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A semi-analytical non-iterative primary approach based on priority list to solve unit commitment problem

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ABSTRACT

For many years, the UC (unit commitment) problem has been solved by complex numerical techniques or intelligent search algorithms, due to nonlinear and complex constraints. Many of the applied algorithms employ random searches, which leads to production of different solutions in different program runs. Priority list-based methods are a way out to this, as they produce robust results during a non-iterative procedure, and without help of trial and error efforts. Nevertheless, they have all proven inefficient. This paper introduces a new approach that generates the solutions using algorithm-specific constraint handling techniques, based on the priority list concept. The solution-making stages include: 1. Minimum up/down time establishment using a probabilistic priority list-oriented selection mechanism, 2. Spinning reserve constraint handling through a deterministic priority list-based process, 3. Power balance handling and a ramp rate modification procedure for generating efficient ramp-constrained solutions. The different steps are designed such that efficient modifications are applied in each step without violating the previously established constraints. Simulation results on different test systems reveal that the approach obtains robust and competitive results. A new 140-unit large-scale test system based on Korean power system is also presented for verifying applicability of the proposed approach on real world power systems.

1. Introduction

1.1. Motivation

Power generation scheduling is a very important branch of power system planning due to the crucial optimization problems involved in it. UC (unit commitment) is one of the most complicated optimization problems which determines the hourly on/off schedule of generating units during time intervals of a scheduling horizon. Thermal UC, multi-objective UC [1], UC considering uncertainty of wind power [2], thermal scheduling in the deregulated electricity market [3], hydrothermal generation scheduling [4], optimal hydro scheduling [5], generation maintenance scheduling [6], pumped storage UC [7], scheduling of combined heat and power generation units [8], Wind/CSP self-scheduling [9], gas network modeling in UC [10], integration of electric vehicles in UC [11], and the role of demand response in UC [12] are among the important research fields involved in power generation scheduling. In this research, a new solution technique is introduced for the conventional thermal UC problem. It aims at minimizing the operating costs of thermal units for providing the forecasted load demand and certain amount of spinning reserve requirement, while a set of operational constraints are satisfied. The conventional UC is mathematically considered as a large-scale nonlinear optimization problem consisting binary and real variables, along with several linear and nonlinear constraints. The only exact solution technique to UC is the complete enumeration which is computationally impractical. In the past three decades, plenty of research has been done to develop new solution techniques that obtain near-optimal solutions.

1.2. Literature review

The solution methods can be classified in three main categories: numerical optimization techniques, intelligent search algorithms

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Nomenclature

a_i, b_i, c_i	coefficients of the quadratic fuel cost function of unit i ($\$/h$, $\$/MWh$, $\$/MW^2h$)
a	number of consecutive periods at which a unit's previous state is changed in order to fulfill the minimum up/down time constraint (h)
b	number of extra periods for which a unit's previous state is retained in order to fulfill the minimum up/down time constraint (h)
CSC	cold startup cost of unit i ($\$/h$)
CST	cold startup time of unit i (h)
$D(h)$	load demand at period h (MW)
$F_i(P_i(h))$	fuel cost function of unit i when generating output power amount of $P_i(h)$ ($\$/h$)
h	period index (index for scheduling hour)
H	total scheduling horizon (h)
HSC_i	hot startup cost of unit i ($\$/h$)
i	unit index
IS_i	initial state of unit i (h)
MDT_i	minimum down time of unit i (h)
MUT	minimum up time of unit i (h)
N	number of units
$P_i(h)$	output power generation of unit i during period h (MW)
P_i^{max}	maximum power capacity of unit i (MW)
P_i^{mean}	mean operating point of unit i (MW)
P_i^{min}	minimum power capacity of unit i (MW)
$R(h)$	spinning reserve requirement at period h (MW)
RD_i	ramp-down-rate value of unit i (MW/h)
RU_i	ramp-up-rate value of unit i (MW/h)
S	number of the periods that a unit gets turned on according to an allocation choice (h)
$SC_i(h)$	startup cost of unit i at period h ($\$/h$)
$T_i^{off}(h)$	number of consecutive periods that unit i has been offline before period h (h)
T_i^{off}	number of the consecutive periods that unit i is offline (h)
T_i^{on}	number of the consecutive periods that unit i is online (h)
TPC	total production cost ($\$$)
$u_i(h)$	on/off state of unit i at period h: equal to 1 when unit is online and 0 when unit is offline
α_i	fuel cost per megawatt value of unit i ($\$/MWh$)
λ	prioritizing criterion of allocation choices ($\$/MW$)

and hybrid methods. The major methods of the first category are: priority list [13], pre-prepared Power Demand table [14], MIP (mixed-integer programming) [15], LR (Lagrangian relaxation) [16], dynamic programming [17], branch and bound [18], Benders' decomposition [19], semi-definite programming [20], and second-order cone programming [21]. Priority list-based methods such as fast extended priority list technique in Ref. [13] and the enhanced priority list method in Ref. [22] generate a priority list solution, and employ some specific heuristics to fulfill the constraints. They are fast, robust, and non-iterative methods, but produce high production costs. In other priority list-based endeavors, Khanmohammadi et al. in Ref. [23], and Amiri et al. in Ref. [24] proposed primary approaches employing a modification process to improve the solution qualities. Dynamic programming and branch-and-bound face serious problems in the case of large-scale systems. LR suffers from sub-optimality problems and deficiency in generating feasible solutions, and the MIP methods – though with the recent substantial improvements of MIP solvers – suffer from exhausting computational time.

So many intelligent algorithms have been applied to solve UC. Some of successful ones in recent years are: GA (genetic algorithm) [25], annular crossover GA [26], PSO (particle swarm optimization) [27], quantum-inspired PSO [28], binary neighborhood field optimization [29], GSA (gravitational search algorithm) [30], GSA with local mutation [31], invasive weed optimization [32], shuffled frog leaping algorithm [33], firefly algorithm [34], differential evolution [35], quantum-inspired evolutionary algorithm [36], artificial bee colony [37], and ant colony optimization [38]. The third category consists of the approaches that integrate different methods. Some of the best are: hybrid Taguchi-ant colony [39], expert system and elite PSO [40], augmented Lagrange Hopfield network [41], meta-heuristic search-based MILP [42], LR hybrid with evolutionary algorithm [43], and LR and PSO [44].

The intelligent search algorithms employ a population of randomly moving candidate solutions, and try to guide them intelligently towards the optimal region by means of trial and error efforts. To eliminate constraint violations, some methods (intelligent either numerical ones) employ penalty functions, and some apply repair strategies. The search algorithms are converged after a rather big number of iterations, and they do not yield robust results (i.e. the simulation results for several program runs reveal different solutions). Another drawback of most of the UC approaches involves the proper tunings of their peculiar control parameters that highly influence the successful generation of solutions. They require proper parameter settings for every specific test system.

To include ramp rates, several mechanisms have been implemented in the literature. Roy suggested a penalty function being integrated to the cost function, in order to guide the solutions to the feasible region [30]. Mhanna et al. proposed a semi-definite programming relaxation approach which suggests a robust technique for ramp rate constraint handling [20]. Chandrasekaran et al. [45] and Datta [46] proposed repair strategies for ramp rate violation cases. A sub-hourly UC model with feasible energy delivery constraints is also proposed by Yang et al. [47], that suggests an accurate ramping process.

1.3. Contributions

In this paper, a new priority list-based approach is introduced that unlike the conventional UC algorithms, generates the solution on one iteration. The major contributions are listed as follows:

1 A semi-analytical solution approach is developed in which the different constraints are efficiently handled during different solution making steps, while the initial solution is established via the simple priority list criterion.
2 A new procedure is suggested to handle minimum up/down time violations, which extracts the possible choices for correcting the violations, and chooses the appropriate ones through a probabilistic selection mechanism.
3 A major modification is introduced to complete the solutions that need more commitments. A new modeling for commitment