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A novel differential evolution application to short-term electrical power generation scheduling

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ABSTRACT

This paper proposes a new way of applying a differential evolution algorithm to short-term electrical power generation scheduling. Traditionally, the problem is divided into two subproblems. An evolutionary algorithm, which works with binary decision variables, is applied to the first subproblem to find a low cost scheduling of power generators, satisfying some operational constraints. Then, the lambda-iteration method, is used to calculate the power generated by the online generators. In this study, the problem is treated as a whole for the first time in literature and an application of a real-valued differential evolution algorithm is proposed. This approach eliminates the use of an iterative local search technique such as lambda-iteration in all solution evaluations. Through comparisons with results from literature, it is shown that the proposed method achieves a similar solution quality to existing methods, without needing the time consuming lambda-iteration step. Finally, the new approach is applied to real-world data from the Turkish interconnected power network.

1. Introduction

Short-term electrical power generation scheduling (SEPGS) is a constrained optimization problem, in which optimal start-up and shut-down schedules need to be determined over a given time horizon, for a group of power generators, under operational constraints. This is also known in literature as the unit commitment problem.The objective is to minimize the power generation costs, while meeting the hourly forecasted power demands. The SEPGS problem has grown in importance recently, not only to promote system economy but also for the following reasons: start-up, shut-down and dynamic considerations in restarting modern generating facilities are much more complex and costly than they were for smaller, older units; systems have grown in size to the point where even small percentage gains have become economically very important; there has been an increase in variation between the peak and off-peak power demands; system planning requires automated, computerized schedulers to simulate the effect of unit selection methods on the choice of new generators.

Commonly the SEPGS problem is treated as consisting of two subproblems [1]: first, a feasible, low cost schedule for turn-on and turn-off times of the power generators over the given time horizon is determined. Then, for each hour, the power outputs of the individual generators scheduled to be online for that hour are obtained in such a way as to minimize the fuel costs, while meeting the forecasted power demands. This second part is termed as the Economic Dispatch Problem (EDP). In literature, the SEPGS problem has been solved using various approaches. These can be grouped as: Simple greedy techniques such as priority lists [2,3] and more recently pre-prepared power demand tables [4]; classical optimization methods such as dynamic-programming [5,6], Lagrangian relaxation [7,8], branch and bound [9], benders decomposition [10]; heuristic search algorithms such as simulated annealing [11,12], tabu-search [13], greedy randomized adaptive search [14]; metaheuristics such as evolutionary algorithms [15–22,1,23–27], particle swarm optimization techniques [28–30], ant colony approaches [31]; and many hybrids, e.g. as in [32,33]. A survey can be found in [34].

Evolutionary algorithms (EAs) [35] is an umbrella term, that covers several slightly differing techniques. EAs are population-based optimization approaches, inspired from classical Mendelian genetics and Darwin's evolutionary theory. A thorough historical perspective is given in [36]. The *Differential Evolution* (DE) [37] algorithm, introduced by Storn and Price in 1995, belongs to the group of evolutionary algorithms for search and optimization in continuous search spaces. DE is a relatively newer technique and has been shown to be promising in many application domains, where the older EAs have been used. DE has not been applied to the SEPGS problem prior to the promising, preliminary results

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reported in [38,39] by the authors of this paper. The authors further compared DE to other evolutionary techniques in [27], showing the superiority of DE. In both of these studies, the traditional approach of tackling the problem as two subproblems was used.

In this study, a novel approach is proposed where the SEPGS problem is treated and solved as a whole. To the best of the authors' knowledge, this is the first time such an approach is used. In this method, a solution candidate consists of real-valued genes, where each value shows the actual power output by the corresponding generator for that time slot. This implicitly gives the on/off schedule too. In this study, we apply a DE algorithm [37] using this representation, where the time consuming lambda-iteration step is not required. The performance of the newly proposed DE application is first observed on standard benchmark problems. It is shown that the proposed approach achieves a good solution quality, competing with existing methods but without needing the lambda-iteration technique. Finally, the approach is used to solve a real-world problem obtained from the Turkish interconnected power network.

The rest of the paper is organized as follows: In Section 2, the SEPGS problem is introduced and its mathematical formulation is given. Section 3 provides an overview of the related work using EA approaches for the SEPGS problem. Section 4 details the proposed application of DE to the problem. In Section 5, the experiments and their results are given and discussed. Section 6 concludes the paper.

2. The short-term electrical power generation scheduling problem

The solution to the SEPGS problem is given as a set of binary decision variable assignments showing which generators are online and which are offline for any given time slot. The objective in the SEPGS problem is to minimize the total power generation costs over a given time horizon, subject to operational constraints, while meeting the power demands. Two factors effect the cost of power generation,[1] namely, fuel costs and start-up costs. Commonly in literature, after the generator online-offline schedule is determined, the EDP is solved using the standard lambda-iteration method [42].

2.1. Problem formulation

The following parameters are used in the formal definition of SEPGS.

- $P_i(t)$: power generated by generator i at time t.
- $F_i(p)$: cost of producing p MW of power by generator i.
- P_i^{max}: maximum amount of power that can be generated by generator i.
- P_i^{min}: minimum amount of power that can be generated by generator i.
- $PD(t)$: power demand at time t.
- $PR(t)$: power reserve at time t.
- $CS_i(t)$: start-up cost of generator i at time t.
- $x_i(t)$: duration for which generator i has stayed on/off since hour t.
- $v_i(t)$: status of generator i at time t (1/0 corresponding to on/off).

To supply the demanded power given for a time slot, all online generators must produce a specific amount of power, such that the total power generation cost is minimized, while the minimum and maximum power generation constraints for each generator are not violated. For N generating units at time t, the objective function and constraints given in Eqs. (1)–(3) are used to obtain the minimum total fuel cost $F_{total}(t)$.

Minimize:

$$F_{total}(t) = \sum_{i=1}^{N} F_i(P_i(t)) \tag{1}$$

Subject to constraints:

$$\sum_{i=1}^{N} P_i(t) = PD(t) \tag{2}$$

$$P_i^{min} \leqslant P_i(t) \leqslant P_i^{max} \tag{3}$$

A generator changing its status from offline to online incurs a cost, called the start-up cost, which depends on the type of the generator and the amount of time it has stayed offline. The function given in Eq. (4) is commonly used for calculating the start-up costs [33].

$$CS_i(t) = \begin{cases} CS_{hot} & \text{if } x_i(t) \leqslant t_{coldstart} \\ CS_{cold} & \text{otherwise} \end{cases} \tag{4}$$

where $t_{coldstart}$ defines the time threshold for a cold or a hot start-up; CS_{hot} is the cost of a hot start-up and CS_{cold} is the cost of a cold start-up.

There is an additional operational constraint which defines a minimum up-time before a generator can be turned-off after becoming online and a minimum down time before a generator can be turned-on after becoming offline. The formulation for this constraint is given in Eq. (5).

$$\begin{array}{ll} \text{if } v_i(t) = 1 & x_i(t-1) \geqslant t_{down} \\ \text{else} & x_i(t-1) \geqslant t_{up} \end{array} \tag{5}$$

where t_{down} is the minimum time the ith generator has to stay offline after it has been turned-off and t_{up} is the minimum time the ith generator has to stay online after it has been turned-on.

Based on these, the objective function of the SEPGS problem for N units and T hours can be stated as given in Eq. (6), subject to constraints as given in Eqs. (7)–(10).

Minimize:

$$F_{total}(t) = \sum_{t=1}^{T} \sum_{i=1}^{N} [F_i(P_i(t)).v_i(t) + CS_i(t)] \tag{6}$$

Subject to constraints:

$$\sum_{i=1}^{N} P_i(t) \cdot v_i(t) = PD(t) \tag{7}$$

$$v_i(t) \cdot P_i^{min} \leqslant P_i(t) \leqslant v_i(t) \cdot P_i^{max} \tag{8}$$

$$\sum_{i=1}^{N} P_i^{max} \cdot v_i(t) \geqslant PD(t) + PR(t) \tag{9}$$

$$\begin{array}{ll} \text{if } v_i(t) = 1 & x_i(t-1) mustbe \geqslant t_{down} \\ \text{else} & x_i(t-1) mustbe \geqslant t_{up} \end{array} \tag{10}$$

The fuel cost of generating p MW of power for the ith unit is calculated using Eq. (11) [42]. Lambda-iteration uses this formulation to find the lowest cost for dispatching the amount of power to be generated by the online generators. This corresponds to the EDP.

$$F_i(p) = a_{0i} + a_{1i}.p + a_{2i}.p^2 \tag{11}$$

[1] It was shown in [40] and in [41], that it is not necessary to include the ramping costs in the cost formulation for the unit commitment problem. Therefore, this cost component is also omitted in the cost calculation used in this study.