

# Analysis of short-term dynamic behavior of an electricity market

Andrés Ramos, Álvaro Baflo, Santiago López, Michel Rivier, Mariano Ventosa  
INSTITUTO DE INVESTIGACIÓN TECNOLÓGICA

Universidad Pontificia Comillas

Alberto Aguilera 23  
28015 Madrid, SPAIN  
andres.ramos@iit.upco.es

**Abstract:** In this paper it is presented the conceptual approach of a model for representing short-term dynamic analysis of the agents' behavior in the electricity market. The main purpose is to explore the interaction among generation companies through the offers systematically sent to a day-ahead single-node uniform-price market. The conceptual framework is aimed to shed light on two main questions: i) How the results of medium-term models (i.e., market share objectives, hydro scheduling, system marginal price) are internalized into daily offers or, alternatively, how to reach medium-term objectives by means of short-term offers and ii) How to analyze in detail the market dynamics in case of severe perturbations of agents' behavior (i.e., price wars).

The model simulates dynamically and iteratively the process each company does everyday by extracting information about the market, creating its own bids and sending to the market operator.

## 1 INTRODUCTION

A complete transformation of the electricity sector is under way in an increasing number of countries. Electric companies now face the new rules of the electricity market and, therefore, must adopt new management approaches in order to survive in this market. Under the old regulation the main concern was the cost minimization subject to all the operating constraints of the generation units and transmission lines. In the new competitive deregulated markets a new element of analysis and uncertainty is introduced in the decision-making process, the competitors' behavior. The consideration of the interactions among strategic generation agents results in the market equilibrium.

So far, the modeling effort of electricity markets has been mainly oriented to the representation of the companies' competition by *static equilibrium models* with different time scopes. The two main modeling approaches of market equilibrium [8] are based on the Cournot conjecture and on the supply function equilibrium. Consequently, several *short-term* (daily or weekly) or *medium or long-term* (yearly) models that maximize the profits of a company subject to the set of relevant operation constraints have been developed, see for example [7], [12], [13] and [17]. Special effort has been devoted in some models to represent in more detail the hydroelectric subsystem in the context of hydrothermal coordination models in competitive markets [14]. Additionally, there are developments for analyzing the effect of transmission network limits in generation markets [15]. And finally, risk management models are being developed to include stochasticity from natural sources such as hydro inflows [5].

However, until now no much effort has been devoted to represent the *short-term dynamic decision process* in the electricity market. The main purpose of this approach is to explore the interaction among companies through the offers systematically sent to a day-ahead single-node uniform-price market. This conceptual framework is aimed to shed light especially on these two main questions:

1. How the results of medium-term models (i.e., market share objectives, hydro scheduling, system marginal price estimation) are internalized into daily offers or, alternatively, how to reach medium-term objectives by means of short-term offers, as in a control system.  
It is worth to note that medium-term parameters are obtained by market equilibrium models that simultaneously consider all the companies while short-term results depend on myopic decisions of each company.
2. How to analyze in detail the market dynamics in case of severe perturbations of market agents' behavior (e.g., price wars, new entrants in the market) or other stochastic variables (e.g., dramatic changes of fuel prices).

Furthermore, the model can also be used to get insight in:

1. How to analyze the consequences of different alternative actions a company or the other agents (reactions) may take in the next future, i.e., a kind of what if analysis.  
This question can use the game theory criteria (e.g., minimax) to choose the best decision.
2. Review of past results to gain understanding of the market and the competitors' behavior.

Game theory is the general framework that allows characterizing clearly the market. From that point of view the model representing the market is an *N-person discrete-time stochastic infinite noncooperative dynamic game* with no prespecified duration [2].

- It is *N-person* because there are more than two players (generation agents) in general.
- It is *discrete-time* because the game is played only at certain periods (once a day in a day-ahead electricity market).
- It is *stochastic* because there are some external factors (namely "nature") that may affect the results of the game in an unpredictable way.  
In electricity markets, the demand can be considered as uncontrolled source of uncertainty for that purpose. Some fuel prices are also stochastic in the short-term. The outcome of the game is partly based on data not yet known and not completely determined by other players' decisions.
- It is *infinite* because there are "infinite" actions and strategies any player can make.  
Action is the actual option or control decided by the player. Strategy is a decision rule that a player may be applying. For example a strategy can be: if agent A gets more market share then I decrease my bidding price. The implementation of an action may depend on the information available that can be of a stochastic nature. Therefore, the actual action is based on data not yet known and not controlled by other players but determined by "nature".  
Depending on how the information is fed back to the players and can be used by them for defining their strategies the game can be referred as a *close-loop structure* if in each period the players know the results of the previous game and an *open-loop structure* in no information is passed to the players. The electricity market can be approximated as a close-loop imperfect structure because some results about competitors are known but not the detailed actions they have taken in the previous act.
- It is *noncooperative* because each agent pursues his own interests, which are partly conflicting with others'.
- It is *dynamic* because the order in which the decisions are made is important.  
If the game is played repetitively along the time in many stages or levels it is called a *multi-act* or *multi-stage* game. In the electricity market no termination bound is prespecified and infinite duration it is supposed.

However, game theory only provides the conditions that must satisfy the Nash or Stackelberg equilibrium points, no the procedure to reach them. Then, simulation is the method chosen as the basic technique to represent, analyze and provide quantitative results of this electricity

market game. Simulation has two powerful characteristics. One is the capability of modeling complex systems and the other it is the ability to incorporate dynamic aspects. Both characteristics are present and important in the short-term electricity market. Furthermore, simulation can be a helpful training tool for traders, because a better understanding of the electricity market can be achieved than with steady state or static models. As a drawback, simulation models are more complex to understand and require much more effort to validate. Only some references, that use dynamic simulation as the technique for representing the market evolution, have been found in the literature, see [3], [6], and [10].

The paper is organized as follows. In section 2, the characteristics of the agents and of the market operator are presented. Then, the general structure of the model is introduced in section 3. The optimization model used to generate the optimal bids of any agent is summarily presented in section **¡Error! No se encuentra el origen de la referencia..**

## 2 SYSTEM CHARACTERIZATION

Generation (seller) and demand (buyer) agents and Market Operator (MO) are the main actors in the electricity market. Other participants, such as the System Operator (SO), that is responsible for the surveillance of technical constraints imposed mainly by the transmission network, or the market regulator body, responsible of the general market supervision, are ignored into this model. Let us review the main characteristics of each one of the main agents.

### 2.1 GENERATION AGENTS

Two main functions represent the behavior of each generation agent, see figure 1:

1. Analysis and data mining about the competitors

In this module it is analyzed all the information available from the market to understand and represent the behavior of all the competitors' agents. The information available (what one player knows relative to others) is very crucial in the context of game theory.

This model is oriented to represent the Spanish electricity market and the information published by the Spanish MO is the following one:

- The system marginal price and the system demand for each day
- The hourly demand for the next month is estimated by the SO
- Each agent can only access the market results corresponding to their own offer units
- The detailed information of selling and buying offers of each agent will made public three months later of having been presented
- The aggregated information of selling and buying offers, for the whole sets of agents, is made public the next day of having been presented

Subtracting the system demand from the competitors' bidding offers it is obtained the residual demand, which represents the system marginal price as a function of the own company production (or market share). Processing this information each company can estimate the set of *residual demand scenarios* that approximately take into account the stochasticity in the competitors' behavior.

2. Determination of optimal bids and operation

This module is crucial in the model because it reproduces the decisions made by any company. It represents the maximization problem of one company assuming all the competitors' tactics are represented by a finite set of residual-demand curves, see details in [1]. This criterion must reflect the strategies obtained by short and medium-term models (e.g., a strate-

gic unit commitment model) and translate them into the daily offers. This module automatically determines the optimal bids for each day in a day-ahead electricity market and the optimal operation of the company's generation units. The objective function is to maximize the company's expected profit for all the residual demand scenarios, which is calculated as the difference between expected market income and expected variable costs. Revenues for each scenario are obtained by multiplying the energy price and the quantity offered by the company. This non-convex function is linearized and divided into convex sections so as powerful MIP solvers can be used. The decisions are subject to the following constraints. The bids chosen by the model for each generation unit must be increasing both in quantity and price, which link all the scenarios of a certain hour by this set of increasing constraints. These constraints complicate significantly the solution of the problem. An energy balance equation relates the quantity offered by the company in the day-ahead market and the scheduling decisions of its units. Furthermore, all the operating limits of the generation units are considered. The optimization problem is solved by Benders decomposition.

The previous module automatically obtains these bids but they could be further manipulated to test alternative aggressive or conservative tactics depending on the results obtained in the previous days or to take into consideration other different objective functions that are translated to the bids. For example, balancing mainly market share, competence transition costs, regulator threat, capacity payments, and new entrants. These are usually not taken into account in static market equilibrium models but may be incorporated into a simulation model as the presented in the paper.

Some indices about the system performance are obtained: market share and market revenues for each generation agent, and system marginal price. These results should conduct the reaction of each agent in the repetition of the game. Agents may learn from past experience, try to improve their decisions and adapt themselves to changes from competitors or from nature. At the same time the model can incorporate some reaction mechanism that considers the achievement degree of these objectives.

In the model the feedback mechanism is closed through the information that any agent gets from the market operator and internalizes it in the previous step.

These modules are conceived as black boxes, so the user can control the behavior of some agents while some others can automatically determine their bids. This allows using the same mathematical techniques, tools or models or, by the contrary, to take advantage of specific developments with different mathematical techniques or different characterization of any electric company or even in the simplest case to be replications of past bids. For example, a company with high hydroelectric generation will use models that adequately represent the operation flexibility of a hydraulic subsystem and its capability to bid in the electricity markets. While other firm with strong thermal mix will put emphasis on the commitment decisions and its feasibility.

## 2.2 MARKET OPERATOR

The market operator module receives the daily offers from the agents and accepts the cheapest generation bids and the most expensive demand bids until an equilibrium point is reached. The information regarding agents' bids and market results are incorporated to the database some of whose results can be accessed by any agent.

The electricity market in Spain is based on single-node clearing process, so the transmission network is ignored.

### 3 MODEL DEFINITION

This model simulates the generation agent and market operator behavior to analyze, test and quantify different dynamic decisions. It is an *electricity market simulator*. Consequently, it reproduces synthetically the electricity market dynamic process in the following stages:

- 1) Each generation agent extracts information about the competitors' behavior, and determines their own optimal bids for the next day according with their own criteria and models.
- 2) All the agents send the daily offers to the market operator.
- 3) The market operator registers the bids, clears the market and publishes some of the daily results.
- 4) Advance to the next day and go to stage 1).

In the literature other disciplines such as multi-agent models [11] or experimental economics have been used. Although more simplified, some similar iterative approach appears in the context of the multi-round auctions in which generation bids are iteratively updated at every round. These multi-round auctions have been explored as alternative bidding mechanism against single-round auctions. Examples of these auctions can be found in [16] in which the generation bidding process is represented as an optimal control problem or where new bids are estimated by genetic algorithms [9] or in [4] and [10] where multi-round auction results are compared with a single-round auction mechanism.

The next figure presents a scheme of this procedure.

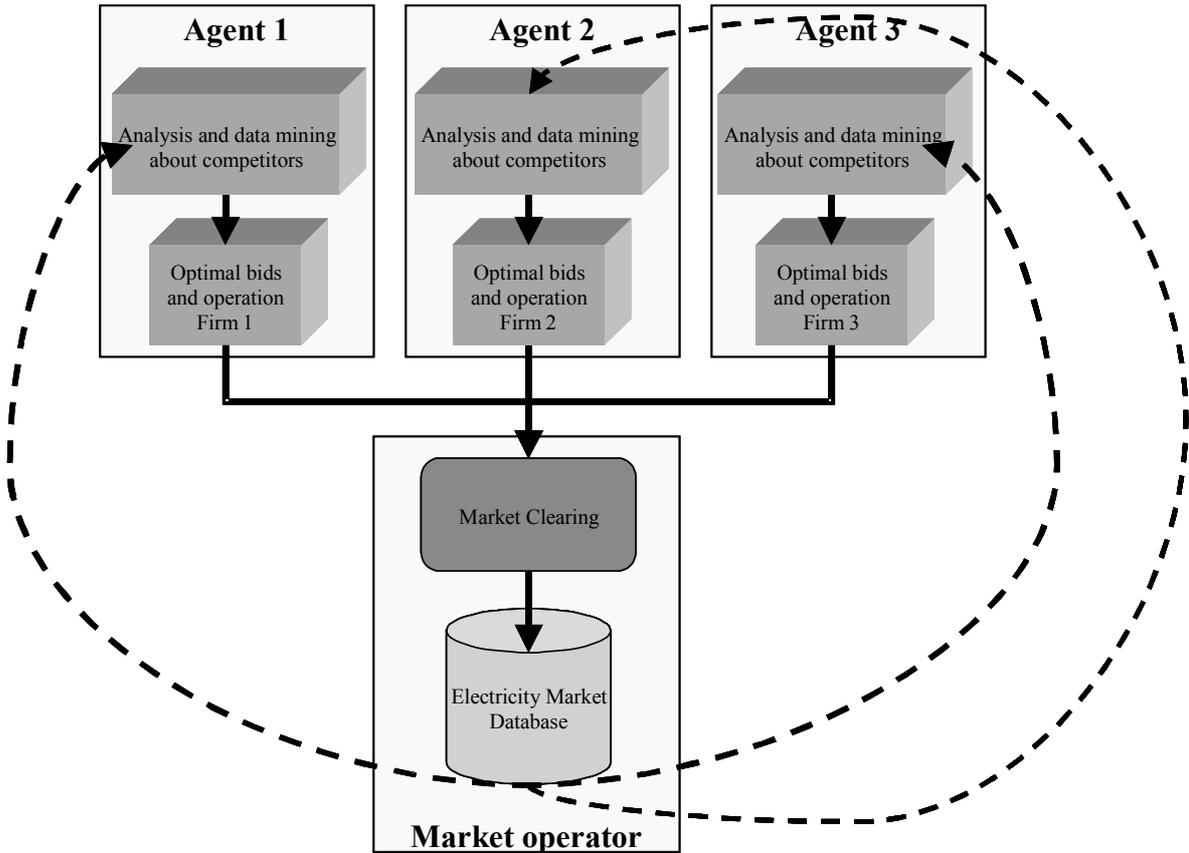


Figure 1. Electricity market simulation model.

This iterative procedure can be affected by random parameters as forced failure of generation units, errors in estimations of the demand agents, changes of fuel prices, etc.

The model has been coded in Visual Basic for Applications and the module dedicated to optimize the bids of an agent has been written in GAMS.

## 4 MODEL USE

The validation of the simulation model is done with past results and has to be made carefully isolating each of the different factors affecting the system results, e.g., uncertainty in demand consumption estimation, changes in competitor tactics, etc.

In this step, system can be subject to uncertainties that may occur in the future and therefore a company can understand and prepare for them.

Test different future scenarios built with alternative decisions or stochastic parameters and decide the best decision under a game theory approach.

Very careful tuning is required to avoid misleading results.

Convergence properties?

## 5 ACKNOWLEDGEMENTS

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