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A stochastic programming model for the thermal optimal day-ahead bid problem with physical futures contracts ☆

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ABSTRACT

The reorganization of the electricity industry in Spain completed a new step with the start-up of the Derivatives Market. One main characteristic of MIBEL's Derivatives Market is the existence of physical futures contracts; they imply the obligation to physically settle the energy. The market regulation establishes the mechanism for including those physical futures in the day-ahead bidding of the generation companies. The goal of this work is to optimize coordination between physical futures contracts and the day-ahead bidding which follow this regulation. We propose a stochastic quadratic mixed-integer programming model which maximizes the expected profits, taking into account futures contracts settlement. The model gives the simultaneous optimization for the Day-Ahead Market bidding strategy and power planning production (unit commitment) for the thermal units of a price-taker generation company. The uncertainty of the Day-Ahead Market price is included in the stochastic model through a set of scenarios. Implementation details and some first computational experiences for small real cases are presented.

1. Introduction

Recently, there has been a reorganization of the electricity industry. The deregulation of the generation and distribution of electricity carried out in most countries in Europe has changed the problems that the generation companies (GenCo) have to face. With the introduction of the Electricity Markets, the price of electricity has become a significant risk factor. One of the techniques for hedging against market-price risk is participation in futures markets [1] and, for this reason, the creation of Derivatives Electricity Markets has been a natural step in the deregulation process.

The most common mechanisms in the Electricity Markets are as follows:

- Out of the market products: the contracts that are traded directly between client and producer such as, for example, bilateral contracts.
- Derivatives Market: pool where the medium term financial and physical derivatives products are traded; futures contracts, swap options and forward contracts can be negotiated in them.
- Day-Ahead Market: pool where the most of physical production is traded. Seller and purchase agents submit their respective bids to the market operator who, the day before the delivery day, matches the bids.
- Intraday Markets: sequence of secondary markets that are used (1) by the system operator to guarantee the reliability of the system and (2) by the producers and consumers to change the result of the Day-Ahead Market.

In this paper, we will focus on the Spanish Electricity Market but as a particular example of many other similar deregulations that have been carried out all over the world. The models presented in this work can be easily applied or adapted to many others Electricity Markets that contain physical derivatives products and Day-Ahead Market auctions.

On the Spanish mainland, the Electricity Market, which was launched in 1998, includes a Day-Ahead Market and a set of balancing and adjustment markets. As the introduction of competition and the deregulation process did not behave as expected, the Spanish Market was improved in 2007 with the start-up of the Iberian Electricity Market (MIBEL) and some other new regulations. The MIBEL brings together the Spanish and Portuguese electricity systems and it complements the previous Spanish Electricity Market with a Derivatives Market. Generation companies can no longer optimize their short-term generation planning decisions without considering the relationship between those

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markets. The short-term bidding strategies are based on the GenCo's day-ahead bid, which is defined as the selling offer submitted by a GenCo to the Day-Ahead Market operator. It is always a non-decreasing step-wise function which gives the price at which the GenCo offers its electricity generation to the pool.

There are two main derivatives physical products, the bilateral contracts (BC) and the futures contracts (FC). The BCs are agreements between a generation company and a qualified consumer to provide a given amount of electrical energy at a stipulated price in a delivering period. The characteristics of the BCs (energy, price and delivering period) are negotiated between the two parts before the Day-Ahead Market, the MIBEL's rules state that each GenCo must notify the scheduling of the BCs to the system and market operator before the closure of the Day-Ahead Market.

The FCs is a medium-term exchange-traded derivative that represents agreements to buy/sell some underlying asset in the future at a specified price. The main characteristics of an FCs are the asset, the contract size, the delivery arrangements and period (weeks, months, quarters or years), and the price. In the MIBEL, the FCs are offered through the Derivatives Market, an average of 2340 GWh are traded monthly. In contrast to other Electricity Derivatives Markets, the delivery arrangements of the MIBEL FCs offer a choice between a physical or financial settlement. Physical futures contracts have cash settlement and physical delivery whereas financial contracts have cash settlement only. This physical delivery option is the feature of the FCs that interacts with the GenCo day-ahead bidding process [2]. Thus, although the physical FC is a medium-term product, the energy amount of this FC has to be physically delivered daily, and included in the day-ahead bid of the GenCo, coupling this way the medium and short term.

The main differences between the BCs and the FCs is that the first ones are traded between the GenCo and the consumer out of the market meanwhile the FCs are traded at the Derivatives Market. Moreover, the quantity committed at the BCs is not bid to the Day-Ahead Market while the MIBEL rules forces the quantity committed at FCs to be bid to the Day-Ahead Market through a sale offer with a bid price of 0 €/MWh. Among this derivatives products, we will focus on the physical futures contracts.

In liberalized Electricity Markets, a GenCo must build an hourly bid that is sent to the market operator, who selects the lowest price among the bidding companies in order to match the demand. Some earlier studies give the optimal bidding quantity once the expected distribution of the spot prices is known [3–5] but do not propose any explicit modelization of the optimal bid. Conejo et al. [6] propose an optimal stepwise bidding strategy for a price-taker GenCo based on the units characteristics, the expected spot price, and the optimal generation. Furthermore, Gountis and Bakirtzis [7] consider the approximation of stepwise bid curves by linear bid functions based on the marginal costs and the optimal generation quantity. Nabona and Pages [8] give a three stage procedure to build the optimal bid based on the optimal generation quantity and the zero-price bid. Also, Ni et al. [9] use the concept of *price-power function*, which is similar to the *matched energy function* used in our work, to derive the optimal bid curves of a hydro-thermal system. Nowak et al. [10] and Fleten and Kristoffersen [11] also distinguish between the variables representing the *bid energy* and those corresponding to the *matched energy* in the case of a price-taker GenCo. In particular, Fleten and Kristoffersen [11] has some aspects that are very related to this work; it presents a stochastic programming model to optimize the unit commitment and the day-ahead bidding of a hydropower producer in the Nord Pool. Moreover, general considerations about optimal bidding construction in Electricity Markets can be obtained in Anderson and Philpott [12] and Anderson and Xu [13]. Neither of these studies mentioned includes FCs.

Some different approaches to the inclusion of FCs in the management of a GenCo can be found in the Electricity Market literature. Most of the literature defines *forward contracts* as contracts with a physical settlement and *futures contracts* as contracts with a financial settlement. The main theoretical differences between these two kinds of derivatives products is the level of standardization and the kind of market where they are traded [14]. We focus on the inclusion of physical derivatives products in the short-term management of a GenCo. Other general considerations about FCs can be found in many works, for instance, Hull [14], Collins [15], Neuberger [16] or Carlton [17].

Prior to deregulation, Kaye et al. [18] illustrate how physical and financial contracts can be used to hedge against the risk of profit volatility, allowing for flexible responses to spot price. After Day-Ahead and Derivatives Markets start-up, Bjorgan et al. [19] present a theoretical framework for the integration of FCs into the risk management of a GenCo. Also, Chen et al. [20] present a bidding decision-making system for a GenCo, taking into account the impacts of several types of physical and financial contracts; this system is based on a market-oriented unit commitment model, a probabilistic local marginal price simulator, and a multi-criteria decision system. Furthermore, Conejo et al. [21] optimize the forward physical contracts portfolio up to one year, taking into account the day-ahead bidding; the objective of the study is to protect against the pool price volatility through FCs. Moreover, Guan et al. [22] optimize in a medium-term horizon the generation asset allocation between different derivatives products and the spot market, taking into account short-term operating constraints; they consider the known price of the contracts and forecast the spot price. In a different framework, Musmanno et al. [5] consider the Italian bilateral contracts in a similar way to our FCs but without developing an explicit bidding function. Once again, neither of these studies proposes an explicit bidding function that coordinates the day-ahead bidding with the economic dispatch of the futures contracts. From another point of view, Tanlapco et al. [23] do a statistical study of the reduction in risk due to forward contracts; it is shown that, for a GenCo, the electricity FCs are better for hedging price risk than other related future as crude oil or gas futures contracts.

As stated above, we are dealing with a new electricity futures contract situation due to the MIBEL definition of physical FCs, hence, as far as we know, there is no previous work that follows the Iberian Market rules and also deals with the short-term management of the GenCo which includes coordination between day-ahead bidding strategies and physical futures settlement. The MIBEL regulation [2] describes the coordination between this physical FC portfolio and the day-ahead bidding mechanism of the GenCo. That regulation obliges the GenCo to determine its generation scheduling in order to be able to cover those obligations and to determine its optimal offer, taking into account those FCs. Following the idea that participation in the Spot and the Derivatives Markets has to be studied jointly, the main objective of this work is to build a stochastic programming model which includes coordination between physical FCs and Day-Ahead Market bidding following the MIBEL rules. In other words, we want to see how the inclusion of FCs in the model affects the short term bidding strategies of the GenCo in the Day-Ahead Market.

The main contributions of this paper are as follows:

- A new quadratic mixed-integer stochastic programming model, for the optimal day-ahead bid with future contracts (DABFC) problem that maximizes the benefits arising from the Day-Ahead Market with the integration of the energy of the physical futures contract in the Day-Ahead Market.
- A theoretical study of the solutions of the DABFC model that provides, for the very first time, the analytical expression of