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Realistic electricity market simulator for energy and economic studies

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Abstract

Electricity market simulators have become a useful tool to train engineers in the power industry. With the maturing of electricity markets throughout the world, there is a need for sophisticated software tools that can replicate the actual behavior of power markets. In most of these markets, power producers/consumers submit production/demand bids and the Market Operator clears the market producing a single price per hour. What makes markets different from each other are the bidding rules and the clearing algorithms to balance the market. This paper presents a realistic simulator of the day-ahead electricity market of mainland Spain. All the rules that govern this market are modeled. This simulator can be used either to train employees by power companies or to teach electricity markets courses in universities. To illustrate the tool, several realistic case studies are presented and discussed.

Keywords: Electricity markets; Energy market simulator; Simulation software

1. Introduction

Power system restructuring has introduced competition in the electricity sector during the last 15 years. Within a market environment, producers compete either in spot markets, such as the pool, or through bilateral contracts. In spot markets, producers' and consumers' bids result in clearing prices through an auction mechanism. In many markets, a simple auction algorithm is a key part of the electricity market design. However, a simple auction mechanism does not properly account for complex technical and economical constraints.

Building a realistic electricity market simulator is not an easy task [1]. Different markets involve different bidding rules [2,3] and different clearing algorithms. In recent years, sophisticated market simulation tools [4] have become available to the power community, some of them making use of JAVA and/or MATLAB-based components [5,6], multiagent system technology [7–9] and even integrated software platforms [10]. On the other hand, simpler simulators [11] might be appropriate for training purposes, but they might not be accurate enough to be used in industrial environments. Complex bidding rules and realistic market clearing algorithms need to be modeled in detail to analyze and replicate results using real data. This is a novel contribution of the simulator presented in this paper. With the maturing of the electricity markets, companies require tools that can replicate the complex bidding conditions and the clearing of the markets, as is the case of the day-ahead electric energy market in mainland Spain. The simulator described in this paper includes a sophisticated graphical interface that allows its use in industry environments.

The contributions of this paper are three-fold:

- It provides an electricity market simulator that reproduces realistically the functioning of the electricity market of mainland Spain.
- The simulator includes a sophisticated graphic interface that makes it particularly useful in an industrial environment.
- The simulator is able to precisely mimic the actual working and the results of the day-ahead energy market within the electricity market of mainland Spain.

We believe this paper might encourage the development of other simulators mimicking electricity markets elsewhere. This might result in better training of operators and better understanding of electricity markets.

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The electricity market in Spain was launched in January 1998, after a new electricity law was released at the end of 1997. It constituted a new legal and institutional framework that introduced competition amongst producers and consumers. The former cost minimization model was replaced by a model where economic agents optimized their decisions independently. In this new market structure, economic agents are generators, distributors,[1] retailers, qualified customers and external agents. Since 1998, four markets compose the electricity market framework in Spain: (i) the day-ahead market, (ii) the ancillary services market, (iii) the hour-ahead market and (iv) the real-time imbalance correction process [12,13]. The most important one is the day-ahead market, managed by the Market Operator (MO). Once the day-ahead market is cleared a technical constraints solution process is carried out by the Independent System Operator (ISO), who is in charge of the technical aspects of the market.

The day-ahead market is cleared on an hourly basis. The generators sell their production using energy bids, and qualified consumers, distribution companies and retailers buy energy using purchase bids. Although the format of the bids may look simple in principle, this realistic market allows including more complex restrictions in the bidding process, both technical and economical. The most important extra bidding conditions that are allowed by the day-ahead Spanish market are: non-divisible quantity, ramp-up and ramp-down rate limits and minimum revenue requirement. A detailed account of these conditions is presented in the next section.

In the day-ahead market, a supply curve is built up for each hour considering the selling bids ordered by increasing prices and also a demand curve is built up considering the buying bids ordered by decreasing prices. The intersection of the supply and demand curves determines the selling and buying bids that are accepted; the hourly market price is the price of the last accepted selling bid. This process results in a uniform price for every hour. Additional conditions imposed by the extra bidding constraints are solved using a repair heuristic algorithm [14]. This algorithm resolves the technical infeasibilities that may occur because of violation of complex bidding conditions.

Within the framework of the Spanish electricity market, this paper provides a realistic simulator that reproduces the main features of the sophisticated day-ahead electric energy market. The paper is organized as follows. Section 2 presents the rules of the Spanish electricity market on which the market simulator is based, as well as several illustrative examples where the effect of the extra bidding conditions on prices and energies is shown, Section 3 shows several case studies based on realistic scenarios and Section 4 provides some relevant conclusions.

2. Day-ahead electricity market

This section is devoted to describing the most relevant aspects of the day-ahead electricity market of mainland Spain, which is reproduced using the developed simulator. Note that we only consider the day-ahead market in our simulations, since 90–95% of the final price is related to this market. Note also that in the Spanish electricity market there are six balancing markets whose level of trade accounts for less of 10% of the final price [13,14]. The timeframe for the simulation is 24 h. Both energy and economic results are obtained in an hourly basis and also as aggregate values.

A detailed description of the market clearing algorithm of the day-ahead market can be found in [14].

2.1. Market clearing algorithm

In the day-ahead electric energy market, market participants can be either sellers—generating companies or buyers—demands. A generating company usually owns several units, or generators. Buyers in the day-ahead market can be retailers, qualified consumers or external agents whose participation as qualified consumers in the electric market is authorized [14]. Distributors that sell energy to regulated customers are also buyers in the day-ahead market.

In this market, the MO has the task of clearing hourly selling and buying bids, submitted by the sellers and the buyers, respectively. Every bid consists of a maximum buying price and an amount of energy. For each hourly scheduling period there can be as many as 25 blocks for any single unit (buyer or seller), with a different price for each of the blocks. For any given hour and unit, prices must increase (decrease) from block to block in case of selling (buying) bid. Selling bids can include additional conditions, such as: ramp-up and ramp-down limits, and minimum revenue. Buying bids do not include additional conditions.

Once the buying and selling bids are submitted, the objective of the MO is to find a solution that determines the 24 clearing prices (corresponding to the 24 hourly scheduling periods of the daily scheduling horizon) and the assignment of power to each of the production units whose owners have submitted bids.

The sellers have the possibility of incorporating extra conditions in addition to prices and quantities. In this case, they submit "complex bids". Conditions associated to complex bids reflect constraints that couple production at different times, technical constraints and revenue requirements of the producers. The extra conditions, as described in the Spanish Market Activity Rules [14] are:

1. *Non-divisible quantity*: The quantity of the cheapest bid can be designated as non-divisible, i.e. in case the bid is accepted, it should be for the total amount, not for a fraction of it. This condition facilitates a feasible schedule for thermal units that must run above a minimum operating level.
2. *Ramp-up and ramp-down maximum rates*: The maximum variation of the unit output between two consecutive hours can be specified. That is, for the considered unit, the energy scheduled by the matching algorithm for two consecutive hours must meet the maximum variation (increasing or decreasing) condition specified as a MW/min quantity. This condition can include the start-up and shut-down maximum rates as well.

[1] Note that distributors buy energy in the pool just to sell it to its regulated customers.