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A multi-objective unit commitment problem combining economic and environmental criteria in a metaheuristic approach

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Abstract

The environmental concerns are having a significant impact on the operation of power systems. The traditional Unit Commitment problem (UCP), which minimizes the total production costs is inadequate when environmental emissions need to be considered in the operation of power plants. This paper proposes a metaheuristic approach combined with a non-dominated sorting procedure to find solutions for the multi-objective UCP. The metaheuristic proposed, a Biased Random Key Genetic Algorithm, is a variant of the random-key genetic algorithm, since bias is introduced in the parent selection procedure, as well as in the crossover strategy.

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1. Introduction

The power system generation scheduling is composed of two tasks [1,2]: On the one hand, one must determine the scheduling of the turn-on and turn-off of the thermal generating units; on the other hand, one must also determine the economic dispatch (ED), which assigns the amount of power that should be produced by each on-line

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unit in order to minimize the total operating cost for a specific time generation horizon. The traditional configuration of this problem, known as the Unit Commitment (UC) Problem, was modified to account for environmental concerns, namely due to the goals imposed by the Kyoto protocol and later by the Paris Agreement. The carbon emissions produced by fossil-fueled thermal power plants need also to be minimized. Hence, it is necessary to consider these emissions as another objective. Therefore, we are in the presence of a problem with two, usually, conflicting objectives.

Current research is directed to handle both objectives simultaneously as competing objectives instead of simplifying the multi-objective nature of the problem by converting it into a single objective problem. Several methods have been reported in the literature concerning the environmental/economic dispatch problem such as Genetic Algorithms [3-5], Differential Evolution Algorithms [6,7], Harmony Search Algorithms [8], Gravitational Search Algorithms [9], Particle Swarm Optimization Algorithms [10–12], and Bacterial Foraging Algorithms [13]. These methods fall into the category of metaheuristics, which are optimization methods known to be able to provide good quality solutions within a reasonable computational time (see e.g. [14,15]). Different MOEAs like Niched Pareto Genetic Algorithm (NPGA) [16], Strength Pareto Evolutionary Algorithm (SPEA) [17] and Non-dominated Sorting Genetic Algorithm (NSGA) [18] have been applied to multi-objective problems. Since they use a population of solutions in their search, multiple Pareto-optimal solutions can, in principle, be found in one single run.

In this paper, we propose to address simultaneously the UC and ED problems using multi-objective optimization. A Biased Random Key Genetic Algorithm (BRKGA) combined with a non-dominated sorted procedure and Multi-objective Optimization Evolutionary Algorithm (MOEA) techniques is proposed. The BRKGA developed is based on the framework proposed in [19] and on a previous version developed for the single objective UC problem [20] and [21]. Here, the BRKGA approach includes a ranking selection method, that is used for ordering the non-dominated solutions, and a crowded-comparison procedure as in NSGAII.

The crowded-comparison procedure replaces the sharing function procedure used in original NSGA, which allows for maintain diversity in the population. Furthermore, we compare the algorithm here proposed with the NSGA-II, SPEA2, and NPGA techniques. Our algorithm is tested on the standard 24-hour test system introduced in [22,23]. For this system several cases involving 10 up to 100 generating units are considered.

Nomenclature

Decision Variables:

$y_{t,j}$:Thermal generation of unit j at time period t, in [MW];
$u_{t,j}$: Status of unit j at time t (1 if on; 0 otherwise);

Auxiliary Variables:

$T_j^{on/off}(t)$: Consecutive time periods for which unit j has been on-line/off-line until time period t, in [hours];

Parameters:

T: Time periods (hours) of the scheduling time horizon;
t: Time period index;
N: Number of generation units;
j: Generation unit index;
R_t: System spinning reserve requirements at time t, in [MW];
D_t: Load demand at time period t, in [MW];
Y_{min_j}: Minimum generation limit of unit j, in [MW];
$\boldsymbol{Y_{max_j}}$: Maximum generation limit of unit j, in [MW];
N_b: Number of the base units;
$T_{min_j}^{on/off}$: Minimum uptime/downtime of unit j, in [hours];
$\boldsymbol{T_{c,j}}$: Cold start time of unit j, in [hours];
SD_j: Shut down cost of unit j, in [\$];
$Se_{t,j}$: Start-up pollutant emissions of unit j, at time period t in [ton-CO_2] if CO_2 or [mg=Nm^3] if nitrogen oxides;
$\Delta_j^{dn/up}$: Maximum decrease/increase output level in consecutive periods for unit j, in [MW].

2. The multi-objective UCP formulation

In the multi-objective UC problem, one needs to determine an optimal schedule, which minimizes the production cost and emission of atmospheric pollutants over the scheduled time horizon subject to system and operational constraints. Therefore, the multi-objective UC problem should be formulated including both objectives, i.e., the minimization of the operational costs and the minimization of the pollutant emissions.