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Medium-term coordination in a network-constrained multi-period auction model for day-ahead markets of hydrothermal systems

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ABSTRACT

This paper investigates strategies for coordinating the decisions calculated by a network-constrained multi-period auction model of hydrothermal systems with the ones calculated by medium-term problems. Initially, we discuss the necessity for implementing such coordination strategies in hydrothermal systems from the standpoint of a market operator. We investigate three alternative strategies for performing the coordination. The first strategy incorporates primal information from the medium-term problem into the auction model in order to perform coordination, while the second one makes use of dual information associated with the medium-term. A third strategy combining primal and dual information from the medium-term problem is also investigated. These strategies are compared by means of simulation results involving the IEEE 24-bus reliability test-system. The results focuses on evaluating the impact of the coordination strategies on market clearing prices and generation scheduling.

Introduction

In the regulated environment, the short-term scheduling of power generation systems was generally carried out by means of a centralized procedure run by the system operator. The main purpose behind the models used to calculate such a centralized dispatch was to minimize the total costs associated with the generation system, while meeting a specific inelastic demand and enforcing all relevant operational constraints associated with the system. For such a purpose, unit commitment (UC) models [13,18] were generally used for thermal systems, while for hydro-dominated systems, short-term hydrothermal scheduling (STHS) [17] or predispatch models [25] were generally used. In such a context, the coordination of short- and long-term generation has been performed by means of a chain of models associated with long, medium and short-term scheduling [19,21].

In the electricity markets environment, short-term scheduling procedures were reoriented in order to promote competition. The old centrally dispatched short-term scheduling procedures were replaced by auction procedures [1,15], where the generation and demand compete in the day-ahead market in order to sell and buy energy, respectively. In the auction procedure, blocks of offers and bids, provided respectively by generation companies (GENCOS) and consumers, are submitted to the market operator (MO), which calculates the accepted blocks of offers and bids, by means of a market-clearing procedure, which is formulated as an auction model.

According to Kardakos et al. [12], centrally organized day-ahead markets may take two basic forms: power exchanges (PX) or power pools (PP). In the PX market, offers and bids are handled hour-by-hour by a series of independent single-period auction models run by the MO. These models tend to neglect the technical aspects associated with the generating units, or with the transmission system. In the PX, each producer is responsible for self-scheduling his own units, by a price-based unit commitment [14,26], while the independent system operator (ISO) is responsible for preserving the system security. For such a purpose, the ISO must handle all technical aspects neglected in the auction by means of ex-post heuristic procedures that generally tend to re-dispatch the system. In the PP market, offers and bids are handled by a multi-period auction model that integrates all technical aspects related to the units (e.g., unit start-up and shut-down costs, minimum-up/down time constraints, min/max power output restrictions, ramp-rate limits, etc.) and the transmission

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system into a single optimization problem. This model is concerned with the maximization of the social welfare function, while taking into account relevant constraints associated with the generation and transmission systems. The model calculates the on/off schedules of the generating units, the active power dispatch of the scheduled units, as well as the market-clearing prices throughout the day.

PX based energy markets are generally adopted for hydropower or hydro-dominated systems [6,27], probably due to its transparency and easiness of implementation and operation. Hydropower systems are generally more complicated to operate due to the need for representing additional modeling aspects associated with the hydraulic system, such as: limits in reservoirs levels and volumes, nonlinear limits in water discharges and power outputs, and uncertainties in future water inflows and prices. Also, these systems must have some sort of coordination strategy in order to properly manage the use of hydro resources in the short- and medium-terms. Such additional modeling issues also contribute to the adoption of PX based energy markets for hydropower systems, since these constraints are handled in an simpler and transparent way in such markets, by means of *ex post* alterations in dispatch and prices. However, all such *ex post* alteration may lead to suboptimal operation points in terms of social welfare, as well as to cross-subsidies, as shown by Conejo et al. [2]. On the other hand, a PP based energy market would integrate all such additional constraints into the auction model, avoiding such economic distortions.

This paper investigates a crucial issue concerning the implementation of PP based markets for hydropower systems: the coordination strategies. The main contributions of the paper are: (i) we discuss the need to coordinate short-term decisions, calculated by a hydrothermal day-ahead auction model, with medium-term decisions; (ii) we propose and investigate three alternative coordination schemes for such a purpose; (iii) we propose a network-constrained multi-period hydrothermal auction (MHA) model that incorporates the coordination procedures discussed in (ii) for a pool-based energy market; and (iv) in the proposed MHA model, the thermal constraints are represented in detail, while the transmission system is represented by means of linear power flows and piecewise linear approximation for power losses. Hydro constraints are represented in a simplified way, by means of coordination equations only.

What remains of this work is organized as follows: in Section "Coordination strategies in hydrothermal auction models" we discuss the need to coordinate as well as some coordination strategies in hydrothermal auction models; in Section "Multi-period hydrothermal auction model with medium-term coordination", we describe the network-constrained multi-period hydrothermal auction (MHA) model and three coordination strategies are incorporated in the model. Numerical results evaluating the impact of the coordination strategies studied are described in Section "Numerical results". Finally, the conclusions are presented in Section "Conclusions".

Coordination strategies in hydrothermal auction models

The need to coordinate

According to Conejo et al. [3] the market operator (MO) is responsible for the economic management of the electricity marketplace as a whole, while the independent system operator (ISO) is in charge of the technical management of the electric energy system pertaining to the marketplace. In some markets, the functions performed by the MO and ISO are carried out by a single entity. The ISO and the MO must establish sound rules on the electricity markets in order to operate them efficiently while ensuring security and reliability of the power system [23].

In hydro-dominated systems, the concepts of security and reliability are strongly related to the availability of hydro resources. The key economic issue in hydro-power production is time dependency: the water used today can alternatively be stored in reservoirs to be used tomorrow [5]. Therefore, there must be some kind of coordination of hydro resources between short- and medium-term planning. Although each independent generating company is concerned with the coordination of its own hydro resources, it is not reasonable to leave the responsibility of coordinating the hydro resources of the entire system for these companies. Since coordination directly affects security and reliability of hydro-dominated systems, the task of coordinating the hydro resources of the system must be carried out by the ISO.

In a traditional regulated environment, the coordination between different time scopes is developed by a system operator trying to minimize the total cost of the system [22]. Some models addressing this problem are described in Soares et al. [24], Pereira and Pinto [19,20] and Franco et al. [7]. In such approaches, the main idea is to describe short- and medium-term problems by a single large optimization model. Then, by using some decomposition approach (e.g. Benders or Dantzig–Wolfe decomposition techniques), this large model is broken into two sub-models, which are associated with short- and medium-term subproblems, respectively. Therefore, in these approaches, the coordination between medium-term planning and short-term operation could be seen as an iteration in the framework of the decomposition theory for optimization problems [22].

Reneses et al. [22] analyze the problem of coordinating resources between short- and medium-term in an electricity marketplace. The analysis is performed from the perspective of a generating company, trying to maximize its profits in the market. The authors point out that short- and medium-term scheduling models used by a generating company in the market are different in essence. While short-term approaches are formulated as unilateral profit maximization models, medium-term approaches are generally formulated as equilibrium models. Therefore, by analyzing the perspective of a generating company in a marketplace, Reneses et al. [22] conclude that medium and short-term models do not result from the decomposition of a single larger model.

The same reasoning apply if an analysis is performed from the perspective of a MO or an ISO seeking to schedule the system resources (generation and water) in the short- and medium-terms. In this case, the short-term scheduling approaches used by the MO involve market clearing procedures (mathematically described by means of auction models), while the medium-term approaches may also be formulated by means of equilibrium models or by auction models (futures market). Thus, we conclude that from the perspective of a MO or an ISO, the auction (short-term) and the equilibrium models (medium-term) may also not result from the decomposition of a larger optimization problem. However, as pointed out in Reneses et al. [22], in spite of this, we may still use decomposition theory as an inspiration for helping the MO or the ISO in their tasks for coordinating short- and medium-term generation scheduling.

The authors in Reneses et al. [22] highlight some coordinating issues that may appear when a generation company, owning only thermal units, is seeking to maximize its profits in the energy market, such as: (i) the need to establish maximum daily production levels for thermal units with limited medium-term emission allowances (scarce resources) and (ii) the need to fulfill minimum fuel-consumption requirements throughout the day due to a take-or-pay contract or a minimum market share that must be accomplished by the company in the medium-term