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Unit commitment problem with ramp rate constraint using a binary-real-coded genetic algorithm

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ABSTRACT

The unit commitment problem (UCP) is a nonlinear mixed-integer optimization problem, encountered as one of the toughest problems in power systems. The problem becomes even more complicated when dynamic power limit based ramp rate constraint is taken into account. Due to the inadequacy of deterministic methods in handling large-size instances of the UCP, various metaheuristics are being considered as alternative algorithms to realistic power systems, among which genetic algorithm (GA) has been investigated widely since long back. Such proposals have been made for solving only the integer part of the UCP, along with some other approaches for the real part of the problem. Moreover, the ramp rate constraint is usually discussed only in the formulation part, without addressing how it could be implemented in an algorithm. In this paper, the GA is revisited with an attempt to solve both the integer and real parts of the UCP using a single algorithm, as well as to incorporate the ramp rate constraint in the proposed algorithm also. In the computational experiment carried out with power systems up to 100 units over 24-h time horizon, available in the literature, the performance of the proposed GA is found quite satisfactory in comparison with the previously reported results.

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1. Introduction

The unit commitment problem (UCP) involves the optimum scheduling of power generating units as well as the determination of the optimum amounts of power to be generated by committed units, so as to meet the forecasted demand at minimum production cost over a daily to weekly time horizon. The problem is subject to various generator- and system-based constraints. Since the size of the discrete search space increases exponentially with the increasing number of units to be scheduled, the UCP is known as one of the most difficult problems encountered in power systems. The problem becomes even more complicated if the ramp rate constraint is also taken into account. It is a dynamic constraint, which imposes restriction on drastic change in power generation by a unit in successive time instants. The inclusion of the ramp rate constraint requires the modification of the range of generated power for each unit at every time instant.

The exact solution of the UCP can be obtained by complete enumeration. But the approach is not applicable to realistic power systems due to its excessive computational time requirement [39]. This has motivated to investigate alternative algorithms, which can be applied to realistic power systems in order to obtain approximate solutions of the UCP in reasonable computational time. Such alternative algorithms studied for the UCP include both deterministic methods and metaheuristic techniques. However, two major drawbacks are observed with such approaches. Firstly, no single algorithm can handle both the integer and real parts of the UCP. Secondly, although the ramp rate constraint is discussed in the theoretical part of many works, the algorithms are silent on its implementation.

It is observed that the genetic algorithm (GA) in different forms is being studied for the UCP since long back. However, it is also used only for scheduling the units of the UCP, along with some other techniques for the load dispatch part of the problem. Further, the ramp rate constraint is discussed only in the theoretical part, without any mention about its experimental implementation.

This has motivated the present work to revisit the GA for handling both the integer and real parts of the UCP by a single algorithm, as well as to investigate if the ramp rate constraint can also be incorporated in the algorithm. For this purpose, a binary-real-coded GA is proposed here, in which the binary part deals with the scheduling of units and the real part determines the amounts of power generated by committed units. Since the UCP is a hard mixed-integer problem, some mechanisms (including a new one) are also incorporated in the GA for forcibly steering an infeasible solution into the feasible region. Moreover, the algorithmic difficulties and remedies in handling both binary and real variables of the UCP by a single algorithm, as well as handling the ramp rate constraint, are discussed in detail. A set of power systems up to

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100 units, available in the literature, are used to evaluate the effectiveness of the approach over 24-h time horizon. A comparison is made between the proposed method and other similar proposals made in last four years. Computational results show the potential of the proposed approach under different scenarios of the problem.

The rest of the article is organized as follows: the related specialized literature is reviewed in Section 2. The formulation of the UCP is presented in Section 3, followed by the repairing mechanisms in Section 4 and the binary-real-coded GA for the UCP in Section 5. The computational results and discussion are presented in Section 6. Finally, the article is concluded in Section 7 with the present findings and future scope of the current theme.

2. Literature review

The algorithms reported in the specialized literature for solving the UCP can be classified into three categories: deterministic methods, metaheuristics, and hybridized techniques. The investigated deterministic methods include the branch-and-bound method [7], dynamic programming [30], mixed-integer linear programming [32], Lagrangian relaxation (LR) method [23], and the priority list method [29]. Because of the inadequacy of the deterministic methods in handling large-size instances and/or non-convex search space of the UCP, various metaheuristics are investigated, such as the simulated annealing (SA) [43], tabu search (TS) [22], memetic algorithm (MA) [37], artificial neural networks [14], particle swarm optimization (PSO) [20,33,42], differential evolution [5,9,17,35,41], evolutionary programming [18], and genetic algorithm (GA) [1–3,6,8,19,24,25,27,28,40]. Apart from these, some hybrid methods combining metaheuristics with deterministic methods or other metaheuristics are also investigated in order to reduce the search space in large-scale UCP. Such hybrid methods include LR and GA [6], LR and MA [37], LR and PSO [4], GA and SA [25], and GA and TS [31].

Kazarlis et al. [19] proposed a binary GA, with traditional as well as some problem-specific operators, for scheduling the units of the UCP, along with economic load dispatch technique for evaluating the optimum amount of power generated by committed units. In this GA the penalty function method is used to handle infeasible solutions, and the best solution of each generation is carried over to the next generation in order to eliminate the possibility of its destruction through GA operators. A similar procedure was proposed by Xing and Wu [40] also. Arroyo and Conejo [3] proposed a binary GA with traditional operators, in which some heuristics, similar with those applied in the present work, are applied to an infeasible solution for forcibly satisfying the problem constraints. Abookazemi et al. [2] investigated another binary GA with traditional GA operators, and an elitism to carry over a group of best solutions to the next generation. Besides, they [2] used another mutation operator to prefer a cheaper unit over an expensive unit, as well as a new scheme to quantify and classify infeasible solutions. The same binary GA (that of [2]) was investigated by Abookazemi et al. [1] along with an additional operator to commit/decommit small units at short intervals based on their production cost characteristics. Pavez-Lazo and Soto-Cartes [24] proposed a binary GA, in which problem-specific operators are used for crossing individuals of better fitness with those of worse fitness. Additionally, they [24] also applied an elitism for carrying over the individuals to the next generation, as well as a mechanism to repair the up/down time constraints of a randomly selected unit of a solution. Rudolf and Bayrleithner [27] proposed a special binary GA, in which the units of the UCP are scheduled by automatically satisfying the up/down time constraints of the units. They [27] used a LR solution of a nonlinear programming formulation for performing the economic dispatch. Senjyu et al. [28] proposed another special binary GA, in which initial feasible solutions are generated based on load data. They [28] applied the UCP instant-based crossover and mutation operators for generating feasible schedule, along with economic load dispatch technique for optimum power generation. Cheng et al. [6] presented a combination of the GA and LR method as the solution procedure for the UCP, which incorporates a binary GA into the LR method for improving the performance of the LR by updating the Lagrangian multipliers through the traditional binary GA operators. Rajan [25] combined a binary GA with a SA in order to overcome some drawbacks of the individual algorithms. Damousis et al. [8] proposed an integer-coded GA with problem-specific operators, in which a chromosome consists of a sequence of alternating sign integer numbers representing the sequence of operation/reservation times of the generating units. The proposed coding achieves significant chromosome size reduction compared to the usual binary coding. In addition, generating minimum up/down time constraints are directly coded in the chromosome, thus avoiding the use of many penalty functions that distort the search space. Sudhakaran and Raj [31] proposed a real-coded GA combined with tabu search for effectively and efficiently solving large-size UCP, in which a set of feasible schedules is first formulated by the real-coded GA and then these pre-committed schedules are optimized by ordinary local search and tabu search. Roque et al. [26] proposed another real-coded GA with random key operator, in which real values generated by the GA are converted to suitable binary values to get a valid solution of the UCP.

It is observed that GA in different forms is being studied for the UCP since long back. However, it is used only for scheduling units. For determining the amounts of power to be generated by committed units, usually some other techniques are employed, such as the lambda iteration technique [2,1,24], quadratic programming [3], Lagrangian relaxation method [6,27,40], and economic load dispatch technique [8,19,25,28]. No work could be found in the specialized literature, in which both the issues are handled by a GA only. Further, the ramp rate constraint is discussed in many GA-based works [1,8,26], as well as in other works like shuffled frog leaping algorithm [15], sequential Lagrangian-MILP approach [16], PSO [20], mixed integer quadratically constrained program [21], and ant colony optimization [36]. However, none of these works reported how the ramp rate constraint can be incorporated in an algorithm.

3. Formulation of the UCP

As stated in Section 1, the UCP is a mixed-integer scheduling problem over a time horizon, in which the total production cost is to be minimized by satisfying a series of generator- and system-based equality and inequality constraints. It involves $\{0, 1\}$ binary variables to represent on/off status of the units and real variables to represent the amounts of power to be generated by committed units. Accordingly, the formulation of the UCP is presented in the following two subsections.

3.1. Objective function in the UCP

The objective function in the UCP is to minimize the total production cost over the entire time horizon, which is the sum of operating fuel costs of the committed units and the start-up costs of the uncommitted units. It can be expressed as:

$$\text{Minimize} \quad F \equiv \sum_{t=1}^{T}\sum_{i=1}^{N}[\phi_{it} + \psi_{it}(1 - u_{i,t-1})]u_{it} \tag{1}$$

where N is the number of units and T is the time horizon. u_{it} is the $\{0, 1\}$ binary variable of the UCP, representing the on/off status of unit i at time t; whose value is 1 if the unit is 'on' at that time,

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