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Combined cycle unit commitment in a changing electricity market scenario

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ABSTRACT

For Generation Companies (GENCOs) one of the most relevant issue is the commitment of the units, the scheduling of them over a daily (or longer) time frame, with the aim of obtaining the best profit. It strongly depends on the plant operational generation costs, which depend in turn on the choices taken at the design stage; it follows that design technical choices should also aim at determining the best generation cost structure of generating units with respect to the market opportunities. In the paper the unit commitment (UC) problem has been considered, with highlights on changes in the market scenario. The paper analyzes the relevance of some design choices (structure, size, regulation type) on the economics of the operation of gas–steam combined cycle generating units. To solve the UC problem, a recently proposed method for mixed integer nonlinear programming problems, with the use of a derivative free algorithm to solve the continuous subproblems, has been considered. The results for two GENCOs are reported: one managing a single unit and the other managing three units. Numerical examples show the sensitivity of the UC solutions to the market conditions and to the design choices on the regulation type in the evolving scenario of the Italian Electricity Market.

Introduction

The unit commitment (UC) can be referred to as the comprehensive problem of determining the on/off status and the production level of generating units over a given time horizon (a day, a week) such that some objective is optimized [1]. The UC is a mixed-integer nonlinear optimization problem.

In the past, the main attention has been devoted to centralized UC, where generators are controlled by a central authority so as to meet its load requirements. The so-called profit-based UC [2–4] calls now for the attention of generation companies (GENCOs). For them, maximizing the net revenues with an operation as profitable as possible is a pivotal issue to optimally participate into the liberalized, re-regulated markets and win competition.

Either for conversion of outdated plants or for new installations, the preferred choice is the gas–steam combined cycles technology, for its short time of return on investments, limited effects of economies of scale and convenient optimal size, high efficiency, low environmental impact, operational flexibility.

Combined cycle units may be of different size, configuration, type of regulation. Any of these technological aspects influences the overall characteristics of the unit as well as the generation cost curve. Since the UC results depend to a large extent on the operational generation costs, it is seen that technological aspects influence the UC solution; in turn, this influence depends on the market conditions the GENCO operates into.

The possibility of getting satisfactory UC solutions depends on the choices made at the design stage; a poor choice of technical characteristics could hamper a good decision-making process at the operational stage. The way technical choices do influence optimal operational results has to be given a clear evidence, and the market conditions have to be taken into account.

When looking for a UC solution, a GENCO faces uncertainty. It is so either if it acts as a price-taker (as in perfect competition) and its operational decision depends on the price forecast (e.g.the day-ahead hourly price forecast), or if it is an oligopolistic player, and its operational decision depend on its forecasted residual demand curve. To cope with the uncertainties embedded in the decision-making process, different approaches are possible, such as mean–variance, value-at-risk, conditional-value-at-risk.

In [4], the UC problem has been formulated with a modified mean–variance approach useful for both a price-taker GENCO and an oligopolistic one; the objective function accounts for the uncertainties of the problem and for the risk aversion of the decision-maker as well. In [5], the influence of the technical

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characteristics of the generating units on the UC solution has been considered for a price-taker GENCO with perfect price forecast.

The aim of this paper is to consider the general case of an oligopolistic GENCO with uncertain residual demand curve forecast and to show the influence of the technical characteristics of the combined cycles generating units on its UC solution. This would give advice on the technical solution to be chosen to ensure the best profit in a changing market scenario.

The UC problem formulation proposed in [4] is firstly recalled. A general discussion on the characteristics of gas–steam combined units is presented, with particular attention paid to the design choices on the plant cycle configuration, size and regulation type. In order to give evidence to the influence of the technical characteristics on the UC solution, we have assumed a simple representations of the combined cycle plant; in particular, we have taken into account only one of all the possible configurations a combined cycle plant can have in operation [6,7]. We made these assumptions since we judge that with different case study settings, the difference among the UC outcomes due to the design choices could be not clearly understood, and even blurred.

As case study, a comparison between two real situation in the evolving Italian Electricity Market is considered; as concern technical aspects, three different size units, configuration and regulation types are taken into account. Eventually, the results for single and multi-unit commitment problem are illustrated.

Unit commitment problem

The formulation of the unit commitment problem presented in [4] is recalled for the general case of a GENCO that can influence the market price and manages more than one generating unit; the simpler cases of a GENCO acting as a price-taker and/or managing just one unit are special cases of the general one.

Objective function

The formulation of the objective function of the UC problem, as a function to be minimized, is first presented and discussed. Technical constraints are added to obtain the complete UC problem formulation.

Costs

The operating costs a GENCO incurs in reflect the variable generation costs and the shutting-down and starting-up commitment costs.

Variable generation cost for the ith unit, C_t^i, can be described as a function of power, generated in the tth interval, P_t^i:

$$C_t^i = C^i\left(P_t^i, z_t^i\right) = a^i {P_t^i}^2 + b^i P_t^i + c^i z_t^i, \tag{1}$$

in (1), a^i, b^i, c^i are the production cost coefficients and z^i represents the set of the operating statuses of the ith unit over the commitment period ($z_t^i \in \{0, 1\}$, where 0 represents inactivity whereas 1 stands for activity):

$$z^i = \left[z_1^i, z_2^i, \ldots, z_T^i\right], \tag{2}$$

in which T is the number of time intervals in the time period relevant to the unit commitment problem (i.e. a day, a week). Cost C_t^i is different from zero only if $z_t^i = 1$ [see also (13)]; it accounts for the fuel costs and for the fixed share of the short-run operating costs.

When the ith unit is in operation and producing, a shut-down cost, CD_t^i, is paid each time the unit is turned off. This cost is usually considered as a constant (d^i), not dependent on the number of hours the unit has been turned on:

$$CD_t^i = CD^i(z^i, t) = \max\left\{0, d^i\left(z_{t-1}^i - z_t^i\right)\right\}; \tag{3}$$

d^i takes into account the costs of maintenance and cooling associated with the shut-down of the unit and can usually assumed negligible ($d^i = 0$).

Start-up cost, CU_t^i, is paid each time the unit is turned on; Indeed, as observed in [8], if a boiler has been shut-down and allowed to cool, its temperature will drop exponentially with time. Then, CU_t^i depends on how long the unit has been off, namely:

$$\begin{aligned} CU_t^i &= CU^i(z^i, t) = \max_{\tau=0,\ldots,\tau_c^i} u_\tau^i \left(z_t^i - \sum_{k=1}^{\tau} z_{t-k}^i\right) \\ u_\tau^i &= \begin{cases} 0 & \text{if } \tau = 0, \\ \alpha^i + \beta^i\left(1 - e^{-\frac{\tau}{\gamma^i}}\right) & \text{if } \tau > 0 \end{cases} \end{aligned} \tag{4}$$

where τ_c^i, in the expression of CU_t^i, is the time the units needs to completely cool down and $\alpha^i, \beta^i, \gamma^i$ in the expression of u_τ^i, are constants that represent the cost of starting the turbine alone, the cost of starting the boiler when it is completely cooled, and the thermal time constant of the unit, respectively. A detailed description of these costs can be found in [8].

The total operating cost incurred by the GENCO over the commitment period, C_{tot}, is:

$$C_{tot} = C_{tot}(z, P) = \sum_{i=1}^{N_u}\sum_{t=1}^{T} C^i\left(P_t^i, z_t^i\right) + CD^i(z^i, t) + CU^i(z^i, t), \tag{5}$$

where N_u represents the number of generating units to be committed; z and P the commitment of all units over the programming period and their production, respectively [see also (2)]:

$$\begin{aligned} z &= [z^1, \ldots, z^{N_u}] \\ P &= [P^1, \ldots, P^{N_u}] \\ P^i &= \left[P_1^i, P_2^i, \ldots, P_T^i\right]. \end{aligned} \tag{6}$$

We remark that no linearization of CD_t^i and CU_t^i is carried out to obtain expression (5) of the total cost C_{tot}. In fact, even if such a linearization had been performed, the overall objective function would still turn out to be nonlinear and non-convex (as it will be clarified in the next subsection).

Revenues

The GENCO's revenue in the tth interval, R_t, derives from selling the power generated in the interval to the electricity market. Recalling [4], the selling price is modeled by using the GENCO's residual demand function, $\rho(\cdot)$, which depends on the total power produced (sold) by the GENCO in the interval, and may vary along the commitment period. Since the residual demand function derives from the forecast of load demand and competitors' behavior, it is affected by uncertainty.

With this understanding, the GENCO's revenues in the tth time interval can be modeled as:

$$R_t = R_t(\rho_t, P_t) = \rho(P_t, \theta_t, t)P_t, \tag{7}$$

where θ_t represents a random variable and P_t is the total power produced (sold) by the GENCO in the tth interval

$$P_t = \sum_{i=1}^{N_u} P_t^i. \tag{8}$$

Total revenues over the commitment period, R_{tot}, are given by:

$$R_{tot} = R_{tot}(P_G, \theta) = \sum_{t=1}^{T} \rho(P_t, \theta_t, t)P_t, \tag{9}$$