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***Abstract*— Electricity Markets are not only a new reality but an evolving one as the involved players and rules change at a relatively high rate. Multi-agent simulation combined with Artificial Intelligence techniques may result in very helpful sophisticated tools. This paper presents a new methodology for the management of coalitions in electricity markets. This approach is tested using the multi-agent market simulator MASCEM (Multi-Agent Simulator of Competitive Electricity Markets), taking advantage of its ability to provide the means to model and simulate Virtual Power Players (VPP). VPPs are represented as coalitions of agents, with the capability of negotiating both in the market and internally, with their members in order to combine and manage their individual specific characteristics and goals, with the strategy and objectives of the VPP itself. A case study using real data from the Iberian Electricity Market is performed to validate and illustrate the proposed approach.**

***Index Terms*—Electricity markets, intelligent decision making, multi-agent simulation, virtual power players**

I. Introduction

The increasing fossil fuels shortage and the consequent increase of its price, supported by the implied environmental concerns that this type of fuel brings, led to a direct increase in the use of renewable energy resources. From the environment point of view the advantages of using renewable energy resources are clear. However, despite the favourable scenario to the distributed generation (DG) growth, there are important aspects to consider, both of economic and technical nature. Issues such as the dispatchability (namely in wind and photovoltaic technologies), the participation of small producers in the market and the maintenance high cost, are problems that must be overcome to take advantage of an intensive use of DG [1].

Aggregating strategies can enable owners of renewable generation to gain technical and commercial advantages, achieving higher profits from the specific advantages of a mix of several generation technologies and overcoming serious disadvantages of some technologies.

The aggregation of DG plants gives place to a new concept: the Virtual Power Player (VPP). VPPs are multi-technology and multi-site heterogeneous entities. In the scope of a VPP, producers can ensure their generators are optimally operated. At the same time, VPPs will be able to commit to a more robust generation profile, raising the value of non-dispatchable generation technologies [2].

To explore and study different approaches in dealing with these issues simulation tools are often used. Several modelling tools directed to the study of restructured wholesale power markets have emerged in the last years. Some relevant tools in this domain are “AMES” [3], and “EMCAS” [4]. For this purpose we use the MASCEM (Multi-Agent System for Competitive Energy Markets) [5, 6] simulator, which is a modelling and simulation tool that has been developed with the purpose of studying complex restructured electricity markets operation. It provides market players with simulation and decision-support resources, being able to give them competitive advantage in the market. Agents, representing the different 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.

This paper addresses the operation of VPPs in the scope of the MASCEM simulator. The management of a VPP coalition must begin by providing adequate means for choosing the players that are more suitable to enter the aggregation [6]. For that a classification mechanism is presented, which analyses each player’s characteristics and tests their suitability to the VPPs objectives. This process provides the VPP with the knowledge of which producers are most likely to favorably contribute to the VPPs’ achievement of better results, and so allowing the VPP to decide which producers to aggregate or not in each moment. When stabilizing on a coalition, an internal negotiation is performed between each VPP and its aggregated members considering the forecasted generation of all the producers and their expected transaction prices [7]. After this internal dispatch, the VPP represents the aggregated members in the electricity market, where the necessary power

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is sold or bought. This means that adequate and fair profits distribution methodologies must also be developed, taking into account the classification value that each member was awarded, in addition to the amounts of energy that it produced.

After this introductory section, Section II presents an overview of the MASCEM simulator, including the considered market types and participating entities. Section III presents the proposed internal negotiation mechanism for VPP's coalitions. This includes the acceptance procedure for candidate players, the internal dispatch and negotiation between the VPP and its members, and finally, the profits and costs distribution among the coalition participants. The proposed methodology is tested and validated in a case study presented in Section IV. This section presents a simulation performed using MASCEM, and a realistic scenario based on real market data from the Iberian market – OMIE [8].

II. MASCEM OVERVIEW

MASCEM (Multi-Agent Simulator of Competitive Electricity Markets) [5, 9] is a modelling and simulation tool with the purpose of facilitating the study of complex electricity markets. The main entities that participate in those markets, such as market players and operators, are considered in MASCEM, and it aims to enable the simulation of the largest possible number of types of players and market models. MASCEM players' can operate in day-ahead (symmetric and asymmetric) and balancing markets, considering both simple and complex bids, as well as in forward markets. Bidding strategies are also available, granting players' competitive advantage in the market and allowing them to achieve the best possible results out of it. The main entities included in MASCEM are a market operator agent, an independent system operator agent (ISO), a market facilitator agent, buyer agents, seller agents, Virtual Power Player (VPP) agents, and VPP facilitators.

The market operator is responsible for the market's negotiation. He analyses and validates the buyer and seller agents' bids according to the negotiation type, determines the market price, the accepted and refused bids, and the economical dispatch which then is sent to the ISO.

The ISO represents the entity responsible for the system's security and to assure that all constraints are met within the system. He analyses the technical feasibility from the power system point of view and solves congestion problems that may occur.

The market facilitator acts as the market coordinator, but only as a computational entity since it does not represent a real market being. Market players register in advance within the market facilitator declaring their roles and services. The market facilitator regulates all existing negotiations, coordinating and assuring the proper market operation.

Buyer and seller agents are the key players of electricity markets. The former may represent electricity consumers or even distribution companies, while the latest represent entities that are able to sell in the market, such as electricity producers.

VPPs [2, 10] are players that represent alliances between smaller independent players, such as small producers, mainly based on distributed generation and renewable sources, or consumers, so they can participate on equal footing with big companies in the market. VPPs provide the proper means to their aggregated players, managing their information, and negotiating in the market representing their aggregates, where they are seen as regular buyer or seller agents.

VPPs are modeled as a coalition of agents which allows installing agents on separate machines, maintaining the best possible performance. VPP facilitators [9] allow achieving such independence by managing the communications between VPPs and their members independently from the rest of the simulation. To participate in the electricity market VPPs send their bids to the market facilitator.

The global structure of MASCEM is presented in Figure 1.

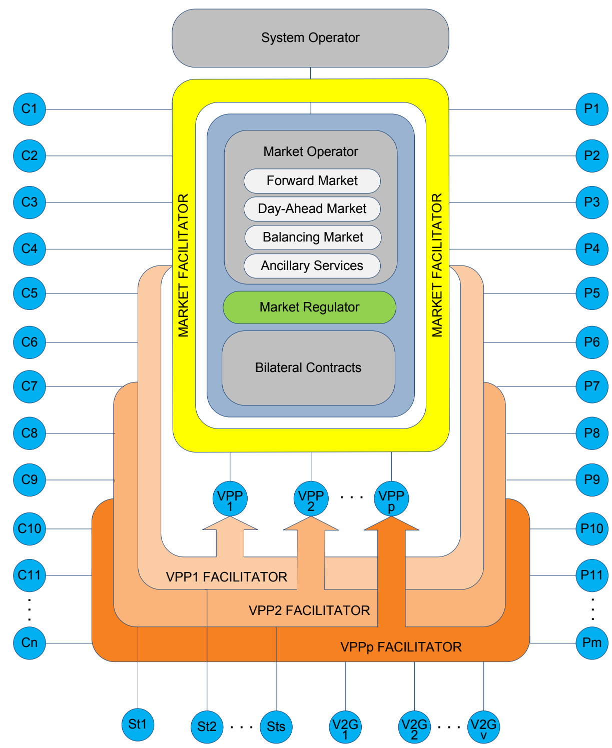

Figure 1 - MASCEM's global structure [11].

The simulation of the following market models are allowed in MASCEM: day-ahead pool (asymmetric or symmetric, with or without complex conditions), bilateral contracts, balancing market, forward markets and ancillary services. Hybrid simulations are also allowed by selecting a combination of the market models listed above.

The user defines the number of buyer and seller agents in each scenario, as well as their intrinsic and strategic behavior for each market type.

III. VPPS INTERNAL NEGOTIATION

Due to environmental and fossil fuels shortage concerns, renewable energy resources are being more used. The advantages of using renewable are clear from the environment point of view. From the technical and economical point of view there are problems that must be overcome to take advantage of an intensive use of distributed generation. An aggregating strategy can enable owners of renewable generation to gain technical and commercial advantages, making profit of the specific advantages of a mix of several generation technologies and overcoming serious disadvantages of some technologies. The aggregation of distributed generation plants gives place to the new concept of VPP. VPPs integration into Electricity Markets is a very challenging domain that motivates our work regarding the evolution of MASCEM to appropriately simulate this entities' operation.

A. Members Acceptance

In order to provide the VPP with the capability of choosing the most appropriate ways to manage its coalition, a classification structure that enables the VPP to choose at each moment the players that are most adequate for the VPP's strategy and goals has been created . The VPP starts by defining its profile, including its characteristics, and then, when a producer requests to join the coalition, it will be classified through a set of formulas that relate the producers' and the VPP's characteristics. At each negotiation period the VPP will choose the best candidates to join the coalition.

The players' 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:

- Parallel VPP (PVPP) – Includes different producers with distinct generation capacities, typically upper to 1MW and lower than 20 MW. The common characteristic is the participation in parallel markets;
- Large Scale VPP (LSVPP) – Includes producers with large generation capacity, typically higher than 10 MW;
- Micro VPP (µVPP) – These are composed of many producers with small capacity, typically lower than 2 MW;
- Global VPP (GVPP) – This type of VPP aggregates both producers and consumers, assuming the function of a trader;
- Several VPP (SVPP) – This VPP type does not have a priori defined characteristics 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 players' 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 they are used by MASCEM as default values [6]. 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 according to the market evolution.

TABLE I - Producers' characteristics weights

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

The classification structure increases VPP's abilities to take the best decisions when confronted with particular situations (in this case, the election of the players who would be a greater asset to the coalition in the present and future, and contribute the most to the achievement of its objectives).

B. Internal Dispatch

The internal negotiation between each VPP and its aggregated members considers the forecasted generation of all the producers and their expected transaction prices.

The VPP manages the resources (distributed generation, demand response and storage systems) of the aggregated players. In this level VPPs have two major goals: the first is to minimize the operation cost by supplying all loads as possible. The second goal is to enforce the established contracts with the aggregated players (producers and consumers). In the developed methodology all relevant aspects are considered, namely the power losses, which are a result of the AC power flow, and the network congestion, which are result of the constraints of lines thermal limits and the bus voltage limits. The solution of the first level is obtained based on a mixed-integer non-linear programming problem [12]. The objective function represents the operation cost of each VPP and it can be represented as in (1) in a simplified way.

$$Minimize\ f = Min\sum_{t=1}^{T}\left[\begin{array}{l}\sum_{G=1}^{Ng} P_{Gen(G,t)} \times c_{Gen(G,t)} + \sum_{S=1}^{N_S} P_{St(S,t)} \times c_{St(S,t)} + \\ +\sum_{L=1}^{Nl} P_{DR(L,t)} \times c_{DR(L,t)}\end{array}\right] \quad (1)$$

$$\forall t \in \{1,..,T\}$$

where G refers to the generation units, S to the storage systems, and L to the loads. $PGen$, PSt and PDR are the power of each generator, storage and load demand response program, respectively. *cGen*, *cSt* and *cDR* are the costs of each resource in period *t*. The problem was implemented in GAMS software [13].

C. Profits Distribution

After the internal negotiations, the VPP is faced with one of two situations: the coalition presents a surplus of power that must be sold dispatched; or that is a lack of power to supply all consumers. This means that the VPP must enter negotiations with other entities to buy or sell the required amounts of power. These negotiations can be conducted through bilateral contracts with other VPPs in nearby control areas, or in the actual market negotiation, in which players submit their bids to the market. Players use the market to sell or buy the energy that they could not negotiate at better prices in other negotiation opportunities. Figure 2 illustrates the VPP process internally, inside its control area (level 1), and externally, negotiating with other VPPs (level 2), and/or in the electricity market (level 3).

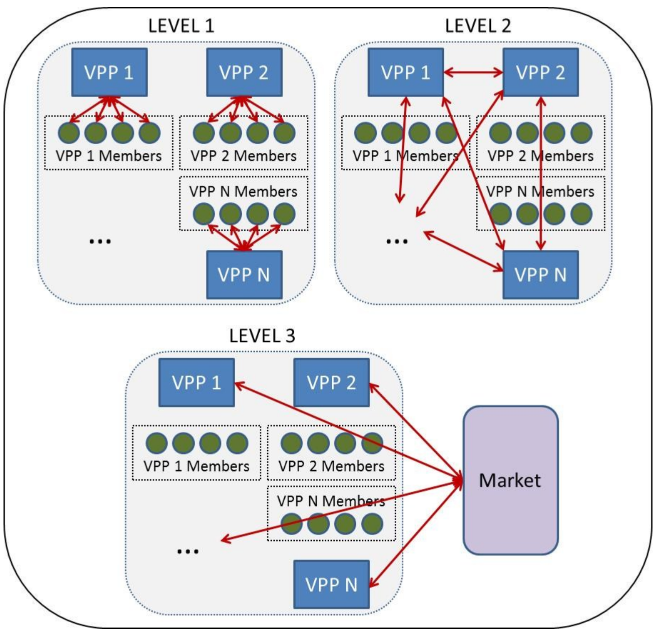

Figure 2 – Internal and external VPP process [7].

After submitting their bids, players wait for the market operator to determine the market price for each period, and the respective traded amounts of energy, according to the conjugation of all participating entities proposals.

The deals that are achieved in the sale of power represent incomes for the VPP. These revenues from all the periods of negotiation must be distributed amongst the members of the aggregation. To manage those transactions, a profits' distribution mechanism determines the amounts of payoff that the VPP members will receive.

This algorithm is based on the total amount of energy that the VPP was able to sell in each period; the market price for that period; and the amount of energy that each producer provided individually, along with the classification awarded by the VPP at the time of its entrance in the aggregation. The use of this mechanism ensures that the payoffs adequately reward the producers that are better classified, and those that produced the most in each period.

Regarding the case when a VPP enters negotiations to buy power, this represents costs, which must also be distributed among the players associated with the coalition. This is done through the settlement of tariffs to the buyer/consumer agents. These tariffs are defined and negotiated every time a player of this type enters the coalition of a VPP. A fixed value for the tariff is settled, and that is the price that the buyer agent will pay for the consumption of power throughout the duration of its contract with the VPP.

IV. Case Study

This section presents a case study that aims to test, validate and illustrate the implemented approach, through a simulation performed in MASCEM. This simulation includes the internal negotiation that occurs inside the VPP, the actual electricity market negotiation, and the profits distribution amongst the members of a VPP.

A. Case Description

The presented case study considers 10 seller agents, 7 buyer agents and 2 VPPs. The data used in this case study is based on real data extracted from the Iberian Market - OMIE [8]. The electricity market simulation is performed for the day-ahead spot market (symmetric pool), referring to Wednesday, 29th October.

The players' bids are defined as follows:

Buyer 1 - This buyer buys power independently from the market price. The offer price is 18.30 c€/kWh (this value is much higher than the average market price);

Buyer 2 - This buyer bid price varies between two fixed prices, depending on the periods when it really needs to buy, and the ones in which the need is lower. The two variations are 10.00 and 8.00 c€/kWh;

Buyer 3 - This buyer bid price is fixed at 4.90 c€/kWh;

Buyer 4 - This buyer bid considers the average prices of the last 4 Wednesdays;

Buyer 5 - This buyer bid considers the average prices of the last 4 months;

Buyer 6 - This buyer bid considers the average prices of the last week (considering only business days);

Buyer 7 - This buyer only buys power if market prices are lower than average market price;

Seller 1 - This seller needs to sell all the power that he produces. The offer price is 0.00 c€/kWh;

Seller 2 - This seller bid considers the average between the average prices of the last 4 Wednesdays and the average prices of the last week (considering only business days);

Seller 3 - This seller bid considers the average prices of the last 4 months with an increment of 0.50 c€/kWh, and it does not include complexity to its offering;

Sellers 4, 5 and 6 - These sellers represent wind farms that offer a fixed value throughout the day. The offer price is 3.50 c€/kWh;

Sellers 7, 8, 9 and 10 – These players represent a wind farm, a photovoltaic, a co-generation and a mini-hydro plant respectively; the offer price is based on generation costs of co-generation and on the total forecasted production.

Finally, VPP 1 aggregates Buyer 1 and Sellers 4, 5 and 6. On the other hand, VPP 2 assembles Buyer 2 and Sellers 3, 7, 8, 9 and 10. The simulation scenario is presented in Figure 3.

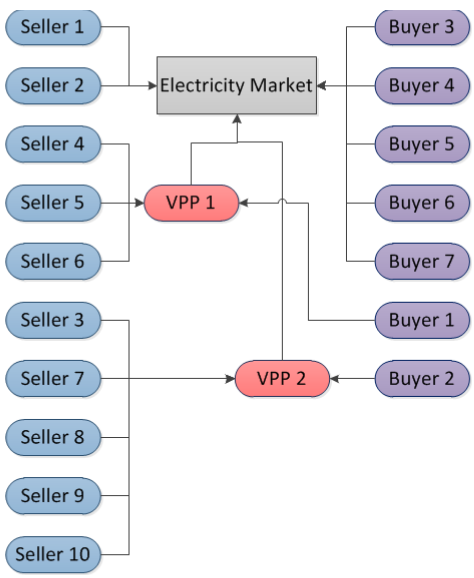

Figure 3 – Simulation scenario structure.

B. *Obtained Results*

After the simulation, it is possible to observe the results graphically in MASCEM.

Regarding the internal negotiation of VPP 1, all sellers sold the available power within the VPP internal negotiation. On the other hand, Buyer 1 couldn't buy all the required energy. Thus, VPP 1 presents a bid in the day-ahead electricity market to satisfy this player's needs. VPP 1 is buying in the market. Figure 4 illustrates the results obtained by Buyer 1.

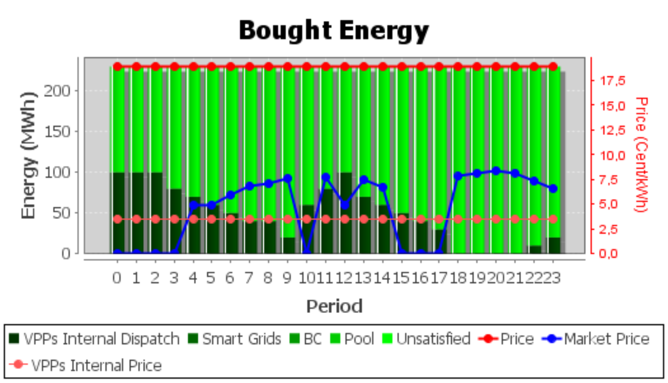

Figure 4 - Buyer 1 results.

As it is possible to observe from Figure 2, most of the energy bought by Buyer 1 was negotiated in the pool market. It is also visible that in some periods the market price is 0.00c€/kWh. This is due to the fact that Seller 1 offered a considerable amount of energy at the price of 0.00c€/kWh, which was enough to satisfy the required power demand.

Resulting from the internal negotiation of VPP 2, Buyer 2 and Sellers 7, 8, 9 and 10 were able to meet their goals. In this case, Seller 3 was the player that did not sell all the available power in the internal negotiation of VPP 2. Thereby, VPP 2 presents an offer to sell in the market. Figure 5 shows the results achieved by Seller 3.

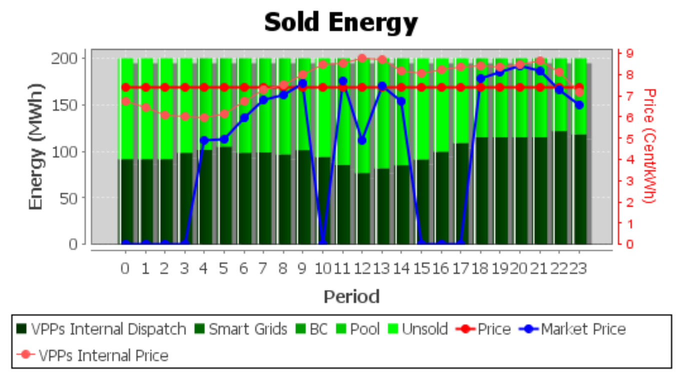

Figure 5 - Seller 3 results.

By analyzing Seller 3 results in Figure 3, it is possible to verify that, unlike Buyer 1, Seller 3 was not able to meet all its goals in the market. This is explained by the fact that the offer of Seller 1 has determined the market price in those periods. Therefore, since the value offered by VPP 2 was higher in those periods, this player was not able to sell in all periods in the market negotiation. This can be seen in Figure 4, where the comparison between the seller agents' bids is presented.

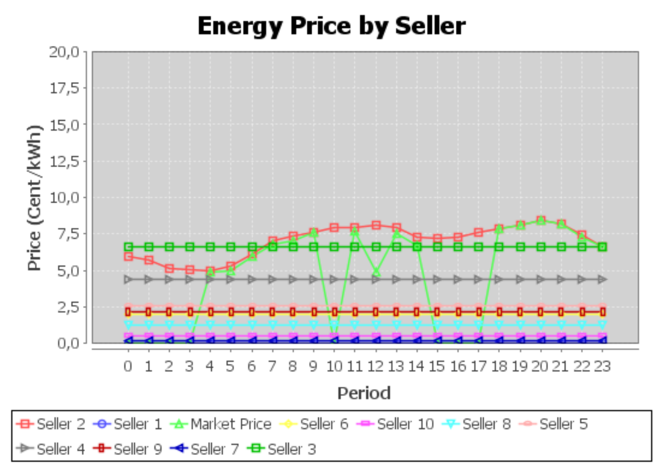

Figure 6 – Sellers bids.

From Figure 4 one can see that the bid of Seller 1 defined the market price in several periods, which originated the sale of power at 0.00c€/kWh in these periods. The individual profits obtained by Seller 3 in the sale of its production are presented in Figure 4.

From Figure 4 it is visible that in spite of not having sold all of its power in the market, Seller 3 was able to achieve higher profits in the periods in which he sold in the market when compared to the profits obtained in the sale inside the VPP's internal negotiation. This is visible by comparing the proportion of the light green bars in Figure 4 to those of Figure 3, which represent the amount of energy sold. Seller 3, as a small player based on a renewable energy source, was only able to achieve such profits through its aggregation to a VPP, that enabled this player to enter the market negotiations, which by his own was not possible.

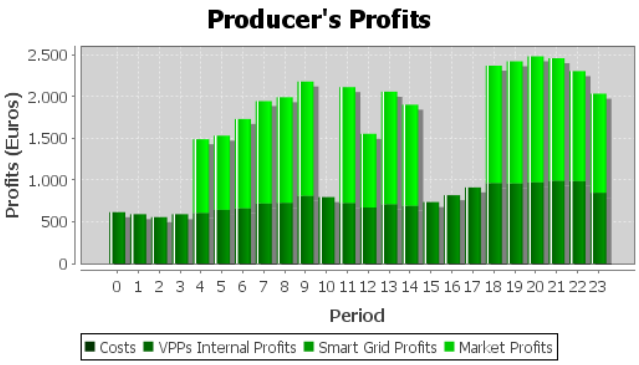

Figure 7 – Seller 3 profits.

From the VPP's point of view, the aggregation of Seller 3 proved to be advantageous since the VPP was able to buy power from Seller 3 in the internal negotiations at a smaller price than the electricity market price, enabling the VPP to achieve higher profits for itself as well.

V. Conclusions

Competitive electricity markets are complex environments, involving a large number of different entities, playing in a dynamic scene to obtain the best advantages and profits. Financial and technical issues must be considered together to assure high levels of power reliability while keeping electricity prices reasonably low.

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

This paper has mainly focused on VPPs' internal negotiation, considering coalition formation, *i.e.*, producers' aggregation, taking advantage of the proposed classification mechanism, and also of the methodologies for internal dispatch and profits distribution.

The proposed mechanisms for classification and coalition entrance and management have proven to be a good asset, and they provide the VPP with a feature that allows it to better adequate its actions to the constantly evolving environment.

The methodology proved to be advantageous both for VPPs and for the aggregated players, as showed in the presented case study. The VPP is able to ensure power at lower prices inside the coalition, while small dimension aggregated sellers gain the possibility to sell power in electricity markets through the VPP. Finally, buyers achieve fixed costs for the consumption of power, being less subject to electricity prices' constant changes.

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