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Programming of thermoelectric generation systems based on a heuristic composition of ant colonies

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ABSTRACT

Studies related to biologically inspired optimization techniques, which are used for daily operational scheduling of thermoelectric generation systems, indicate that combinations of biologically inspired computation methods together with other optimization techniques have an important role to play in obtaining the best solutions in the shortest amount of processing time.

Following this line of research, this article uses a methodology based on optimization by an ant colony to minimize the daily scheduling cost of thermoelectric units. The proposed model uses a Sensitivity Matrix (SM) based on the information provided by the Lagrange multipliers to improve the biologically inspired search process. Thus, a percentage of the individuals in the colony use this information in the evolutionary process of the colony. The results achieved through the simulations indicate that the use of the SM results in quality solutions with a reduced number of individuals.

1. Introduction

The daily operations scheduling of thermoelectric generation systems consists of determining a dispatch strategy of the generating units to meet the demand for energy that satisfies the operating and functional constraints of the electrical power system [1].

The problem can be divided into two sub-problems: (i) one referring to the determination of the units that should be in operation, given the requested demand, ''*Thermal Unit Commitment-TUC*'', and (ii) the other referring to the determination of the power generated by each of the units in service, ''*Economic Dispatch*''. Due to the variation in the load over time, operational scheduling involves decisions of the generation system every hour, within the horizon of 1 day–2 weeks [2].

The representation of costs and operating constraints increases the complexity of the problem through temporal coupling of the down/up decisions for the generating units, resulting in a mixed-integer, non-linear programming problem with the following unique aspects [3]: (i) non-convex solution region, (ii) high computational time due to the combinatory nature of the problem and (iii) dynamic decision process. Therefore, it can be seen that these aspects require constant improvement to the existing algorithms.

The method proposed by [4] uses a priority operation list based on the economic characteristics of the units. Other studies use this technique to mitigate the unfeasibility of enumerating all the possible solutions [5,6].

Dynamic scheduling was the first method based on optimization applied to the problem [7], offering advantages because it considers non-convex and non-linear problems. However, this method requires working in a discrete space, demanding a large memory capacity and high computational time [8,9].

Lagrangian relaxation [10–12] separates the constraints of the problem, allowing the solution to be found through sub-problems solved by dynamic programming. However, due to the non-convexity of the problem, there is no guarantee that the optimality of the dual solution found will lead to a feasible primal solution.

The study reported in [13] examined the biologically inspired optimization techniques used to solve the daily operating scheduling of thermoelectric generation systems, with an emphasis on optimization by ant colonies, artificial neural networks, genetic algorithms and particle swarm optimization. Analyses indicate that the combination of biologically inspired computational methods and other optimization techniques plays an important role in achieving better solutions in less processing time.

Reference [14] presents an investigation into the application of the genetic algorithm to solve the thermal unit commitment problem. A parallel structure was developed to handle the infeasibility problem in a structured and improved genetic algorithm. Typical constraints, such as the system power balance, minimum up and down times, start-up and shut-down ramps, were considered

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Differential evolution based approaches have also been applied to short-term electrical power generation scheduling [15]. In this reference, a new way of applying a differential evolution algorithm, which comprises the search procedure involving binary decision variables and the power dispatch calculation in a unique problem, is proposed. This approach eliminates the use of an iterative local search technique in all solution evaluations.

In [16], a hybrid Taguchi–Immune algorithm, which integrates the Taguchi method and the traditional immune algorithm, is presented to consider the unit commitment problem. The Taguchi method is incorporated in the crossover operations to select the better gene for achieving crossover, consequently enhancing the immune algorithm.

A simulated annealing embedded evolutionary programming approach is presented in [17] to solve the hydro-thermal unit commitment problem. The objective is to determine the generation scheduling such that the total operating cost can be minimized when subjected to a variety of constraints.

Following this line of research, the objective of this paper is to present an improvement in the ant colony optimization (ACO) evolution process for application to the daily operation planning problem for thermoelectric generation units. The results obtained will be evaluated through the simulation of systems that are widely described in the literature.

2. Formulation of the problem

The optimization problem referring to daily operational scheduling of thermoelectric generator units can be formulated as follows [18]:

$$Min\,OF = A + B \tag{1}$$

where

$$A = \sum_{t=1}^{T}\sum_{i=1}^{N}[CO_i(Pg_i(t)].FDO_i^t \tag{1.a}$$

$$B = \sum_{t=1}^{T}\sum_{i=1}^{N}SC_i(t).FDO_i^t.(1 - FDO_i^{t-1}) \tag{1.b}$$

$$CO_i = a_i + b_i.Pg_i(t) + c_i.Pg_i^2 \tag{1.c}$$

subject to

$$FDO_i^t \times Pg_i(t) - Pl(t) = 0 \tag{2}$$

$$\sum_{i=1}^{N}FDO_i^t \times Pg_i^{\max} \geqslant Pl(t) + rg(t) \tag{3}$$

$$X_i^{on}(t) \geqslant T_i^{on} \tag{4}$$

$$X_i^{off}(t) \geqslant T_i^{off} \tag{5}$$

$$Pg_i^{\min} \leqslant Pg_i(t) \leqslant Pg_i^{\max} \tag{6}$$

where

N	total number of thermal units;
T	total operating period;
i	thermal unit index;
t	hour index;
FDO_i^t	discrete variable [0, 1] of "ON/OFF" decision referring to unit i at hour t;
$Pg_i(t)$	active power generated (MW) by thermal unit i at hour t;
$Pg_i^{\max}$	maximum limit of active power generated (MW) by thermal unit i;
$Pg_i^{\min}$	minimum limit of active power generated (MW) by thermal unit i;
$Pl(t)$	demand requested (MW) at hour t;
$rg(t)$	spinning reserve requested (MW) at hour t;
T_i^{on}	minimum on time (h) of thermal unit i;
T_i^{off}	minimum off time (h) of thermal unit i;
$X_i^{on}(t)$	time (h) during which thermal unit i is on;
$X_i^{off}(t)$	time (h) during which thermal unit i is off;
$SC_i(t)$	start-up cost (US$) of thermal unit i at hour t;
a_i, b_i, c_i	coefficients related to fuel costs of thermal unit i ($/h, $/MWh and $/MW^{2}h).

The Objective Function (OF), Eq. (1), consists of the minimizing the sum of the total operating cost (A) and the start-up costs (B) of the generating units during the operating period studied.

The active power balance constraint, Eq. (2), represents the state of equilibrium of the load/generation of the system at all times. Eq. (3) is the spinning reserve of the system to meet unexpected increases in load or deviations from the forecast.

The following constraints were applied to the generating units: (i) minimum up/down times, Eqs. (4) and (5), respectively; (ii) maximum and minimum production limits, Eq. (6).

To avoid the inherent difficulties associated with optimization problems of a discrete nature, the decision variables were allowed to assume continuous values [19] within the discrete interval [0–1]; this strategy aims to obtain the Lagrange coefficients associated with these variables. The sigmoid function (7) was adopted due to its similarity with the step function. Eq. (8) refers to the canalization of the argument of the sigmoid function.

$$FDO_i^t = \frac{e^{x_i^t} - 1}{e^{x_i^t} + 1} \tag{7}$$

$$x_i^{\min} \leqslant x_i^t \leqslant x_i^{\max} \ldots \pi_{xi} \tag{8}$$

where x_i^t Argument of the sigmoid function of thermal unit i in hour t, $x^{\min}$, $x^{\max}$ Minimum and maximum limits of the sigmoid function argument, $\pi_{xi}(t)$ Lagrange multiplier associated with the sigmoid function argument of unit i in hour t.

The objective of the formulation presented here is to enable a comparison of the proposed method with thermoelectric systems widely described in the literature, which use the same modeling. However, it is important to mention that there are other significant constraints, such as ramp limits [20], prohibited operating zones [20,21] and the "valve point" effect [22,23], inherent to the generating units. These constraints increase the complexity of the sub-problem referring to the economic dispatch, making it non-convex.

3. Proposed methodology

The proposed methodology is described below. Its objective is to solve the daily scheduling problem of thermoelectric generation systems using biologically inspired optimization based on ant colonies [24]. For this purpose, two extra stages will be used to help the colony in the search process: (i) relaxation of the discrete variable referring to the operation decision, enabling it to assume con-