresponding hydropower generation set equal to zero to avoid unfeasible values (i.e. values lower than the minimum power or even negative). In such cases, all the reservoir discharge rates should be considered as spillages since the power delivered by the hydropower units has to be set equal to zero.

The first novelty of this paper is the development of a fair spillage modelling and a complete treatment of inequality and equality constraints of the hydrothermal systems in order to exclude any constraints violation during the optimization process, where possible. Constraint repair strategies certainly limit the exploration capability of the swarm, since cause a repeated and wide-ranging manipulation of many turbine discharge rates with a possible reduction of the population diversity but are necessary to achieve a feasible solution to the SHTS problem, as testified by the great number of infeasible solutions resulting from a reduced use of repair strategies [3,4] or by their substitution with penalty functions [3,5,13].

The second novelty is the development of a new performing two-swarm PSO (Particle Swarm Optimization) algorithm, derived by a recent evolution of the particle swarm optimization algorithm ASD-PSO (Adaptive Search Diversification Strategy – Particle Swarm Optimization Algorithm) [23]. The original ASD-PSO version, characterized by one swarm, showed very good results in many benchmark functions [23] and real world problems [24,25]. To adapt and improve the performance of the ASD-PSO in case of STHS problems characterized by complex and interconnected equality and inequality, in this paper a secondary swarm, interacting with the primary one, has been