A New Agent-based Framework for the Simulation of Electricity Markets

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Abstract

As electric utility systems around the world continue to move towards open, competitive markets, the need for new modelling techniques will become more obvious. To study electricity markets behaviour and evolution we propose a multi-agent simulator where agents represent several entities that can be found in electricity markets, such as generators, consumers, market operators and network operators, but also entities that are emerging with the advent of liberalization, such as traders. The simulator probes the possible effects of market rules and conditions by simulating the strategic behaviour of participants. In this paper a special attention is devoted to the strategic decision processes of Seller, Buyer and Trader agents, in order to gain advantage facing the new emerging competitive market.

1. Introduction

To gain insights into decentralized electricity markets, we developed a Multi-Agent Simulator. Unlike traditional tools, our Simulator does not postulate a single decision maker with a single objective for the entire system. Rather, agents, representing the different independent entities in Electricity Markets, are allowed to establish their own objectives and decision rules. Moreover, as the simulation progresses, agents can adapt their strategies, based on the success or failure of previous efforts. Some agent-based simulators have been constructed for Electricity Markets [1] [2] [3] [4] [5]. These models have hinted at the potential of agent-based models for the analysis of Electricity Markets. However, our simulator has different characteristics: it is intended as a Decision Support Tool, so, instead of just studying a particular market, it includes several types of negotiation mechanisms, such as Bilateral Contracts, Symmetric and Asymmetric Pools, and Hybrid Markets, to let the user test them and obtain sensibility about the best way to negotiate in each one. It includes agents representing several entities: ongoing and emerging ones. The different agents have their own objectives and strategic behaviour. To obtain an efficient decision support, agents have the capability of using a *Scenario Analysis Algorithm* that analyses different bids under several scenarios.

2. Overview of the Multi-Agent Simulator

We propose a market simulator for the electricity spot market, with 24 negotiation periods each day. The different types of agents in our model are: Market Facilitator (MF), Seller Agents (SAs), Buyer Agents (BAs), Trader Agents (TRs), Market Operator Agent (MO) and Network Operator Agent (NO). Three types of markets are simulated: Pool Markets, Bilateral Contracts and Hybrid Markets.

The MF is the coordinator of the 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. The first step agents' have to do is the registration at the MF, specifying their market role and services.

SA and BA agents are the two key players in the market. SAs represent entities able to sell electricity in the market, e.g. companies holding electricity production units. BAs represent electricity customers and distribution companies. The user, who must also specify their intrinsic and strategic characteristics, defines the number of SAs and BAs in each scenario. By intrinsic characteristics we mean the individual knowledge related to reservation and preferred prices, and also to the available capacity (or power needs if it is a BA). By strategic characteristics we mean the strategies the agent will employ to reach its objectives. SAs 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, SAs will cooperate with BAs 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 NO is 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 the NO, who analyses its technical viability from the Power System point of view (e.g. feasibility of Power Flow to attend all needs).

The MO is responsible for the Pool mechanism. This agent is only present in simulations of Pool or Hybrid markets. The MO will receive the bids of the SAs, BAs and TRs, analyse them and establish the marginal price and accepted bids. The process of determining the accepted bids is done according to the technical validation by the NO, after, the MO communicates to the SAs, BAs and TRs the acceptance, or not, of their bids and, optionally, the market price.

The increase in competitiveness creates opportunities for many new players to enter the market; one of these players is the TR. The introduction of this new entity allows liberalization and competition in the electricity industry to be developed and simplifies the way the whole process works with producers and customers on the market and the relationship with the market operator. This entity participates in the market on behalf of customers. 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.

In Pool markets the most common type of negotiation is a standard uniform auction [6]. If only suppliers are able to compete in the Pool, it is called an Asymmetric Pool. If both suppliers and buyers are able to compete, it is called a Symmetric Pool, based on a Double auction. Both of these types of Pool mechanisms are included in our simulator. In Pool Markets, the negotiation process starts by the MO, who sends a request for proposals, at the beginning of each negotiation period. All interested agents, SAs, BAs and TRs, reply by sending bids to the Pool. Then, the MO analyses the received bids, determines market price and selects the accepted and rejected bids. Bids matching process is done with the technical approval of the NO. After the processing of all bids, and market price established, the results are communicated to Pool participants.

Bilateral contracts are agreements between a single SA and a single demand agent (a BA or a TR). If a demand agent chooses to participate in the bilateral market it will start by sending a request for electricity. This request triggers the negotiation process and is delivered to all SAs existing in the simulated market. In response, a SA analyses its own capabilities, current availability, past experience and checks its technical feasibility, through the feedback of the NO. Then, it formulates a proposal and sends a message to the source agent. Demand agents evaluate the received proposals and either accept or reject them.

In Hybrid Markets a Pool exists simultaneously with Bilateral Contracts. Agents must decide whether to establish a Bilateral Contract before trying the Pool, or just after Pool results if bids were not accepted. To make this type of decision agents use their past experiences and market strategies. Details about agents message handling in the described types of markets can be found in [7]. On the basis of the results obtained in a negotiation period SAs, BAs and TRs revise their strategies for the next period.

2.1. Simulator Architecture

A prototype of the Multi-Agent Simulator was developed in Open Agent Architecture (OAA) [8] and in Java. Each agent is implemented in Java, as a Java thread. The model can be distributed over a network of computers, which is a very important advantage to increase simulation runs for scenarios with a huge amount of agents.

OAA is a framework for integrating a community of heterogeneous software agents in a distributed environment. The OAA's Interagent Communication Language (ICL) is the interface and communication language shared by all agents, no matter which machine they are running on or which programming language they are programmed in. OAA imposes a common protocol for agents entering and registering at the market. First, agents must connect to the coordinator of the market, in our case it is the MF :

```
if(!myoaa.getComLib().comConnect("MarketFacilit
atorAgent", new IclStruct ("tcp", new IclStr
("neptuno.dei.isep.ipp.pt"), new IclInt(3378)),
(IclList) IclUtils.icl("[]"))){
    /* the agent is connected}
else /* the agent is not connected;
```

Then the services, called *solvables* in OAA, provided by the agent must be defined, and registered in the MF. The following code illustrates the registering process of some of the services, defined in variable *agentSolvables*, provided by SAs.

```
super.agentSolvables = "[request_CB(Pot, Price,
Local, Params), sell(Pot, Price, Local,
Params), pool_offers(Pot, Price, Local),
sell_pool(Pot, Price)]";
if(!myoaa.oaaRegister("MarketAgentFacilitator",
agentName, IclUtils.icl(agentSolvables),
(IclList)IclUtils.icl("[]"))){
      /* the agent is registered;}
else /* the agent is not registered;
```

The function that deals with incoming messages for requesting services provided by the agent, is *oaaDoEventCallback*, where the code to process each service request must be placed. For example, for a *request_CB* to a Seller:

```
public boolean oaaDoEventCallback(IclTerm goal,
IclList params, IclList answers){
   if(goal.iclStr().toString().equals("request_
CB")){
   /*code to define a proposal for the request}
   return true;}
```

3. Trader Agents

Traders are emerging in the context of liberalization as intermediaries between consumers and suppliers. Consumers have incentives to become members of an alliance guided by a Trader. One of them is the fact that consumers can gain market power by grouping their purchases, another one is that some skills and market knowledge are required to be an efficient player in the market, and not all consumers will have the ability or interest in dominating those issues, while Traders will necessarily be specialized in the field. Traders are included in our model as TRs agents.

The protocol for establishing a TR set of clients will be detailed in this section. The protocol for establishing Bilateral Contracts and for trading in the Pool is similar to the one defined for BAs and detailed in [7]. The simple negotiation protocol for establishing a TR set of clients involves the TR and a set of BAs, who are possible customers of the TR, B={b_1, b_2, …b_m}.

1. First, TR proposes B to represent them on the market. TR $\rightarrow$ B "calls_for_clients" message.

2. Each $b_i \in$ B considers whether to make a contract with the TR and defines its parameters, such as consumption needs, price and duration. $b_i \rightarrow$ TR "contract_params" message.

3. TR evaluates parameters and replies to every b_i who answered its request. Usually, TR accepts every client, unless its parameters are unrealistic. TR $\rightarrow$ B "reply_contract_params" message.

Steps 2 and 3 may have several iterations. When the time limit of a contract is approaching, the TR contacts its clients in order to negotiate its renewal. If a client, from the set of clients C={c_1, c_2,…c_k}, is interested in the renewal it will send a message to the TR specifying the parameters of the contract renewal, such as its duration and other issues such as new consumption needs:

1. First, TR suggests to $c_j \in$ C to renew the contract that is finishing. TR $\rightarrow c_j$ "contract_renewal" message.
2. Then, $c_j \in$ C, if interested in renewing the contract, will contact TR to update the previous established parameters. $c_i \rightarrow$ TR "update_params" message.
3. TR replies to c_j acknowledging the contract prolongation with the updated parameters. TR $\rightarrow c_j$ "reply_update_params" message.

Steps 2 and 3 may have several iterations. TR negotiate on the market, either through Bilateral Contracts or in the Pool using the same message exchange as defined between BAs - SAs and BAs - MO, detailed in [7]. However, TR evaluation function and decision analysis process is different and takes into account the contract parameters established with its clients to fulfil them while trying to obtain some profit. An important distinction is that TR is forced to assure that the total demand of their clients is satisfied.

4. Agent Strategies for Bid Definition

The policies implemented by each agent must be analysed carefully since the development of a strategic offer that ensures high profitability is a fundamental issue for the market participants. Agents take into account their past experiences and their expectations about market evolution. Both SAs, BAs and TRs have dynamic pricing strategies, which define the price they are willing to obtain in each negotiation period. Agents have strategies to change their price under a negotiation period, also referred as time-dependent strategies. To adjust price between negotiation periods, also referred as behaviour-dependent strategies, two different strategies were implemented: one is called *Composed Goal Directed* and another is called *Adapted Derivative Following*. Detailed explanation and examples about strategies performance can be found in [7]. These agents also have the capability of using a *Scenario Analysis Algorithm* that analyses different bids under several scenarios.

4.1. Scenario Analysis Algorithm

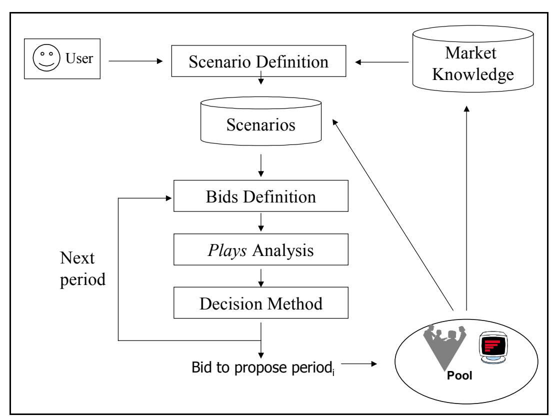

Figure 1. Scenario Analysis Algorithm

This algorithm provides a more complex support to develop and implement dynamic pricing strategies since each agent analyses and develops a strategic bid, for the next period, taking into account not only their previous results but also other players results and expected future reactions. It is particularly suitable for markets based on a Pool or for Hybrid markets, to support SAs, BAs and TRs decisions for proposing bids to the Pool and accepting or not a bilateral agreement. The algorithm is based on analysing several bids under different scenarios, constructing a matrix with the obtained results and applying a decision method to select the bid to propose.

4.1.1. Scenarios and Bids Definition. Each agent has historical information about other agents, demand and market price forecasts. To obtain warrantable data, each agent uses techniques based on statistical analysis and knowledge discovery tools. With these data, agents build a profile of other agents containing their probable proposed prices, limit prices and capacities. Based on it, several scenarios are defined and analysed to obtain conclusions about the best way to deal with competitors.

The definition of the proposed bids and scenarios to be analysed is important. For each market player there will be two prices {*limit_pr*, *probable_pr*}, *limit_pr* will be the minimum price, if the player is a SA, and maximum price, if the player is a BA or TR, *probable_pr* will be the previewed proposed price. The number of scenarios each agent needs to analyse, results from the different arrangements that it is possible to establish considering the two prices for each agent, and is given by the formula $2^{(n-1)}$, where n is the number of agents in the model. On the other hand it is necessary to define which bids, or which move, should an agent, or player, analyse. The agent should analyse the incomes it is capable of obtaining by bidding its limit price and by bidding prices, higher (or lesser, if it is a BA or TR) than its limit, that are nearby other agents' proposals, but are a little smaller (or higher, if a BA or TR). So, the agent will try to compete with others by proposing prices that are closer to their probable and limit prices, but are sufficiently smaller to overcome them. The algorithm will be detailed for an agent that represents a SA. The analysis for a demand agent (BA or TR) is symmetrical, since they have opposed objectives.

Let j be the agent that is doing the analysis, cap_j its available capacity, $limit\_pr_j$ its minimum acceptable price and $expected\_pr_j$ its expected price. Let P denote the set of all the players, SAs, BAs and TRs in the market. Lets say ε is the smallest positive number allowed as a bidding increment. The bids agent j must analyse are:

$$\begin{cases} bid(limit\_pr_j, cap_j) \\ bid(expected\_pr_j, cap_j) \\ bid(limit\_pr_i - \varepsilon, cap_j) \\ bid(probable\_pr_i - \varepsilon, cap_j) \end{cases}, \ \forall\ i \in P, i \neq j$$

subject to

$limit\_pr_i - \varepsilon > limit\_pr_j$ AND $probable\_pr_i - \varepsilon > limit\_pr_j$

The maximum number of bids to analyse happens when $limit\_pr_j$ is smaller than every other agent probable or limit price and is given by $(2*(n-1)+2)$. We will call a *play* to a pair bid – scenario. The total number of *plays* to analyse is *bids_number*scenarios_number*, and the maximum value it can achieve is: $(2*(n-1)+2)*2^{(n-1)}$.

Until now we just considered that agents only bid their limit or expected prices, however, an agent may bid prices between its limit and probable price, or even above it, so, if we consider each agent may bid *np* prices, the number of scenarios becomes: $np^{(n-1)}$, and the number of *plays* to analyse $(np*(n-1)+2)*np^{(n-1)}$. Even in a model with few players the number of *plays* can be high. For example, with 4 players, considering 3 different prices for each, to do this analysis a maximum of 1134 *plays* needs to be analysed! Furthermore, since the market is organized in several periods, after each negotiation period an agent may increase, decrease or maintain its bid (3 possible actions), increasing the number of scenarios to analyse. After k periods, considering the possible bid updates, the number of *plays* the agent has to analyse becomes: $(np*(n-1)+2)*np^{(n-1)}*3^{(k-1)*(n-1)}$.

Considering a 4 players, 3 prices example, after 3 negotiation periods, an agent needs to analyse 7 440 174 *plays*. It becomes an enormous number of *plays*, even for a distributed execution of the model. But, is it important to analyse every possible scenario? Since our simulator is intended as a Decision Support tool, the user should have the flexibility to decide which scenarios, and how many, are important to analyse. To do so, the user must define the scenarios to be simulated by specifying the price agents will propose:

$Price_i = \lambda * Probable\_Price_i + \varphi * Limit\_Price_i$, where λ and φ are scaling factors that can be different for each agent. Suppose that the user selects λ=0 and φ=1 for every Seller and λ=1 and φ=0 for every Buyer, this means she/he is interested in analysing a pessimistic scenario. But, if she/he selects λ=1 and φ=0 for every Seller and Buyer, she/he is interested in analysing the most probable scenario! With this formula the user can define for each agent the proposed prices for every scenario she/he wants to be considered. If the user defines *nc* scenarios, the number of plays to analyse is $(nc*(n-1)+2)*nc$.

After all *plays* are analysed, a matrix will be constructed, with the results obtained, and a Decision Method will be applied to decide which bid to propose.

4.1.2. Decision Method. The analysis of the matrix with the results of the simulated *plays* is inspired in the Game Theory [9] concepts for a Pure Strategy Game of two players, considering each player seeks to minimize the maximum possible loss or maximize the minimum possible gain. A SA, like an "offensive" player, will try to maximize the minimum possible gain, so a Seller will use the MaxiMin decision method. A BA or TR, like a "defensive" player, will select the strategy with the smallest of the maximum payoffs; so, it will use MiniMax decision method. The matrix analysis for BAs and TRs is done taking into account that only situations where it is possible to buy all the consumption needs are selected, to avoid situations where an agent will select an option with a reduced payoff but that not satisfies completely its consumption needs. After the Decision Method is applied the agent has selected one bid, which it will propose on the Pool, unless it reaches an agreement for a Bilateral Contract profitable than the previewed Pool results. This analysis gives the agent not only decision support about the best bid to propose in a Pool but also makes possible the improvement of the negotiation mechanism for establishing Bilateral Contracts, since the agent can evaluate the benefits it can get from a Bilateral Contract, compare it to the benefits expected in a Pool and make counter-proposals.

4.1.3. Scenarios and Bids Actualisation. The analysis of the negotiation period results will update the *Market Knowledge* of the agent and the scenarios to study. After each negotiation period, instead of considering each agent may increase, decrease or maintain its bid, agents use knowledge rules, that restrict modifications based on the expected behaviour of agents. Some example rules to update SAs behaviour are the following:

- *If a Seller bid is higher than market price, and higher than its limit price ⇒ the agent will decrease its bid*;
- *If a Seller bid is higher than market price, and equal to its limit price ⇒ the agent will maintain its bid*;

Since, it is not probable that a Seller will increase its bid if it was not able to sell in previous period; and, if it was not able to sell but is already bidding its limit price, then the most likely is that it will maintain its bid. Considering the knowledge rules each scenario is updated, by updating agents' bids, 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 made a wrong evaluation about other agents, then it will carry out a rectification on other agents' profiles, based on the calculated deviation from the real results.

5. Conclusions

We propose an agent-based simulator to study new electricity market rules and behaviours and to analyse their possible evolution. The simulator permits combinations of bilateral trading and power pool markets. In fact, the possibility of simulating several types of markets, and not just a particular one, is an important feature of our simulator. Another important aspect is the strategic behaviour of both Seller and Buyer agents. Considering Buyers with strategic behaviour is a significant advantage in obtaining warrantable results, particularly in markets with Symmetric Pools. The strategies for bid definition are another contribution, namely the *Scenario Analysis Algorithm* based on Game Theory. The inclusion in the model of entities that are emerging in decentralized electricity markets, such as Traders, is another important issue, since it permits to gain insights into the evolution of the market and behaviour of these new entities. This simulator is also a first step to support a future architecture for an electronic marketplace where agents will negotiate with each other substituting the real entities involved in this kind of electricity markets.

6. References

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