Electrical Power and Energy Systems 59 (2014) 14–22

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

# Metaheuristic search based methods for unit commitment ☆

Dewan Fayzur Rahman [a,*], Ana Viana [a,b], João Pedro Pedroso [a,c]

[a] INESC TEC - INESC Technology and Science (formerly INESC Porto), Portugal
[b] Instituto Superior de Engenharia, Instituto Politécnico do Porto, Portugal
[c] Faculdade de Ciências, Universidade do Porto, Portugal

ARTICLE INFO

*Article history:*
Received 5 May 2013
Received in revised form 16 January 2014
Accepted 19 January 2014
Available online 19 February 2014

*Keywords:*
Unit commitment
Combinatorial optimization
Matheuristics

ABSTRACT

This paper presents two new solution approaches capable of finding optimal solutions for the thermal unit commitment problem in power generation planning. The approaches explore the concept of "matheuristics", a term usually used to refer to an optimization algorithm that hybridizes (meta)heuristics with mixed integer programming solvers, in order to speed up convergence to optimality for large scale instances. Two algorithms are proposed: "local branching", and an hybridization of particle swarm optimization with a mixed integer programming solver.

From extensive computational tests on a broad set of benchmarks, the algorithms were found to be able to solve large instances. Optimal solutions were obtained for several well-known situations with dramatic reductions in CPU time for the larger cases, when compared to previously proposed exact methods.


## 1. Introduction

The unit commitment problem (UCP) consists of deciding which power generator units must be committed/decommitted in order to satisfy demand over a planning horizon. Short-term planning usually lasts from one day to two weeks, generally split into periods of one hour each. The production levels at which units operate (pre-dispatch) must also be determined, and the committed units must generally satisfy the forecasted system load and reserve requirements, as well as a large set of technological constraints. The most common objective is that of minimizing production costs.

Although it has been extensively studied for several decades, and many different optimization techniques have been proposed, the problem is far from being closed, and research on this topic is still ongoing. Several reasons justify the interest that remains on the UCP: (1) it is of major practical importance for generation companies (GENCOs), the quality of the schedules proposed having a strong economical impact; (2) as new problem variants continuously arise, it is necessary to capture their singularities and adapt or develop new optimization methods to tackle the novelties; and (3) being a hard combinatorial problem, until very recently there were no methodologies that could solve instances of practical relevance up to optimality.

For a long time the high dimensionality and combinatorial nature of the UCP curtailed attempts to solve the problem through mixed-integer linear programming (MILP) formulations within a general purpose MILP solver. Because of that, lagrangian relaxation (LR) was an industrial standard, as it seemed to be the most robust technique available that was capable of solving practical size problems and of providing independent system operators (ISOs) with a feasible, near optimal solution within the available time. Extensive surveys on different optimization techniques and modeling issues are provided in [1–3]. Some recent publications are e.g. [4–6] or [7]. Recently [4] proposed a mixed integer quadratically constrained program (MIQCP) based approach to solve the UCP. They consider thermal conventional units and a simplified representation of combined cycle units, independent power producers, and interruptible loads. In [5], a MILP based profit maximization UCP was proposed. It considers bilateral contracts and the day-ahead auction market. The authors in [6] proposed a method that is a combination of improved Lagrangian relaxation and augmented Lagrange Hopfield network enhanced by heuristic search, to solve the UCP with ramp constraints. Finally, a sequential Lagrangian-MILP approach was proposed in [7] to solve UCP in hydro-thermal

☆ Financial support for this work was provided by the Portuguese Foundation for Science and Technology (under Project PTDC/EGE-GES/099120/2008) through the "Programa Operacional Temático Factores de Competitividade (COMPETE)" of the "Quadro Comunitário de Apoio III", partially funded by FEDER. Project "NORTE-07-0124-FEDER-000057" is financed by the North Portugal Regional Operational Programme (ON.2 – O Novo Norte), under the National Strategic Reference Framework (NSRF), through the European Regional Development Fund (ERDF), and by national funds, through the Portuguese funding agency, Fundao para a Cincia e a Tecnologia (FCT).
* Corresponding author. Tel.: +351 935814664; fax: +351 2 22094050.
*E-mail addresses:* dmrahman@inescporto.pt (D.F. Rahman), aviana@inescporto.pt (A. Viana), jpp@fc.up.pt (J.P. Pedroso).

http://dx.doi.org/10.1016/j.ijepes.2014.01.038
0142-0615/

**Nomenclature**

*Constants*
- $T$ length of the planning horizon
- $U$ number of thermal units
- $\mathcal{T} = \{1, \ldots, T\}$ set of planning periods
- $\mathcal{U} = \{1, \ldots, U\}$ set of units
- $P_u^{\min}, P_u^{\max}$ minimum and maximum production levels of unit $u$
- $T_u^{\text{off}}$ minimum number of periods unit $u$ must be kept switched off
- $a_u, b_u, c_u$ fuel cost parameters for unit $u$
- $a_u^{\text{hot}}, a_u^{\text{cold}}$ hot and cold start up costs for unit $u$
- $t_u^{\text{cold}}$ number of periods after which start up of unit $u$ is evaluated as cold
- $\gamma_{ut}^{\text{off}}$ number of consecutive periods unit $u$ was off before period $t$

*Parameters of particle swarm optimization*
- $w$ inertia weight
- $c_1$ social constant
- $c_2$ cognitive constant
- $r_1, r_2$ random function
- $I$ number of particles
- $N$ maximum number of iterations

*Local branching parameter*
- $k$ neighborhood size

*Variables: Decision variables*
- $y_{ut}$ 1 if unit $u$ is on in period $t$, 0 otherwise
- $p_{ut}$ production level of unit $u$, in period $t$

*Auxiliary variables*
- $V_{ut}$ velocity
- $s_{ut}^{\text{hot}}$ 1 if unit $u$ has a hot start in period $t$, 0 otherwise
- $s_{ut}^{\text{cold}}$ 1 if unit $u$ has a cold start in period $t$, 0 otherwise

*Auxiliary function*
- $\mathcal{R}(V_{ut})$ probability function of $V_{ut}$

*Production costs*
- $F(p_{ut})$ fuel cost of unit $u$ in period $t$
- $S_{ut}$ start up cost of unit $u$ in period $t$
- $H_{ut}$ shut down cost of unit $u$ in period $t$

power generation. Complementary strengths of LR and MILP are explored in order to improve algorithm efficiency.

In the last few years the dramatic increase in efficiency of MILP solvers encouraged thorough exploitation of their capabilities and a considerable part of research in this area was directed towards the definition of alternative, more efficient MILP formulations of the problem (see *e.g.* [8–10]). Recently [11] proposed a MILP-based procedure that is able to converge to optimality, even for large size instances.

MILP-based approaches present several advantages compared to LR, as thoroughly discussed in [12]. They allow easier integration of additional constraints in the formulation; can incorporate more complex units (such as Combined Cycle Turbines) in the model; and even if optimal results are not available within reasonable time, intermediate feasible solutions usually have better or equal optimality gaps than the ones associated with LR solutions. Such advantages have already led several ISOs to move from LR to MILP-based solutions, and several others are considering this move.

An open issue is related to solution optimality and how it affects individual pay-offs in restructured markets where the ISO performs a centralized unit commitment. As stated in [12], only if problems are solved to optimality can one guarantee that units will receive their correct dispatch and pay-off. It is therefore of vital importance that exact methods are further explored and improved.

Although the algorithm proposed in [11] proves that it is now possible to solve to optimality UCP instances of practical size (with up to 100 units, for a 24 h time horizon), for the larger instances the computational time required to reach the optimal solution was still high. This supports the idea that new engines must be developed and coupled to the algorithm to speed up convergence.

In this paper we explore the concept of "matheuristics" and use it to speed up convergence to optimality of the algorithm proposed in [11] for the larger instances. The term "matheuristics" is usually used to refer to an optimization algorithm that integrates (meta)heuristics and MILP strategies exploiting synergies between them. Two approaches are explored in this work: one based on "local branching" [13] and another where particle swarm optimization (PSO) [14] cooperates with the MILP solver. Both approaches were tested on several well-known test instances and, for all of them, converged to the optimal solution. Furthermore, for larger instances convergence to optimality was much faster than with the methodology proposed in [11].

## 2. Problem formulation and base algorithm

The use of matheuristics requires the definition of a mathematical model that conveniently addresses the problem to optimize. In [11] a full, comprehensive linearized UC model is presented. It considers the following constraints: system power balance, spinning reserve requirements, units' minimum up and down times, production limits, and ramps.

The objective of this problem is to minimize the total production cost over the planning horizon, expressed as the sum of fuel, start-up costs and shut-down costs:

$$\text{minimize} \quad \sum_{t \in \mathcal{T}} \sum_{u \in \mathcal{U}} (F(p_{ut}) + S_{ut} + H_{ut}). \tag{1}$$

We consider the traditional quadratic function for the fixed costs $F(p_{ut})$, as follows:

$$F(p_{ut}) = \begin{cases} c_u p_{ut}^2 + b_u p_{ut} + a_u & \text{if } y_{ut} = 1, \\ 0 & \text{otherwise}. \end{cases} \tag{2}$$

Shut-down costs $H_{ut}$ are assumed to be zero and start-up costs are modeled as:

$$S_{ut} = \begin{cases} a_u^{\text{hot}} s_{ut}^{\text{hot}} & \text{if } \gamma_{ut}^{\text{off}} \leqslant t_u^{\text{cold}}, \\ a_u^{\text{cold}} s_{ut}^{\text{cold}} & \text{otherwise}, \end{cases} \tag{3}$$

with $\gamma_{ut}^{\text{off}}$ as the number of consecutive periods unit $u$ was off before period $t$.

For the algorithm in [11] to be used it is required that all nonlinearities of the UC problem, either in constraints or objective function, are removed. A detailed description of the linearization procedure of (2) proposed there is given below.