# Integrating Virtual Power Producers into MASCEM Simulator

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*Abstract:* - The future vision of the sector considers many decentralized players. Distributed energy resources will provide a significant amount of the electricity generation and will be a normal profitable business, without the need of government incentives and subsidies. In the new decentralized grid, customers will be among the many decentralized players and may even help to co-produce the required energy services such as demand-side management and load shedding. Customers will have a choice to select and collaborate with their preferred supplier. So, they will gain the opportunity to be more active market players.

In this paper we propose the improvement of MASCEM, a multi-agent simulation tool to study negotiations in electricity spot markets based on different market mechanisms and behavior strategies, in order to take account of decentralized players such as distributed energy resources. With this improvement other features, such as local producers' agreements, coalitions formation and its effects on the market, may also be analyzed.

*Key-Words:* - Simulation, Decision-making, Intelligent Agents, Coalitions, Electricity Markets.

## 1 Introduction

Electricity market entities are heterogeneous and autonomous, have their own objectives and follow their business strategies in order to reach them.

Multi-agent systems are adequate to represent the interactions between several different entities, their different behaviors and strategies. Multi-Agent Simulation allows the modeling of decision processes and actions of individual agents (e.g. consumers, generators, regulators), simultaneously with the aggregate system behavior pattern and trends. On the other hand, a multi-agent model can be easily extended without the need to redefine the entire model, since new components, or agents, can be easily integrated. These advantages allied to the traditional simulation advantages make multi-agent simulation a very useful technique to study electricity markets.

All these features led us to develop MASCEM – Multi-Agent Simulator of Competitive Electricity Markets [1], and give electricity market entities a tool to support their decisions and to obtain knowledge about market behavior and evolution. Unlike traditional tools, our Agent-based 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.

With MASCEM several experiences have already been made, leading us to achieve some conclusions and define future developments. One of the most important goals of MASCEM is the simulation of several different electricity market mechanisms.

Due to the emergence of distributed energy resources we are extending MASCEM model to include a Virtual Power Producer agent, which represents the coalition of several producers, acting on the market as a unique entity. There are several questions behind this producer's coalition that must be taken into account to define Virtual Power Producers structure and functioning. In this paper we present our approach for MASCEM evolution.

## 2 MASCEM Overview

MASCEM is a system to study several negotiation mechanisms usually found in electricity spot markets. In Electricity spot markets electricity is traded for each hour, or mid-hour, of the next day. That is why usually these markets are organized in 24 or 48 negotiation periods.

An electricity market's main objective is to decrease the cost of electricity through competition. Several market structure models exist that could help achieve this goal. The market environment typically consists of a Pool, as well as a floor for Bilateral Contracts.

A Pool is a marketplace where electricity-generating companies submit production bids and consumer companies submit consumption bids. A Market Operator regulates the pool. The Market Operator uses a market-clearing tool to set market price and a set of accepted production and consumption bids for each period. In Pools, an appropriate market-clearing tool is an auction mechanism.

Bilateral Contracts are negotiable agreements between two traders about power delivery and receipt. The Bilateral-Contract model is flexible: negotiating parties can specify their own contract terms.

The Hybrid model combines features of Pools and Bilateral Contracts. In this model, a Pool isn't mandatory, and customers can either negotiate a power supply agreement directly with suppliers or accept power at the spot market price. This model therefore offers customer choice.

There are several entities involved in the negotiations, we propose a multi-agent model to represent all the involved entities and their relationships.

MASCEM multi-agent model includes: a Market Facilitator Agent, Seller Agents, Buyer Agents, Trader Agents, a Market Operator Agent and a Network Operator Agent. Three types of markets are simulated: Pool Markets, Bilateral Contracts and Hybrid Markets. Figure 1 illustrates MASCEM multi-agent model.

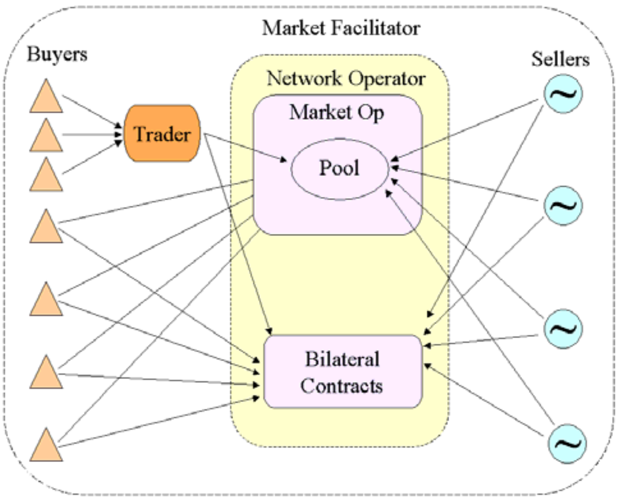


Fig. 1 – MASCEM Multi-Agent Model.

The Market Facilitator 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 Market Facilitator, specifying their market role and services.

Seller and Buyer Agents are the two key players in the market. Sellers represent entities able to sell electricity in the market, e.g. companies holding electricity production units. Buyers may represent electricity consumers or even distribution companies. The user, who must also specify their intrinsic and strategic characteristics, defines the number of Sellers and Buyers 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 Buyer). By strategic characteristics we mean the strategies the agent will employ to reach its objectives.

Sellers 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, Sellers will cooperate with Buyers while trying to establish some agreement that is profitable for both. This is a very rich domain where it is possible to develop and test several algorithms and negotiation mechanisms for both cooperation and competition.

The Network Operator Agent represents the responsible for the transmission grid and all the involved technical constraints. Every contract established, either through Bilateral Contracts or through the Pool, must first be communicated to the Network Operator, who analyses its technical viability from the Power System point of view (e.g. feasibility of Power Flow to attend all needs).

The Market Operator Agent represents the responsible for the Pool mechanism. This agent is only present in simulations of Pool or Hybrid markets. The Market Operator will receive the bids of the Sellers, Buyers and Traders, analyze 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 Network Operator, after, the Market Operator communicates to the Sellers, Buyers and Traders 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 Trader. 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. The increasing role of this type of entity in Electricity Spot Markets, turn it an important feature of our simulator.

# 3 MASCEM Negotiation

The process of negotiation can be of many different forms, such as auctions, protocols in the style of the contract net, and argumentation. MASCEM focuses on mechanisms usually found in Electricity Markets, so it includes the possibility of negotiation through bilateral contracts, through auctions, single and double uniform auctions, and through a hybrid 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 analyzed through different negotiation mechanisms.

## 3.1 Pool

In Pool markets the most common type of negotiation is a standard uniform auction [2]. 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 uniform auction. Both of these types of Pool mechanisms are included in our simulator.

In Pool Markets, the negotiation process starts by the Market Operator, who sends a request for proposals, at the beginning of each negotiation period.

All interested agents, Sellers, Buyers and Traders, reply by sending bids to the Pool. Then, the Market Operator 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 Network Operator. After the processing of all bids and market price established, the results are communicated to Pool participants.

## 3.2 Bilateral Contracts

Bilateral contracts are agreements between a single Seller and a single demand agent (a Buyer or a Trader). 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 Sellers existing in the simulated market. In response, a Seller analyses its own capabilities, current availability, past experience and checks its technical feasibility, through the feedback of the System Operator. Then, it formulates a proposal and sends a message to the demand agent. Demand agents evaluate the received proposals and either accept or reject them.

## 3.3 Bilateral Contracts

In Hybrid Markets a Pool exists simultaneously with Bilateral Contracts [3]. 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 [4]. On Figure 2 the negotiation parameters for both Pool and Bilateral Contracts negotiations are presented.

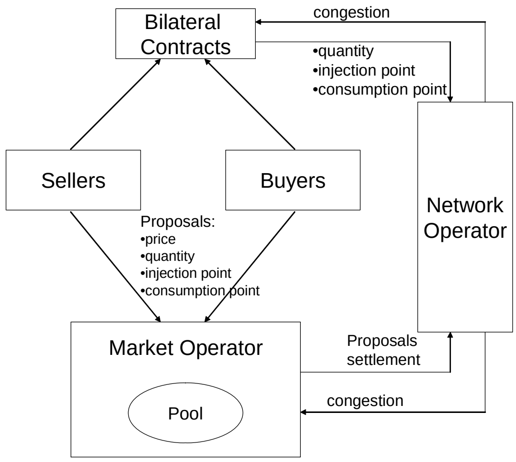


Fig. 2 – Negotiation parameters for Hybrid Markets.

# 4 Agents Strategic Behavior

On the basis of the results obtained in a negotiation period Sellers, Buyers and Traders revise their strategies for the next period. Seller, Buyer and Trader Agents have strategic behavior to define their desired price.

## 4.1 Dynamic Strategies

Agents have time-dependent strategies, to change the price according to the remaining time until the end of the negotiation period; and behavior-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 [5], they are very important since they allow the simulation of important issues such as: emotional aspects and different risk behaviors. For example: an agent using a Determined Strategy is a risk indifferent one; while Gluttonous agents exhibit the behavior 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 behavior-dependent strategies, two different strategies were implemented: one called Composed Goal Directed and another called Adapted Derivative Following, see details in [4]. These are important strategies that use the knowledge obtained with past experiences to define bid prices for next periods.

### 4.2 Scenario Analysis Algorithm

To obtain an efficient decision support, Seller and Buyer agents also have the capability of using the 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 Sellers, Buyers and Traders decisions for proposing bids to the Pool and accepting or not a bilateral agreement. The algorithm is based on analyzing several bids under different scenarios, constructing a matrix with the obtained results and applying a decision method to select the bid to propose.

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

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 [6].

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 fulfill all their consumption needs. They avoid situations in which agents will accept reduced payoff but can't satisfy their consumption needs completely.

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 behavior.

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 analyzing market results — that it incorrectly evaluated other agents' behavior, it will fix other agents' profiles on the basis of the calculated deviation from real results.

## 5 Virtual Power Producers

The development of new low emission generation technologies (wind generation, solar cells, fuel cells, micro-turbines) leads us to rethink the location of a significant part of the production: distributed generators owned by decentralized players will provide a significant amount of the electricity generation.

A deregulated market where every single low power rating generation unit sells its power on the market would be optimal for the whole community both economically and technically.

However, there are serious barriers to the successful participation of these generators in the market. Effectively, the characteristics of the technologies used in Distributed Generation, are usually dependent on not controllable factors such as wind, sun or waves. Also, there are problems related to energy commercialization by small units, which in many situations do not exceed some MW, since the commercialization cost will be very relevant and these units may loss competitiveness.

An aggregating strategy can enable owners of DG to gain technical and commercial advantages, making profit of the specific advantages of a mix of several generation technologies. In this context serious disadvantages of some technologies can be overcome.

The aggregation of DG plants gives place to a new concept: the Virtual Power Producer (VPP).

VPPs are multi-technology and multi-site heterogeneous entities. In the scope of a VPP, producers can make sure their generators are optimally operated and that the power that is not consumed in their installation has good chances to be sold on the market. At the same time, VPPs will be able to commit to a more robust generation profile, raising the value of non-dispatchable generation technologies.

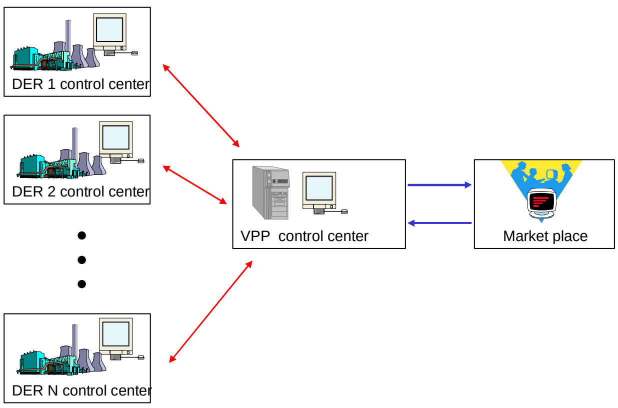


Fig. 3 – Virtual Power Producers.

Under this context, VPPs can ensure secure, environmentally friendly generation and optimal management of heat, electricity and cold and optimal operation and maintenance of electrical equipment, including the sale of electricity to the energy market.

To include this type of units MASCEM model must be updated. The model will be enlarged and a VPP agent included. This agent will be a kind of Producers Coalition Leader, acting on the market on behalf of all the coalition members.

## 5.1 Coalitions in Multi-Agent Systems

Coalition formation is an important form of interaction in multi-agent systems. Coalition formation is the coming together of a number of distinct, autonomous agents in order to act as a coherent grouping in which they increase their individual gains by collaborating [7]. Coalition formation process can be viewed as being composed of the three main activities [8]:

- Coalition structure generation: forming coalitions of agents such that those within a coalition coordinate their activities, but those in different coalitions do not;
- Optimization of the value of each coalition: pooling the resources and tasks of the agents in a given coalition to maximize the coalition value;
- Payoff distribution: dividing each coalition's value among its members.

Coalitions have been advocated in e-commerce (where buyers may pool their requirements in order to obtain bigger discount groups [9]), in grid computing (where multi-institution virtual organizations are viewed as being central to coordinated resources sharing and problem solving [10]), and in e-business (where agile groupings of agents need to be formed in order to satisfy particular markets niches [11]).In all of these cases, the formation of coalitions aims to increase the agents abilities to satisfy goals and to maximize their personal, or the system, outcomes.

## 5.2 Coalitions in MASCEM

A kind of negotiation mechanism regarding coalition formation will be included in MASCEM, and strategies will be developed considering the three phases of a coalition's formation process. Some important parameters will be the localization of the distributed resources, their technology, load, generation and price forecasts.

VPP agent will have the same market interface as Seller or Buyer agents. According to its members generation capabilities and consumption needs for a given period the agent will need to sell or buy electricity.

There are some preliminary steps to define its proposals. First all the capacity available from the different dis-tributed energy resources must be gathered, to establish the electricity amount to trade on the market, and the different production costs analysed to define the interval for acceptable proposals. This means VPP agents will have a utility function that aggregates all the involved units' characteristics. The analysis of received proposals will be done according to each unit capabilities and costs.

## 6 Conclusion

This paper describes the use of an agent-based simulation approach to understand a complex system.

We have made a short description of MASCEM, a multi-agent simulator to study electricity spot markets. We propose the inclusion of another agent in the model, the Virtual Power Producer, to represent distributed energy resources. With the inclusion of this agent in the model other features, such as coalition formation, based on the characteristics and generation profiles of producers, local producers agreements, and its effects on the market, may also be analyzed.

The multi-agent technology allied to an object-oriented implementation enables easy future improvements and model enlargement.

The electric power industry provides a very rich domain for illustration, but there are many other areas where these ideas could also be fruitfully applied.

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