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A Nash equilibrium simulation model for the competitiveness evaluation of the auction based day ahead electricity market

Mariagrazia Dotoli [a,*], Nicola Epicoco [a], Marco Falagario [b], Fabio Sciancalepore [b], Nicola Costantino [b]

[a] Department of Electrical and Information Engineering, Polytechnic of Bari, Italy
[b] Department of Mathematics, Mechanics and Management Engineering, Polytechnic of Bari, Italy

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ABSTRACT

This paper presents a simulation model based on the Nash equilibrium notion for the auction based day ahead electricity generation market. The presented model enhances a previous formalism proposed in the related literature by employing empirical data distributions of the market clearing price as registered by the market authority (e.g. the Independent System Operator). The model is effective when power suppliers with different generation capacities are considered, differently from the starting model that unrealistically assumes equal capacities. The proposed approach aims at evaluating the electricity market competitiveness with regard to the bidder strategies in order to prevent their anticompetitive actions. The framework is applied to a real data set regarding the Italian electricity market to enlighten its effectiveness in different scenarios, varying the number and capacity of participating bidders. The model can be employed as a basis for a decision support tool both for market participants (to define their optimal bidding strategy) and regulators (to avoid collusive strategies).

1. Introduction and context

1.1. Introduction

Electricity markets worldwide have traditionally been monopolistic, but since the 1990s in many countries or regions a significant restructuring process has started to liberalize the power industry with the aim of encouraging competition and increasing its efficiency [38]. Though significant differences exist around the world, due to the significance of the purchasing task [10], the common goals of deregulation are the reduction of prices for end-users and the increase of social welfare [39]. As a result, the energy market is gradually transitioning from being dominated by large producers to a market in which liberalization and privatization are encouraged. Therefore, in today's energy market, different alternative power suppliers are available and consumers may negotiate significant commercial elements, such as energy price, supplying conditions, etc. Hence, deregulation in the electrical industry has introduced the concept of a competitive market, where electricity is traded in the same way as other commodities. However, electricity prices are more volatile than any other commodity price since electricity cannot be stored and its transmission is limited by physical and reliability constraints. Anyway, the electricity industry operates as a distribution chain [6,11] from a generating station to the end users, with four key domains: energy production or consumption, energy transmission, energy economics, and environmental impact of energy use.

This work focuses on energy generation, a production sector characterized by two peculiarities: the impossibility to store the product apart from minor quantities, and the fact that a permanent equilibrium between demand and supply has to be attained to preserve the energy network system stability. In such a complex scenario, business intelligence approaches can be a solution to address numerous emerging issues, such as: trend prediction, analysis of supply and demand, modelling and simulation of market behaviour. In particular, [23] present a set of integrated tools that supports business and IT users in managing process execution quality by providing several features, such as analysis, prediction, monitoring, control, and optimization; Argotte [3] provides a survey related to prediction, pattern recognition, modelling and other subjects in the electricity market; Costantino et al. [13] and Dotoli and Falagario [17] make an analysis of supply and demand and a simulation of market behaviour.

* Corresponding author at: Dipartimento di Ingegneria Elettrica e dell'Informazione, Politecnico di Bari, Via Re David 200, 70125 Bari, Italy. Tel.: +39 080 5963667; fax: +39 080 5963410.
E-mail address: mariagrazia.dotoli@poliba.it (M. Dotoli).

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This paper addresses the strategic issue of competitiveness in the auction based day ahead electricity market. Starting from a previous work in the related literature, the authors develop an approach aiming at modelling and simulating the electricity generation market. In particular, the purpose of the presented model is twofold: it allows defining the optimal bidding strategies and identifying/preventing their eventually anticompetitive behaviour. The former result is useful for producers; the latter one is important for the authority regulating the market.

1.2. The energy market context

In the new energy market context, the electricity price is no longer determined by a power authority, but rather by competitive bidding behaviours of the available suppliers. As a result, the actual operation of the generating units depends on the complex interactions with the available producers. The resulting risks to which electricity firms are exposed significantly increase their need for suitable models that may be employed as a starting point for decision support tools to forecast the market dynamics, by simulating the competitiveness of the various suppliers and deriving the possible scenarios of price and competitiveness variations, which effects are on both the participants and the society.

A competitive electricity market is typically regulated by an authority under different names and structures in each country. For instance, two of them can be the Independent System Operator (ISO) and the Transmission System Operator (TSO). The ISO manages the power system and administrates wholesale electricity markets with the task of keeping the physical integrity of the transmission system while providing nondiscriminatory access to all participants in the market. This organization can be structured as not-for-profit, private for-profit, regional public governance, or federal administration. In addition, the ISO makes predictions (accessible to all market participants) regarding real-time electricity demand at the beginning of the trading period. TSO instead transmits electrical power from generation plants over the electrical grid to regional or local electricity distribution operators, being the owner of the power grids. In the sequel the authors refer to ISO without losing generality.

In such a new electric market scenario, customers are able to buy their necessary power from different sellers in order to achieve the lowest rates. Two main models can be considered for such a deregulated market structure: the bilateral market and the pool or auction [41]. In a bilateral market, transactions are contractual agreements for power supply between sellers (generation companies, GenCos) and buyers (distribution companies). These transactions can be long-term or short term, for energy, instantaneous power or reserves. In any case, specific details such as trading quantity (MW), trading duration (hours), trading price (€/MWh) and delivery point are bilaterally negotiated between the producer and its counterparts. Bilateral contracts are signed before the actual trading period, so trading quantity and price are set in advance. The ISO does not play any role in this contract process and in the trades, but governs the system implementing several tasks, including operation of the forward market for energy, operation of the forward market for ancillary services, dispatch of the physical system, computing settlement payments to market participants. Both contracting parties are required to provide complete details of the contract to the ISO, which ensures that system security limitations are not violated by them. On the contrary, the pool is a market structure in which suppliers and buyers transact based on some sort of auction under the supervision of the ISO. An auction is a market institution with an explicit set of rules determining resource allocation and prices on the basis of bids from the market participants [12,13]. In real electricity markets, the auction mechanism is a preferred choice for setting prices, since it is an efficient mechanism to allocate demand to suppliers under competition [25]. Auctions used in electricity markets are called multi-unit, since more than one unit of the same type is auctioned. Two forms of multi-unit auctions are commonly used in deregulated electricity markets: the uniform price auction and the discriminatory auction. In the former type, all the selected suppliers are paid a uniform price, equal to the Market Clearing Price (MCP), while in the latter suppliers are paid according to their own bids. This paper focuses on the former and more common type of auction.

Among the uniform price electricity auctions, day ahead markets are emerging as an important way through which power is allocated in many deregulated environments. It is a short term market that operates a day in advance of the physical delivery of power and where the generation decisions for the next day are the result of a two sided auction where producing (selling) and consuming (buying) agents submit a set of price and quantity hourly curves (bids) at which the producer is willing to sell for the hourly trading period of the next day. Based on the received supply bids and demand offers, the ISO runs a market clearing algorithm that matches production with demand producing a series of hourly prices and accepted quantities. In particular, the ISO arranges the bids for each trading period in the increasing price order until the system demand is met and determines the MCP as the price of the bid of the last supplier needed to meet the announced demand (price clearing process). All suppliers whose bid are below or equal to the MCP supply power are admitted to produce and they are paid the MCP. A supplier is called (infra/extra) marginal if its bid equals (is below/above) the MCP.

Day ahead markets are beneficial since they offer benefits both to energy producers and consumers in terms of price transparency, reduction of price uncertainty, and reduction of strategic gaming. Nowadays, a significant amount of power worldwide is allocated through day ahead markets [18,29]. The specific day ahead market advantages may be summarized as follows [35]: (1) the opportunity for the ISO to commit to sufficient generating units and transmission elements to meet the next day's load; (2) the opportunity for a generator's bid to better reflect the operational constraints and costs of generating units through multipart bids; (3) the increase of scheduling opportunities for the demand side to participate in the market. Hence, the day ahead market can achieve the objective of maximizing the combined economic value of transmission service, energy, and ancillary services based on the submitted bids while ensuring that reliability standards are met.

Prices in an electricity market depend on various factors such as stochastic demand, competing bids of the market participants (generators and retailers), forward contracts, auction based pricing strategies, and network parameters (including transmission constraints, reactive power limits and commitment status of generators) and are therefore uncertain. There are three pricing systems currently adopted in the electricity market: uniform marginal pricing, zonal pricing and locational marginal pricing. Unlike locational marginal pricing, uniform and zonal pricing rely on being able to predefine regions within which congestions are insignificant, and hence, prices can be deemed uniform. The uniform pricing approach suits well to the common practice and has been adopted in several markets [35]. However, the uniform pricing approach works when ample transmission capacity with no congestion is available, otherwise it gives the wrong price signals and causes difficulties in the physical system operation. In the zonal pricing approach, instead, few transmission constraints are assumed, that can be a priori identified and used to divide the network into several zones, each with its own uniform price. However, practical experience has proven that the number of transmission constraints is not small, the congestion pattern is