Abstract – This paper presents MASCEM - a multi-agent based electricity market simulator. MASCEM uses game theory, machine learning techniques, scenario analysis and optimization techniques to model market agents and to provide them with decision-support.

This paper mainly focus on the MASCEM ability to provide the means to model and simulate Virtual Power Players (VPP). VPPs are represented as a coalition of agents, with specific characteristics and goals.

The paper details some of the most important aspects considered in VPP formation and in the aggregation of new producers and includes a case study based on real data.

Keywords - Decision-making, Distributed Generation, Electricity Markets, Intelligent Agents Coalitions, Virtual Power Producers, Virtual Power Players

I. INTRODUCTION

The increase of distributed generation (DG) has brought about new challenges in electricity markets and in DG units operation and management.

Despite the favorable scenario to DG growth, there are important aspects to consider, both of economic and technical nature. Issues such as the dispatch ability (namely in wind and photovoltaic technologies), the participation of small producers in the market and the maintenance high cost require further attention. Virtual Power Producers are composed of multi-technology and multi-site heterogeneous production entities, which can enable overcoming some of these problems. They can also aggregate consumers and other energy resources such as storage, becoming Virtual Power Players (VPP).

This paper presents a market simulation tool, MASCEM (Multi-Agent Simulator of Competitive Electricity Markets), which models several electricity market mechanisms. Agents, representing the different independent entities in Electricity Markets, are allowed to establish their own objectives and decision rules. They have dynamic strategies that consider other agents' behavior, learning from past situations and agents' past actions. MASCEM uses game theory, machine learning techniques and scenario analysis to model market agents.

MASCEM includes simulation modules to deal with VPP operation, from production and load forecasting to real-time operation, after market clearance and generation dispatch. These tools provide resources for the set of tasks that VPP have to deal with, including reserve management, strategic bidding and producers’ remuneration.

This paper mainly focus VPP formation and producers’ aggregation. These must take into account VPPs’ strategic goals. MASCEM considers producers’ classification, determined by each VPP, as well as the identified VPP needs, according to their importance in the considered context.

MASCEM treats VPPs as agent coalitions, so VPP formation uses the process used in multi-agent systems for coalition formation. This attends to general goals of coalitions as well as to specific goals of the VPP.

Section 2 explores the concept of VPPs and producers aggregation and Section 3 gives an overview of MASCEM. Section 4 deals with coalitions, in the context of multi-agent systems, detailing its use for VPP modeling in MASCEM. Section 5 presents a case study and, finally, section 6 presents the most relevant conclusions of the paper.

II. VIRTUAL POWER PRODUCERS

In the scope of a VPP, producers can make sure their generators are optimally operated and that the energy has a good chance of being sold on the market. At the same time, VPPs are able to commit to a more robust generation profile, raising the value of non-dispatchable generation technologies [1].

Under this context, VPPs can ensure secure and environmentally friendly generation and optimal management of heat, cold and electricity. They can also provide the means to ensure optimal operation, maintenance of generation equipment and electricity market participation.

In practice, VPPs will have three distinct fields of activity:
1) Energy markets - In this area VPPs have the function of a trading floor with intentions of selling the maximum energy to brokers at the best price at a particular moment, guaranteeing the supply security. VPPs will have to define delivery points, as well as possible alternative scenarios to account for variations of their associates’ generation. VPPs can also act in ancillary services markets;
2) Aggregated producers - VPPs act as a dispatch center, determining the power delivered by each associated producer;
3) Parallel markets - VPP can negotiate in other business areas such as carbon markets and selling the hot/cool water obtained with some DG technologies.
In a deregulated market, generation is scheduled through an open wholesale market where large amounts of electrical energy are traded daily. Today, market places are organized across one or several countries, each market having its own set of rules.

Current electricity markets have effectively implemented real-time and day-ahead markets. VPPs should adopt organization and management methodologies so that they can make DG a really profitable activity able to participate in these markets [2].

The energy produced by distributed producers at different locations can be delivered to the grid. This energy can be produced by a micro generation unit, with several tens of kW, where the customer uses the LV grid. Alternatively, it can be directly injected in transmission or distribution networks by a larger generation plant.

So that the virtual power producer is an entity able of coexisting with the other market agents, it is necessary that it obtains profits and credibility. VPP’s results obviously depend, on a great extent, on the producers associated with it. This is why the issues of coalition formation and the aggregation of new producers should be carefully treated.

### III. MASCEM – A MULTI-AGENT ELECTRICITY MARKET SIMULATOR

MASCEM is a modeling tool with the purpose of studying complex restructured electricity markets operation. It provides market players with simulation and decision-support resources, able to give them competitive advantage in the market.

As market players are complex entities, having their very own characteristics and objectives, making their decisions and interacting with other players, MASCEM was developed as a multi-agent based simulation tool, modeling the complex dynamic market players, including their interactions and medium/long-term gathering of data and experience. MASCEM uses game theory, machine learning techniques, scenario analysis and optimization techniques to model market agents and to provide them with decision-support [3].

MASCEM purpose is to be able to simulate as many market models and players types as possible so it can reproduce in a realistic way the operation of real electricity markets. This enables it to be used as a simulation and decision-support tool for short/medium purposes but also as a tool to support long-term decisions, such as the ones taken by regulators.

The presented model includes the following entities as part of the Multi-Agent System (MAS): Buyer Agents, Seller Agents, Virtual Power Producers (VPP) Agents, VPP Individual Facilitator Agents, a Market Facilitator Agent, a Market Operator Agent and a System Operator Agent. All these entities play a distinct and equally important role in the simulation. However, Buyer, Seller and VPP Agents benefit from highlighted positions, as these are players with high influence over price definition, and consequently over the global revenues and respective profits. Our main focus is directed to these agents, their interactions and strategies.

Figure 1 presents the MASCEM global structure, with the representation of its most important entities and interactions.

### A. Market Mechanisms

MASCEM includes several negotiation mechanisms usually found in electricity markets. 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. MASCEM can simulate several types of markets, namely: Forward Markets, Pool Markets, Balancing Markets and Bilateral Contracts [4].

Forward contracts, which are a significant part of electricity trading, play a crucial role in the electricity market. These are contracts that fix prices now for electricity that will be supplied later, and enable speculation on future price development or hedging.

Power exchanges established the trade of forward and futures contracts early on and, by now, large volumes are being traded. A power forward contract is characterized by a fixed delivery price per MW, a delivery period and the total amount of energy to be delivered. One can observe that contracts with a long delivery period show less volatile prices than those with short delivery periods [5].

VPP Forward Market operation will be limited by the aggregated producers. If the VPP has many producers whose generation depends on natural resources, it is complicated to establish forward contracts because the guarantee of the energy supply is low.

In day-ahead electricity markets electricity is traded for each hour, or mid-hour of the next day. The energy price in balancing markets can obviously be different from the day-ahead market price enabling the VPP to incur in damages or profits.

### B. Market Agents

Competitive electricity markets involve several entities interacting in complex negotiations [6]. These entities are of very different types and can be complex organizations involved in difficult decision making processes. Attending to these, we propose a multi-agent model to represent all the involved entities and their relationships [7].

MASCEM includes the following types of agents: Market Facilitator Agent; VPP Facilitator Agent; Seller Agents; Buyer
Agents; Trader Agents; VPP Agents; Market Operator Agent; System Operator Agent; Market Regulator Agent.

This architecture has two types of facilitators, the Market Facilitator and the VPP Facilitator, and allows the evaluation of several scenarios, according to market agents and to VPP’s strategies. Moreover, as the simulation progresses, agents can adapt their strategies, based on the success or failure of their previous actions.

Facilitators are used in the scope of MAS in order to ease relationship management; they do not directly correspond to physical entities in the market [8].

The Market Facilitator coordinates the market. It knows the identities of all agents present in the market, regulates the negotiation process and ensures the market is functioning according to the established rules. The first step agents have to make in order to participate in the market is to register them at the Market Facilitator, specifying their market role and services.

The VPP Facilitator supports VPPs business. It gathers information about generation agents, both those who are playing in the market and those who are not. This information is relevant for VPP business because some producers of reduced dimension cannot participate separately in the market, but can be associated to a VPP.

The VPP Facilitator manages the information between the producers, and the VPP in the VPP aggregation process and in its operation process. The VPP Facilitator informs the Market Facilitator about new agreements between producers and VPPs.

Seller and Buyer Agents are two key players in the market. Sellers represent entities able to sell electricity in the market (e.g. companies holding electricity generation units and VPPs). Buyers may represent electricity consumers, consumer aggregators, retailers, etc.

MASCEM can be used by any type of market agent to simulate the envisaged scenarios and to obtain decision support for operation in the market. The user must specify his intrinsic and strategic characteristics and defines the number of Sellers, Buyers and VPPs in each scenario. By intrinsic characteristics we mean the individual knowledge related to reserve and preferred prices, and also to the available capacity. By strategic characteristics we mean the strategies that the agent envisages to employ to reach his objectives.

In the case of use of MASCEM by a regulator, the regulator agent assumes itself as an entity able to introduce regulation changes in the market and MASCEM simulates the behavior of the other agents according to these changes. Regulators can also use MASCEM to play the role of any other type of agent in order to analyze market operation, in face of established rules and according to each agent strategy.

Sellers will compete with each other, since they aim obtaining the highest possible profits. 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 Independent System Operator (ISO) Agent 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 System Operator, who analyses its technical viability from the power system point of view (e.g. feasibility of power flow without technical constraint violation, as congestion management).

The Market Operator Agent represents the entity that is responsible for the Forward, Pool and Balancing mechanisms. The Market Operator will receive the bids of the Sellers, Buyers, Traders and VPPs, analyze them and establish the market price and accepted bids (using the offer and demand aggregated curves).

The increase in competitiveness creates opportunities for many new players to enter the market; one of these players type being the Trader. The introduction of this entity allows liberalization and competition in the electricity industry to be developed. It can also simplify the whole process for some entities, freeing some producers and customers from participating directly in the market, allowing them to focus on their core business. Traders participate in the market on behalf of customers acting as an intermediary between them and the market. Players can delegate to the trader the selling of their production or the purchasing of their needs. The increasing role of this type of entity in Electricity Markets turns it into an important feature of our simulator.

C. VPP Agents

From the point of view of the multi-agent system, VPP are seen as coalitions of agents, requiring specific procedures for coalition formation. Once a coalition is established, it can aggregate more agents or even discard some agents. This model allows modeling all the decision making concerning VPP formation and also subsequence aggregation of more producers.

To take decisions about these issues, VPPs have to detain knowledge related with the existing producers, which can eventually be aggregated. Decisions concerning VPP formation and aggregation of new producers result mainly from two distinct matters. On one hand, each VPP classifies the producers according to a set of criteria defined by itself. On the other hand, it establishes the goals of VPP formation or of aggregation of more producers, according to its operating strategies and to its necessities at the moment. Aggregation proposals are then elaborated in function of the resulting knowledge.

MASCEM considers that VPPs can also aggregate consumers, what means that they can act in the market both as sellers and as buyers, according to their needs in each period.

Considering the VPP formation process finished, the VPP needs to co-ordinate its operation. The VPP must place bids in the market, considering the contracts with producers, the generation forecast, the reserves and its market strategy.

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

However, as VPPs are themselves a set of other agents, there are some preliminary steps to define their bids.

Firstly, all the capacity available from the different aggregated distributed energy resources must be gathered to establish the electricity amount to trade on the market. The different generation costs must be analyzed to define the interval for envisaged proposals. This means VPP agents will have a utility function that aggregates all the involved units’
characteristics. The analysis of the aggregated producers’ proposals will be done according to each unit capabilities and costs.

After the market session, the VPP agent undertakes an internal dispatch, analyzing and adjusting its generation and reserve to maximize profits. The VPP informs the aggregated producers about their dispatch.

Finally, in function of the generation, the used and unused reserve of each producer and the established contracts of the VPP fulfillment, the VPP determines the producers’ remuneration [9].

IV. COALITIONS

A. 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 [10]. Coalition formation process can be viewed as being composed of three main activities [11]:

1) Coalition structure generation: forming coalitions of agents such that those within a coalition coordinate their activities, but those in different coalitions do not;

2) Optimization of the value of each coalition: pooling the resources and tasks of the agents in a given coalition to maximize the coalition value;

3) 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 [12]), in grid computing (where multi-institution virtual organizations are viewed as being central to coordinated resources sharing and problem solving), and in e-business (where agile groupings of agents need to be formed in order to satisfy particular markets niches [13]). 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’s, outcomes.

B. Coalitions in MASCEM

MASCEM includes a negotiation mechanism regarding coalition formation which considers the strategies associated with the three phases of a coalition’s formation process.

The producer’s selection criteria are different for each VPP, depending on the dimension and on the already aggregated producers.

In MASCEM VPPs are classified according to the following five different types:

1) Parallel VPP (PVPP) – Include different producers with distinct generation capacities, typically upper to 1MW and lower than 20 MW. The common characteristic is the participation in parallel markets;

2) Large Scale VPP (LSVPP) – These are constituted by producers with large generation capacity, typically higher than 10 MW;

3) Micro VPP (µVPP) – These are constituted by many producers with small capacity, typically lower than 2 MW;

4) Global VPP (GVPP) – This type of VPP aggregates both producers and consumers, assuming the function of a trader;

5) Several VPP (SVPP) – This VPP does not present a defined characteristic so that it allows users to create more specific VPPs.

Decision making for VPP formation and subsequent aggregation of more producers takes into account a large set of producers’ characteristics (listed in the first column of table I). The weight of each of these characteristics depends on the VPP type, as shown in table I.

These weights are based on economic criteria and on VPP market strategies. The characteristics weight ranges from 0 to 10.

These values have been determined based on a set of a priori analyzed cases, considering possible VPP strategies and are used by MASCEM as default values. However MASCEM users can modify these values to adjust the VPP strategy according to their own needs.

The user also has the possibility of developing and simulating scenarios in which VPPs change their aggregated producers, in order to improve VPP strategy in function of market evolution.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>PVPP</th>
<th>LSVPP</th>
<th>µVPP</th>
<th>GVPP</th>
<th>SVPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speculative energy cost</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Dispatchability</td>
<td>7</td>
<td>9</td>
<td>7</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Reliability</td>
<td>7</td>
<td>8</td>
<td>2</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Use of installed power</td>
<td>5</td>
<td>7</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Lifespan</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Volatility of prices</td>
<td>7</td>
<td>8</td>
<td>3</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>2nd Market</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>GHG emissions</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Location</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Dimension</td>
<td>4</td>
<td>3</td>
<td>8</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Technology type</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Social Impact</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Maturity of technology</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Commercial behavior</td>
<td>5</td>
<td>6</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

The classification structure has been integrated with MASCEM simulator with the purpose of being tested in an actual market simulator, and so allowing to derive conclusions about the efficiency of this procedure, and about the development of the behavior of the VPPs when including such mechanisms. We expect this new feature to prove to be a real added value to the intelligence of the VPP agents, by increasing their ability to take the best decisions when confronted with particular situations (in this case, the election of the producers who would be a greater asset to the coalition in the present and future, and contribute the most to the achievement of its objectives).

The integration in MASCEM has been done through the implementation of this mechanism in LPA-Prolog, and its inclusion in the private facilitator of each VPP. This facilitator is also implemented in Prolog and has the responsibility of managing the communications with the agents that form the coalition.

The features of this new mechanism are:

- The registration of new VPP types - There are five standard VPP types defined at first. They present static
factor weights, for an easier choice when a new VPP is created. Additionally, at the time of creation of a new VPP, we have the choice of defining a new VPP type, naming it, and attributing the desired weights for the factors presented before. This allows the new VPP to present the best possible suiting to the objectives that it ought to have;

- The classification of producers that intend to join the aggregation - A new producer that desires to be a part of a particular VPP must at a first instance provide all the data necessary for its classification concerning the VPP’s goals, characteristics, and constituents. Each producer that sends its request for entering the VPP is awarded a classification that can vary from -2 to 2;

- The acceptance or refusal of a producer application - Depending on the strategy adopted by each VPP, the applicant producers will be accepted or refused in the coalition. This acceptance process can be based on an a priori defined limit for the minimum classification for which the coalition will allow the new producer to be aggregated. Moreover, the VPP can also define a maximum number of members to be part of the coalition, refusing the entrance of all that apply when that number is reached. Alternatively, a VPP can accept all the applicants, assuming that each one can be an asset for the growth of the coalition.

When a new VPP is created in the simulator, it is required to define the various aspects that will characterize its objectives and desired orientation in the market. These factors and preferences will be the basis for the classification of each producer that intends to join this aggregation, together with the producer’s individual characteristics. These characteristics are also required when a new producer is created.

Once a producer makes its application to join a certain VPP, all the information is sent to that VPP’s facilitator, which will be responsible for its classification, and for the acceptance/refusal of the application. If it is accepted, it will from that point on be a member of the coalition.

V. CASE STUDY

In this case study we consider 11 producers of OMEL (Spanish electricity market) with several technologies. The main goal is that the VPP chooses the best producers to aggregate, according to its initial objectives.

The tables of producer’s characteristics and VPP objectives can be found in following link: www.gecad.isep.ipp.pt/ies/casestudies/coalitions.pdf.

Using the proposed method for the classification with the inputs being the historical values from the various producers, combined with the VPP’s data shown before, originates an individual classification for each of the producers, and consequent proposal results (entrance in the coalition being accepted or refused).

Table II shows the classification assigned by the VPP to the producers that proposed to enter the aggregation.

<table>
<thead>
<tr>
<th>Candidates</th>
<th>Classification</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biblioteca</td>
<td>9.09</td>
<td>Yes</td>
</tr>
<tr>
<td>Facultad</td>
<td>9.21</td>
<td>Yes</td>
</tr>
<tr>
<td>Iberdrola</td>
<td>18.11</td>
<td>Yes</td>
</tr>
<tr>
<td>Zorreras</td>
<td>21.96</td>
<td>Yes</td>
</tr>
<tr>
<td>Espiel</td>
<td>6.89</td>
<td>Yes</td>
</tr>
</tbody>
</table>

VI. CONCLUSIONS

Competitive electricity markets have been in operation in several and very different points of the globe for some years. Experience shows that their good performance is crucial for obtaining good results from power systems deregulation, both in terms of prices and power reliability.

Successive changes have been introduced in the power and energy sector, as an increasing penetration of distributed generation (DG), mainly based on renewable primary sources. As environment and sustainability concerns are also increasing, DG has gained a stronger importance. Virtual Power Producers, aggregating mainly producers based on DG, are seen as a good platform to increase the use of clean energy and reinforce its role in the market.

This paper presented MASCEM, an electricity market simulator able to model market players and simulate their operation in the market. As market players are complex entities, each one with its own characteristics and needs, which must take their own decisions interacting with other players, a multi-agent architecture is used and proved to be adequate. This architecture includes learning capabilities, so that players are able to redefine their strategies according to their past experience (both real and simulated), considering also other agents’ behavior.

MASCEM architecture has recently been improved to provide the means for VPP modeling and simulation. MASCEM includes simulation modules to deal with VPP operation, from production and load forecasting to real-time operation, after market clearance. These tools provide resources for the set of tasks VPPs have to deal with, including reserve management, strategic bidding and producers’ remuneration.

This paper has mainly focused on VPP formation and producers aggregation. In fact, this must take into account strategic goals as VPP formation and aggregation should be the means to attain these goals.

MASCEM provides a very flexible and rather complete platform to undertake electricity market simulation. It can efficiently provide market players with competitive advantage and adequate decision-support. With the recent enhancement of modeling and simulating VPP formation and operation, it can also provide a powerful tool to support DG integration in competitive markets.

VII. REFERENCES


