TESTING THE SCENARIO ANALYSIS ALGORITHM OF AN AGENT-BASED SIMULATOR FOR COMPETITIVE ELECTRICITY MARKETS

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ABSTRACT

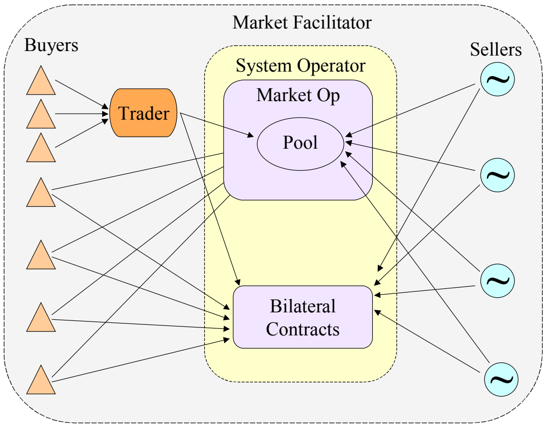
The main goal of MASCEM – Multi-Agent Simulator of Competitive Electricity Markets, is to give electricity market entities a tool to support their decisions and to obtain knowledge about market behaviour and evolution. Intelligent agents with strategic behaviour represent entities from electricity markets. In this paper we propose some illustrative scenarios to explain and take some conclusions about MASCEM agent's Scenario Analysis Algorithm behaviour.

INTRODUCTION

The electricity industry is becoming competitive; a market environment is replacing the traditional centralized-operation approach. New entities have emerged and the role of existing ones has changed. There are different market rules, based on different negotiation mechanisms. In this context, new modelling approaches that simulate how electric power markets might evolve over time and how market participants might react to the changing environment are welcome. Electricity market entities are heterogeneous and autonomous, have their own objectives and follow their business strategies in order to reach them; they interact among them in a dynamically changing environment. All these characteristics led us to develop MASCEM – Multi-Agent Simulator of Competitive Electricity Markets, and give electricity market entities a tool to support their decisions and to obtain knowledge about market behaviour and evolution. With MASCEM several experiences have already been made, leading us to achieve some conclusions and define future developments.

MASCEM: MULTI-AGENT MODEL

There are different types of agents in our model: Market Facilitator Agent, Seller Agents, Buyer Agents, Trader Agents, Market Operator Agent and System Operator Agent. In this section we will briefly describe their roles, functionalities and the interactions between them, for details please consult (Praça et. al 2003). Figure 1 illustrates MASCEM Multi-Agent model.



Figures 1: Multi-Agent Model

The Market Facilitator plays the role of market coordinator of the Electricity Market. It knows the identities of all the agents present in the market, regulates the negotiation process and assures the market is functioning according to the established rules. Agents before entering the market must first carry out the registration with the Market Facilitator, specifying their market role and services.

Seller and Buyer agents are the two key players in the market, so a special attention is devoted to them, and particularly to their objectives and strategies they can use to reach them. Seller agents represent entities able to sell electricity in the market, e.g. generating companies holding electricity production units. Buyer agents represent electricity consumers and electricity distribution companies. The number of Seller and Buyer Agents in each scenario is completely defined by the user, who must also specify their intrinsic and strategic characteristics. By intrinsic characteristics we mean the individual knowledge related to reservation and preferred prices, and also to the available capacity (or consumption needs if it is a Buyer agent). By strategic characteristics we mean the type of strategies the agent will employ to reach the objective of selling the

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available capacity at the best price, if the agent is a Seller, or to buy the needed power if the agent is a Buyer. Seller Agents will compete with each other, since they are all interested in selling all their available capacity and in obtaining the highest possible market quote. On the other hand Seller Agents will cooperate with Buyer Agents while trying to establish some agreement that is profitable for both. This is a rich domain where it is possible to develop and test several algorithms and negotiation mechanisms for both cooperation and competition.

The increase in competitiveness creates opportunities for many new players or agents to enter the market; one of these players is the Trader. The introduction of this new entity, with well-defined responsibilities, allows liberalization and competition in the electricity industry to be developed and simplifies the way the whole process works with producers and consumers on the market and the relationship with the Market Operator. This entity participates in the market on behalf of consumers. It is an intermediary between them, who delegate on the Trader the purchasing of their needs, and the suppliers. One important feature of our simulator is the inclusion of this type of agent, usually not considered in related works.

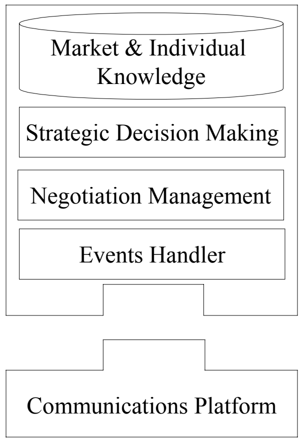
The System Operator Agent is specific to the application domain, i.e. Electricity Markets, representing the responsible for the transmission grid and all the involved technical constraints. Every contract established, either through Bilateral Contracts or through the Pool, must be communicated to it, which analyses its technical viability from the Power System point of view (e.g. feasibility of Power Flow to attend all needs).

The Market Operator is responsible for the Pool. A Pool is based on an auction mechanism. Market price is established taking into account the auction mechanism, the previewed demand and the submitted bids. This agent is only present in simulations of Pool or Hybrid markets. It will receive the bids of Sellers and Buyers (according to the type of Pool – Symmetric or Asymmetric), analyse them and establish the marginal price and accepted bids. The process of determining the accepted bids is done according to the technical validation made by the System Operator. After, the Market Operator communicates to Sellers and Buyers the acceptance, or not, of their bids and, optionally, the market price.

Seller and Buyer Agents Structure

Seller and Buyer agents are the two key players in the market. These agents have similar structure and a kind of symmetrical (due to their antagonistic objectives) behaviour, for this reason they are both treated in this section, however, whenever necessary the differences between them will be pointed.

The structure of these types of agents comprises three functional modules: Events Handler, Negotiation Management and Strategic Decision Making, plus one knowledge-based module: the Market & Individual Knowledge module. Figure 2 illustrates this structure.



Figures 2: Seller and Buyer Agents Structure

The Events Handler Module is responsible for all processes related with messages handling. Incoming messages are ordered by degree of importance and time of arrival. Out coming messages are sent only to those agents that are known to be possibly interested in that particular piece of information. Agents use ICL – Interagent Communication Language – to exchange messages between themselves.

During a negotiation period agents analyse and formulate several proposals. The Negotiation Management module contains all the processes related to this subject. The proposals received are analysed taking into account issues such as the price, quantity of energy and viability of the transaction (based on the technical analyses made by the System Operator). The process of formulating proposals results from the interaction of this module with the Strategic Decision Making module.

The Strategic Decision Making module is the most complex one. This is a module that analysis previous results and determines how to quote bids and which strategy to use. This module contains several dynamic strategies.

The market simulator is organised in several negotiation periods and Seller, Buyer and Trader Agents have strategic behaviour to define their desired price. These agents have time-dependent strategies, to change the price according to the remaining time until the end of the negotiation period; and behaviour-dependent strategies, to define the next period price according to the results obtained in the previous ones.

MASCEM implements four types of strategies to change the price during a negotiation period: Determined, Anxious, Moderate and Gluttonous. The difference between these strategies is the time instant at which the agent starts to modify the price and the amount it changes. Determined agents maintain their prices constant during the negotiation period. Anxious agents start modifying the prices early in the negotiation period but by small amounts. Moderate agents will start changing the prices in the middle of the period by a small amount, and Gluttonous agents will only start changing the prices at the end of the negotiation period but by major amounts.

Although time-dependent strategies are simple to understand and implement, they are very important since they allow the simulation of important issues such as: emotional aspects and different risk behaviours. For example: an agent using a Determined Strategy is a risk indifferent one; while Gluttonous agents exhibit the behaviour more risk disposable, since they maintain the same price until very close to the end of the negotiation period, taking the risk of not selling.

To adjust price between negotiation periods, also referred as behaviour-dependent strategies, two different strategies were implemented: one called Composed Goal Directed and another called Adapted Derivative Following, see details in (Praça et al. 2004). These are important strategies that use the knowledge obtained with past experiences to define bid prices for the next periods.

To obtain an efficient decision support, Seller and Buyer agents also have the capability of using an algorithm, the Scenario Analysis Algorithm, described later.

The Market & Individual Knowledge module contains information about the organisational and operational rules of the market, as well as other agent commitments and capabilities, and about the agent itself: agent own capabilities, current availability, past experiences and strategies. Through the analysis of historical market results, this module constructs the profile of each agent in the market, particularly in what concerns their capabilities, reservation prices and expected prices.

MASCEM: INTERFACE

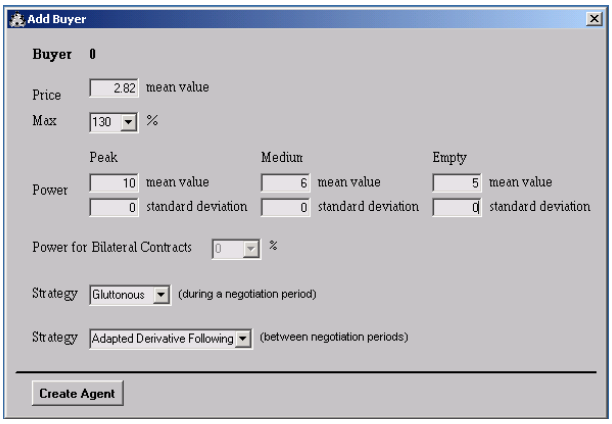
MASCEM aim is to study the electricity spot market, where negotiation is divided into several negotiation periods, usually 24 or 48 periods, meaning next day's 24 hours or 48 mean-hours.

In spot markets the process of negotiation can be of many different forms. So, our simulator includes the possibility of negotiating through bilateral contracts, through a Pool, with either a single or a double uniform auction, and through a mixed market, where the agent must decide whether to negotiate in the auction and/or establish a bilateral agreement.

This is an important characteristic giving to the simulator a high degree of flexibility and usefulness, since the same scenario can be analysed through different negotiation mechanisms (Praça et al. 2005). Figure 3 shows the interface screen to settle simulation parameters.

Figures 3: Scenario Definition

The user may also define Seller, Buyer and Trader Agents intrinsic and strategic characteristics. Figure 4 illustrates the parameters that characterize a Buyer Agent.



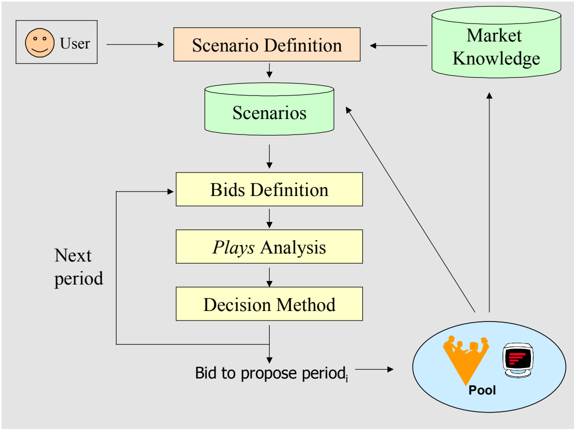
Figures 4: MASCEM screen for Buyer Agent input data

One important issue is the fact that Buyers consumption diagram is based on peak, empty and full consumption periods, and even within these periods, demand needs is allowed to fluctuate, while being represented by a probability distribution function.

SCENARIO ANALYSIS ALGORITHM

This algorithm is based on the analysis of several bids under different scenarios. The aim of this algorithm is to help agents organize and extract knowledge from the information they gathered.

Agents use the information contained on their Individual and Market Knowledge Module to build the most probable scenarios for the next negotiation periods, and analyse them in order to take the most suitable behaviour to overcome their competitors, while assuring their needs will also be fulfilled. Figure 5 illustrates the algorithm steps.



Figures 5: Scenario Analysis Algorithm

Scenario and Bid Definition

Each agent has historical information about market behaviour and about other agents' characteristics and behaviour. To get warrantable data, each agent uses techniques based on statistical analysis and knowledge discovery tools, which analyse the historical data.

With the information gathered agents can build a profile of other agents based on their expected proposed prices, limit prices, and capacities. With these profiles, and based on the agent own objectives, several scenarios, and the possible advantageous bids for each one, are defined. The agent should analyse the incomes that result from bidding its limit, desired prices, and competitive prices—those that are just slightly lower (or higher, in the Buyer's case) than its competitors' prices.

We call a *play* to a pair bid-scenario. After defining all the scenarios and bids, market simulation is applied to build a matrix with the expected results for each *play*.

Decision Method

The matrix analysis with the simulated plays' results is inspired by the game theory concepts for a pure-strategy two-player game, assuming each player seeks to minimize the maximum possible loss or maximize the minimum possible gain (Fudenberg and Tirole 1991).

A Seller—like an offensive player—will try to maximize the minimum possible gain by using the MaxiMin decision method. A Buyer—like a defensive player—will select the strategy with the smallest maximum payoff by using the MiniMax decision method. In Buyers' matrix analyses, they select only situations in which they can fulfil all their consumption needs. They avoid situations in which agents will accept reduced payoff but can't satisfy their consumption needs completely.

This analysis not only provides the agent with decision support about the bid to propose in a Pool but also helps improve the negotiation mechanism for establishing bilateral contracts. With this information, the agent can evaluate a bilateral contract's potential benefits; compare them to the benefits expected in a Pool, and make counterproposals.

Scenario Analysis

The analysis of each period's results will update the agent's market knowledge and the scenarios to study. After each negotiation period, instead of considering how they might increase, decrease, or maintain their bid, agents use knowledge rules that restrict modifications on the basis of other agents' expected behaviour.

The knowledge rules update agents' bids in each scenario, but the number of scenarios remains the same. If at the end of a negotiation period the agent concludes — by analysing market results — that it incorrectly evaluated other agents' behaviour, it will fix other agents' profiles on the basis of the calculated deviation from real results.

EXPERIMENTS

Several experiences were made to evaluate the benefits of the Scenario Analysis Algorithm (SAA). In this section we describe a small and simple scenario to illustrate them. The scenario used is very simple to let the reader better understand it. Table 1 presents Seller agent intrinsic characteristics and Table 2 those for Buyer Agents.

Table 1: Seller Agents

	Limit Price Cent/kWh	Pretended Price Cent/kWh	Energy kWh
S1	1.56	1.95	13
S2	2.86	3.57	12
S3	3.15	3.93	14

Table 2: Buyer Agents

	Limit Price	Pretended Price	Empty kWh	Full kWh	Peak kWh
B1	3.67	2.82	5	6	10
B2	3.30	2.54	6	6	10

Seller S1 is the most competitive one, having prices smaller than the other agents. This agent may increase its profits by raising its pretended price, without being overcome by competitors. The agent can use the SAA to take this conclusion. Let's see what happens in the Asymmetric Pool and in the Symmetric Pool.

Asymmetric Market

In this type of market only Sellers are able to compete by presenting bids to the Pool. The Pool mechanism is usually the First Price Sealed Bid Auction. According to this mechanism, market price will be established based only on Seller bids and previewed demand. So, agents will consider only profiles of other Seller agents.

Agent S1 may use SAA to build a profile of other agents and test bids that approach their expected bids but are sufficiently smaller to overcome them. Table 3 shows S1 profit fluctuation when compared to the same scenario simulated without the use of SAA.

Table 3: Seller S1 Profits in Asymmetric Market

	S1 Profit Fluctuation
Only S1 uses SAA	25 %
All Sellers use SAA	3 %
All Sellers except S1 use SAA	- 6 %

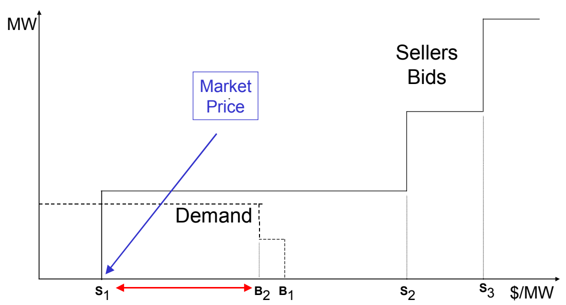
As we can see the major profit increase happens when S1 is the only agent using SAA. That makes sense since the other agents, which are less competitive, are not using SAA to conclude it and so they will keep trying to obtain their desired prices instead of making smaller bids, like those based on their limit prices. When the other Sellers also use SAA they conclude they cannot overcome S1, but they may compete with each other and so they reduce their pretended prices. In periods where S1 is not able to satisfy all consumption needs, such as in peak periods, the market price will be established by S2 or S3. Since they decrease their bids, market price will also be decreased, and so S1 profits will, indirectly, be reduced.

Symmetric Market

In Symmetric Markets, the Pool functions according to a Double Uniform Auction, so both Sellers and Buyers are able to compete by presenting bids to the Pool.

When using SAA agents will also analyse bids that approach Buyers proposals that means that when studying Symmetric Markets the number of *plays* to analysed is higher.

As we can see in Figure 6, since Buyer Agents pretended prices are smaller than those presented by Sellers, the S1 Agent will conclude he is not able to increase bids as much as in the Asymmetric Market.



Figures 6: Symmetric Market Mechanism

Table 4 shows S1 profit fluctuation when compared to the same scenario simulated without the use of SAA.

Table 4: Seller S1 Profits in Symmetric Market

	S1 Profit Fluctuation
Only S1 uses SAA	12 %
All Sellers use SAA	-5 %
All Sellers except S1 use SAA	- 13 %

As expected S1 profits are smaller than the obtained in the Asymmetric Market. On one hand, according to the Pool mechanism, Buyer Agents are able to submit bids, so they are also able to influence market price. On the other hand, since Buyers pretended prices are smaller than Sellers prices, S1 concludes, trough the SAA, that he can not raise its price, as much as in the Asymmetric Market, since in that market only Seller profiles are considered.

MASCEM RELATED WORK

MASCEM ideas seem very promising and innovative, when compared to other approaches to study Electricity Markets, such as: as PowerWeb (PowerWeb-URL), where demand is always fixed and just single uniform auctions are studied; the Auction Agents for the Electric Power Industry, which only implements a Dutch Auction (EPRI-URL); the SEPIA-Simulator for Electric Power Industry Agents (Harp et al. 2000), which only implements a bilateral contracts market. Very relevant is the work of John Bower (Bower and Bunn 2001), Monclar e Quatrain (Monclar and Quatrian 2001), and Nicolaisen (Nicolaisen et al. 2001), however they are interested in studying only a particular market, the England and Wales market. However, our work is intended as a Decision Support Tool for the analysis and comparison of the negotiation mechanisms most used in Competitive Electricity Markets.

On the other hand, MASCEM has been selected, to illustrate agent technology application to electricity markets, as one of the six worldwide reference systems illustrating the use of agent based simulation in different types of markets (Praça et al. 2003).

MASCEM ideas are currently being applied to other types of markets, in the perspective of Electronic Commerce applications, under the scope of the project *Agents&Markets* (POSI/EIA/56260/2004) supported by the Portuguese Agency for Scientific Research (FCT).

CONCLUSIONS

This work describes the use of Multi-Agent Simulation to study and understand the restructuring process of the electric power industry. In this context of recent and strong transformations, decision support tools are very welcome.

MASCEM is an agent-based simulator to study electricity spot markets. MASCEM agents include a Scenario Analysis Algorithm, that analyses market information and help agents define their bids and preview market results. Some experiences are reported suggesting the importance of this scenario analysis.

Although this is a very rich domain for illustration, there are many other areas where these ideas could also be fruitfully applied.

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