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Multi-agent simulation of competitive electricity markets: Autonomous systems cooperation for European market modeling

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ABSTRACT

The electricity market restructuring, and its worldwide evolution into regional and even continental scales, along with the increasing necessity for an adequate integration of renewable energy sources, is resulting in a rising complexity in power systems operation. Several power system simulators have been developed in recent years with the purpose of helping operators, regulators, and involved players to understand and deal with this complex and constantly changing environment. The main contribution of this paper is given by the integration of several electricity market and power system models, respecting to the reality of different countries. This integration is done through the development of an upper ontology which integrates the essential concepts necessary to interpret all the available information. The continuous development of Multi-Agent System for Competitive Electricity Markets platform provides the means for the exemplification of the usefulness of this ontology. A case study using the proposed multi-agent platform is presented, considering a scenario based on real data that simulates the European Electricity Market environment, and comparing its performance using different market mechanisms. The main goal is to demonstrate the advantages that the integration of various market models and simulation platforms have for the study of the electricity markets' evolution.

1. Introduction

The electricity markets (EM) restructuring has been changing the EM paradigm over the last few decades. The privatization, liberalization and international integration of previously nationally owned systems are some examples of the transformations that have been applied [1].

Nowadays EM operate using more complex and reliable models. However, EM are still restricted to the participation of large players [2]. All around the world this problem is being addressed in different ways. However, during the last years some common solutions are being globally adopted. EM are evolving to regional markets and some to continental scale, supporting transactions of huge amounts of electrical energy and enabling the efficient use of renewable based generation in places where it exceeds the local needs.

A reference case of this evolution is the European EM where the majority of European countries have joined together into common market operators, resulting in joint regional EM composed of several countries [3]. According to [4], Italy has recently joined Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Great Britain, Latvia, Lithuania, Luxembourg, The Netherlands, Norway, Poland (via the SwePol Link), Portugal, Slovenia, Spain and Sweden in a day-ahead coupled European electricity market. The integration of all the regional electricity markets in a Pan-European market is made through a Multi-Regional Coupling algorithm called EUPHEMIA[1] [5] used on a day-ahead basis [6]. The newly developed unique single price coupling algorithm has been developed by the Price Coupling of Regions (PCR) Project [7]. PCR is an initiative of 7 European market operators, who together have developed the procedures, redundant decentralised but interlinked IT systems and a single algorithm that calculates electricity prices, net import and export positions, and cross border electricity flows in one single run. This market has a yearly consumption around 2800 TW h. The daily average cleared volume over these countries amounts to over 4 TW h, with an average daily value of over EUR 150 millions. Several coupling initiatives have been

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[1] EUPHEMIA – Pan-European Hybrid Electricity Market Integration Algorithm.

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realized [8], however significant work still has to be done. Currently, the involved market operators and Transmission System Operators (TSOs) are occupied with important integration developments, such as the coordinated cross-border coupling of intraday electricity markets, which is foreseen for the end of 2014.

The transformation of National EM into Regional and Continental EM is evidenced by other examples, such as the U.S. EM like in California Independent System Operator (CAISO) [9]. Midcontinent Independent System Operator (MISO) [10] is other example of regional market in US. In Latin-American, Brazil also integrated all the regions in a joint electricity market [11]. These markets, although not representing a Continent as a whole, can be considered as Continental EM due to these countries' size.

Due to the constant evolution of the EM environment, and the inclusion and change in the operation and players' participation in EM, it becomes essential for professionals in this area to completely understand the markets' principles and how to evaluate their investments under such a competitive environment. The usage of simulation tools has grown with the need for understanding those mechanisms and how the involved players' interaction affects the outcomes of the markets. The necessity for the integration of different models and platforms brings out the need for communication capabilities that allow entities of different environments (such as software agents) to be able to understand each other and cooperate toward a common goal. Ontologies allow just that [12] by representing concepts and defining a common "language" that can be understood by all software systems. Therefore allowing systems to coexist and collaborate.

The main contribution of this paper is the development of an upper-ontology that represents the main concepts present in power systems and electricity markets. These concepts and their connection are represented in OWL and can be used and extended by each different simulation platform, in a way to integrate efforts and different perspectives. The use of languages that can be understood by different systems facilitates the connection and cooperation between them, which enables simulators, such as MASCEM, to integrate several different EM models and power system approaches that allow a broader study capability in this field. The integration of the diverse models and systems is not achieved by means of a specific computational model, but by the use of the proposed ontology as communication language between the software agents that are present in the simulators. With the use of such a common communication language, agents from the different systems are able to participate in simulations performed by other systems, and use computational models that until now were only available to entities of the same system.

After this introductory section, Section 2 presents a discussion on the most relevant related work, and Section 3 provides an overview of the current state of the European EM. Section 4 presents three multiagent systems (MAS) that are directed to study of power systems, and that are connected using the upper-ontology proposed in Section 5. A case study is presented in Section 6. Finally, Section 7 presents the most relevant conclusions and future work.

2. Related work

The constant evolution of EM makes it essential for professionals to completely understand the markets' principles and how to evaluate their investments under such a competitive environment. The usage of simulation tools has grown with the need for understanding those mechanisms and how the involved players' interaction affects the outcomes of the markets. With a multi-agent simulation tool the model may be enlarged and future evolution of markets may be accomplished.

Multiagent simulation combined with other artificial intelligence techniques results in sophisticated tools, namely in what concerns players modeling and simulation, strategic bidding and decision-support [13]. There are several experiences that sustain that a MAS with adequate simulation abilities is suitable to simulate EM [14]. It is important to note that a MAS is not necessarily a simulation platform but simulation may be of crucial importance for EM study, namely concerning scenarios comparison, future evolution study and sensitive analysis. Several examples of EM simulators based on MAS technology can be found in the literature. GAPEX (Genoa Artificial Power Exchange) [14] is an agent-based framework for modeling and simulating power exchanges implemented in MATLAB. AMES (Agent-based Modeling of Electricity Systems) [15] is an agent-based computational laboratory designed for the systematic experimental study of restructured wholesale power markets. Other platform is the EMCAS (Electricity Market Complex Adaptive System), [16] which uses a novel agent-based modeling approach to simulate the operation of today's complex power systems. Finally, MASCEM (Multi-Agent Simulator of Competitive Electricity Markets) [17] which has been proposed by the authors and detailed described in next sections.

Some other electricity market simulators can be found in the literature, which are not MAS based. Power Web [18] is a web-based market simulator; Simulator for Electric Power Industry Agents (SEPIA) [19] is a Microsoft Windows oriented simulator; the Short–Medium run Electricity Market Simulator (SREMS) [20] is directed to the simulation in broader time horizons, allowing the simulation of scenarios throughout several months. These are important contributions but, in general, lack flexibility as they adopt a limited number of market models and of players' behaviors. At the present state, it is important to go a step forward in EM simulators as this is crucial for facing the changes in power systems. The increasing number and diversity of players (due to high penetration of distributed resources and demand side participation) are a huge challenge.

Some large scale projects have been providing a substantial contribution for dealing with the most prominent issues in the field. WILMAR (Wind Power Integration in Liberalised Electricity Markets) has focused on the study of the impact of large scale penetration of wind based generation, and its accommodation in EM [21]. The Optimate project [22] has a simulation platform as output, which aims at accommodating the simulation of the PAN-European EM. Although the outputs of such works are important contributions, these still remain as solutions for partial problems.

The co-simulation field has brought about huge advances concerning the cooperation between simulators, predominantly when based on MAS technology. There are several experiences of co-simulation in the power system area [23]. In what concerns smart grid operation and management [24] proposes an integrated platform. In order to achieve a coherent and advantageous cooperation between different systems, the use of open standards is critical. Reference examples in the field are the Common Information Model (CIM) and SGAM (Smart Grid Architectural Model) [25]. The use of ontologies to represent systems' information, and support communications between the different systems is also extremely important, particularly when considering MAS based systems. An Upper Ontology for power engineering applications, based heavily on CIM has been proposed in [26], resulting from the authors' work throughout the last years concerning the interoperability between MAS [27].

Although this ontology is generic enough to be used by practically all applications in the power system's field, it is still not broad enough to become useful for applications whose focus of actuation is somewhat divergent from this ontology's original source of application. As the authors' themselves state: "*The applications that have employed this ontology are from the condition monitoring domain, and therefore the ontology is slanted toward condition monitoring terms and concepts. This does not mean the ontology is only applicable for monitoring applications, merely that a different application that employs this ontology will need a slightly larger lower ontology to cover all the required terms*" [26]. For this reason, in order to avoid having to develop very complete lower ontologies, directed to each different system, which would result in a repetition of represented terms in several lower ontologies, and very possibly lead to mapping difficulties when the same terms are represented differently in different lower ontologies; the authors decided to develop a new version of an Upper-Ontology for Power Systems and Electricity Markets.

3. Electricity market overview

Each electricity market has its rules and clearing price mechanisms taking into account the power systems reality and the available energy mix. The increase of distributed generation based in natural sources introduces new challenges to the market operators due to the changes in the energy mix. These units have high impact in the day-ahead market clear price and also in the balancing market. On the other hand, the reserves should consider the uncertainties introduced by these units.

Some markets have the clearing mechanism based on the optimization of offers, such as most of electricity markets in the U.S. [10]; and other based on symmetric or asymmetric auctions, as is the case of most European countries, where market mechanisms are tending to become more and more alike, in order to ease the accommodation to the unification of these markets. Recently, the integration of European regional electricity markets in a Pan-European market has become a reality [8]. One of the key elements of the recent market coupling is the newly developed unique single price coupling algorithm that has been developed by the Price Coupling of Regions (PCR) Project [7]. The used algorithm, called EUPHEMIA, handles standard and more sophisticated order types to calculate energy allocation and electricity prices across Europe [5]. EUPHEMIA aims at rapidly calculating solutions with the highest possible overall welfare [5]. The objective is that the welfare of the solution is maximized, so that the most competitive price arises, using an efficient capacity allocation. As detailed in [7], with this solution each market operator operates several bidding areas, taking into account that: (i) all bidding areas are matched at the same time; (ii) a different price can be obtained for each bidding area; (iii) the price for the bidding area must respect maximum and minimum price market boundaries. The EUPHEMIA algorithm operates as a symmetric auction based day-ahead spot market [28], similarly to the majority of electricity markets in Europe. Additionally, EUPHEMIA integrates the specific particularities of all participant electricity markets, including the possibility of presenting block orders, flexible orders, and complex offers, as detailed in the following sub-sections. Hence, EUPHEMIA in fact executes all participating market mechanisms in a collective way, while respecting the specificities of each market operator. As detailed in [5], the results achieved by EUPHEMIA are: (i) a price per bidding area; the net position per bidding area; (iii) flows per interconnection; and (iv) matched energy for each order.

Although European countries are tending to uniform their market mechanisms, and even though many are already integrated in the common EUPHEMIA platform, there are still differences and particularities from market to market. In this paper three market mechanisms based on reference European markets are analyzed: (i) MIBEL Iberian market; (ii) EPEX – central Europe; (iii) Nord Pool – Northern Europe.

3.1. MIBEL – Iberian market

The MIBEL spot market consists of 24 hourly periods per day. The market closure takes place at 10 am of the day before the date of delivery, and the results are published at 11 am.

Since July, 1st 2007, this market is based on a split mechanism of markets to enable the best possible use of the available interconnections capacity. Under this mechanism the Iberian system is treated as a single market. When there are no congestions on the interconnection the same market price is set for both areas (Portugal, and Spain) [29].

An offer to buy or sell energy can be carried out based on 1–25 fractions in each period. Simple offers feature for each fraction and production unit, held by them, a price and a quantity of energy. In the case of the selling price, it should be increasing in each fraction, and the buying bids, decreasing [29]. Intentions of selling energy can still be accompanied by certain restrictions denominated complex conditions:

- Indivisibility: allows the producer to ensure that the total volume of energy supply will be accepted for sale, otherwise, if the accepted amount is lower than stipulated in the first fraction of that offer, the total amount is excluded from the market.
- Minimum Income: allows the sale offer to be only accepted when the producer is able to achieve a fixed minimum income value, specified in Euros, and a minimum variable value per MW h.
- Scheduled Stop: allows the removal of the condition of minimum income in the first three periods of the next day, when the offer is not accepted in any period.
- Charge Gradient: sets a maximum capacity range of energy production, expressed in MW per minute, to avoid abrupt production changes inconsecutive periods.

3.2. EPEX spot

Similarly to MIBEL, the EPEX Spot market is a symmetric market of stock exchange. In this market there is a maximum price limit with regard to the offers that lies in € 3000, and the minimum price is the same value with a negative sign (for the sale of energy). It is also possible to carry out bids independent of price, where the transaction price will be dependent on the supply and demand of energy for that day.

If the auction results in a price that exceeds the policies of EPEX Spot SE, a second auction may occur: (a) In the case of excessively high prices, participants may increase the volume of electricity for sale, remove power purchase intentions or decrease prices for sale/purchase of power. (b) In case of too low price, participants may increase the amount of energy to purchase, remove intentions of selling energy or increase the prices charged for sale/purchase of power.

EPEX Spot allows two types of offers:

- Per period: simple offers, similar to the bids of MIBEL, without complex conditions. These may contain up to 256 combinations of price/amount of energy for each hour of the auction.
- Block offers: have the purpose of connecting various periods, and the offer is accepted in all periods or is rejected altogether. These present a lower priority when compared to period offers [30].

3.3. NordPool Elspot

The Elspot market works as a stock exchange market and allows its participants to transact energy for the following day. It's a symmetric market once both sale and purchase offers are allowed.

Table 1
Day-ahead Electricity Markets Comparison.

	Nord Pool Elspot	EPEX spot	MIBEL
Bidding deadline	12 h CET	12 h CET – Austria/Germany and France 11 h CET – Swiss	12 h CET
Bidding periods	24 periods (1 h periods)		
Maximum price	3000 EUR/MW h	3000 EUR/MW h	180.3 EUR/MW h
Minimum price	−500 EUR/MW h	−500 EUR/MW h	0 EUR/MW h
Minimum bidding volume	100 kW	100 kW	1 MW
Minimum price	−500 EUR/MW h	−500 EUR/MW h	0 EUR/MW h
Number of bids for the same period	64	30	25
Bidding types	Simple bids Block orders Flexible hourly orders	Simple bids Block orders	Simple bids Complex bids (Condition of indivisibility; Minimum income condition; Scheduled stop condition; Production capacity variation or load gradient condition)
Areas	16	3	2

Offers placed in this market should be expressed in a positive volume of energy in case of a purchase and as negative if the volume is available for sale. The offers must still be contained in the price range set by Nord Pool Spot. Elspot offers three possible types of offers [31]:

- Hourly Orders: similar to the simple, per period offers in MIBEL and EPEX spot.
- Flexible Hourly Offers: participants have the opportunity to make additional sale offers (purchases are not permitted) without indicating a specific period for the same, i.e. these volumes can be transacted in any period of the day, depending on the offer price, and on the necessities of the market for each period.
- Block Orders: similar to the block offers in EPEX.

The negotiation process is similar to the MIBEL and EPEX Spot markets, with offers of purchase and sale represented by curves of supply and demand. Sale offers below the market price and purchase offers higher to the same will be accepted. For flexible offers, trading occurs in the same way, and these deals will apply in the period when its use maximizes the market profit. Regarding to the block offers, they will be accepted if the market price of all periods in which the block applies is equal to or higher than the price of the block bid in case of offers for sale; or if the market price of the block periods is equal or less than the price of the block in the case of purchase bids. This condition is called fill-or-kill [32].

3.4. Day-ahead markets comparison

Similarly to MIBEL, the EPEX Spot market is a symmetric market of stock exchange. In this market there is a maximum price limit with regard to the offers that lies in € 3000, and the minimum price is the same value with a negative sign (for the sale of energy). It is also possible to carry out bids independent of price, where the transaction price will be dependent on the supply and demand of energy for that day. Table 1 shows a general comparison of the main rules of the described electricity markets.

As it is possible to see in Table 1, many rules are coherent in the three markets. Some of them are changed very recently to guarantee the rules uniformization between the markets. For example the gate close hour in MIBEL was 10 am CET until 14th October 2013, and the minimum and maximum prices in Nord Pool were −200 EUR and 2000 EUR, respectively until 26th November 2013. A pilot project for joint electricity trading, called day-ahead market coupling, evolving 15 European countries (Belgium, Denmark, Estonia, Finland, France, Germany, Austria, UK, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Sweden and Norway started at February 4th of 2014 [33]. This project is one of the most important milestones concerning the integration of all electricity markets in European Electricity Markets. However, behind the economic aspects, the main challenge to the real markets integration is to avoid the technical constraints that exist in many European regions. In [34] estimate the requirements considering three different scenarios to 2050, resulting in the necessity to expand or upgrade the transmission network between 28,000 to 51,000 km with a total cost of €20bn to €56bn.

4. Multiagent simulation of electricity markets

Electricity market and power system simulators must be able to cope with an evolving complex dynamic reality in order to provide players with adequate tools to adapt themselves to the new reality, gaining experience to act in the frame of a changing economic, financial, and regulatory environment [35]. With a multi-agent simulation tool the model may be easily enlarged and future evolution of markets may be accomplished. The integration of different models and the interconnection with other systems, with their own social environment are some of the best advantages of multiagent based platforms.

This section presents an overview of three multiagent systems that are directed to study of electricity markets. These three platforms are complementary, as they provide the means for studying different subjects. Their interconnection is highly advantageous in order to achieve a realistic and coherent representation of a broader environment.

MASCEM (Multi-Agent System for Competitive Electricity Markets) [17] provides the means to simulate the electricity market environment, by supporting several different market models that can be found in different countries. ALBidS (Adaptive Learning strategic Bidding System) [36], provides decision support capabilities to electricity markets' negotiating players, enabling them to analyze different contexts of negotiation, and act accordingly. MASGriP (Multi-Agent Smart Grid simulation Platform) [37] is a multi-agent system that models the operation of smart grids, including the interactions between a large number of distinct players.

4.1. Electricity markets simulator: MASCEM

MASCEM aims to facilitate the study of complex electricity markets. It considers the most important entities and their decision support features, allowing the definition of bids and strategies, granting them a competitive advantage in the market. Players are provided with biding strategies so they are able to achieve the best possible results depending on the market context. Its players include a market operator agent, an independent system operator agent (ISO), a market facilitator agent, buyer agents, seller agents, Virtual Power Player (VPP) [38] agents, and VPP facilitators. Fig. 1 presents the global structure of MASCEM.

In order to be able to compete in the market on equal footing with the big companies, small producers, mainly based on distributed generation and renewable sources, or consumers need to make alliances between them. VPPs [38] represent these alliances providing the adequate means, managing their aggregates' information, and are viewed as common seller or buyer agents from the market's standpoint. They are modeled as a coalition of agents, maintaining high performance allowing the use of agents in different machines.

MASCEM allows the simulation of several market models: day-ahead pool (asymmetric or symmetric, with or without complex conditions), bilateral contracts, balancing market, forward markets and ancillary services. Hybrid simulations are also permitted by selecting a combination of the market models mentioned above. The user determines for each agent whether to, and how to, participate in each market type.

4.2. Strategic behavior: ALBidS

In order to allow players to automatically adapt their strategic behavior according to their current situation, a new multi-agent system has been integrated with MASCEM [36]. This platform is ALBidS, and provides to the agents the capability of analyzing contexts of negotiation, such as the week day, the period, the particular market in which the player is negotiating, the economic situation and weather conditions, allowing players to automatically adapt their strategic behavior according to their current situation.

The way prices are predicted for each market can be approached in several ways, through the use of statistical methods, data mining techniques, artificial neural networks, support vector machines, among others [39]. There is no method that can be said to be the best for every situation, only the best for one or other particular case.

ALBidS uses reinforcement learning algorithms to choose the player's most adequate action, from a set of different proposals provided by the several algorithms that present distinct approaches. To this end, the reinforcement learning algorithm considers the past experience of the action's responses and the present characteristics of each situation, such as the week day, the period, and the particular market that the algorithms are being asked to forecast.

ALBidS is implemented as a multi-agent system itself. Each algorithm is under the responsibility of an agent who holds the knowledge to perform it. Thus, the system can execute the algorithms simultaneously, increasing the performance of the system. As each agent gets its answer, sends it to the main agent, which is responsible for choosing the most appropriate answer among all that it received.

Since there are many algorithms running simultaneously, it became necessary to build a suitable mechanism to manage the algorithms efficiency in order to guarantee the minimum degradation of the previous implementation performance, i.e. the MASCEM simulator's processing time without considering ALBidS integration. For this purpose, a methodology to manage the efficiency/effectiveness (2E) balance of ALBidS has been developed [36], to guarantee that the degradation of the simulator processing times takes the correct measure, depending on the type of the simulation.

4.3. Smart grid operation: MASGriP

MASGriP [37] is a multi-agent system that proposes a set of possible coalitions that facilitate the management of smart grids (SG) and microgrids (MG). It models the distribution network and the involved players, such as Domestic Customers (DM), Small (SC), Medium (MC) and Large Commerce (LC), Small (SI), Medium (MI) and Large Industrial (LI) and Rural Consumers (RC), all of them may consider Demand Response (DR) and/or micro/mini-generation and/or Electric Vehicles (EVs) [40], as well as different sizes of DG [41] and EV Parks. Each player is represented by a software agent with the ability of simulating its actions and behaviors.

Each agent, with the exception of the facilitator, represents a physical player or part of it, detaining all the information concerning the physical installation, including its geographic coordinates and the electric characteristics. Concerning the type of player, the business model and the contracts being used, each agent has the necessary information to share with the other agents. The sharing rules can be modified according to negotiations between the players and the aggregators, making MASGriP a dynamic system.

Players establish contracts with two types of aggregators: the VPP or the Curtailment Service Provider (CSP). A CSP can be defined as a special player aggregating consumers' DR participation, enabling small and medium consumers to participate in DR events. Small and medium consumers without the reduction capacity required by the DR program managing entity (usually a system operator) establish a contract with a CSP to participate in the DR program.

The integration between MASGriP and MASCEM provides the means for simulating appropriately the resources management in the scope of SG, including all the most important features it requires, such as the internal management of SG and MG, the use of DR, the management by VPPs, and the actual market negotiations.

5. Upper ontology for systems' interoperability

The integration of multi-agent systems raises inherent issues to the inter-operation of those systems, particularly the ones involving the use of different ontologies [42]. To disseminate the development of interoperable multi-agent systems, especially in the power industry, these issues need to be addressed [27]. In order to take full advantage of the functionalities of those systems, there is a growing need for knowledge exchange between them. Open standards are needed to provide full interoperability.

5.1. Multi-agent open standards on interoperability

When developing multi-agent systems, the use of standards is important to allow the integration of separate systems. Within power engineering, the increasing application of multi-agent technology promotes the adoption of standards that enable the communication between heterogeneous systems, bringing future advantages [26].

The Foundation for Intelligent Physical Agents (FIPA) is devoted to develop and promote open specifications that support interoperability among agents and agent-based applications [43]. Multi-agent systems using FIPA's standards should be able to interoperate but it does not mean that the agents are able to share useful information due to the employment of different ontologies.

FIPA proposes the Agent Communication Language (ACL) as a standard for communications between agents. The content of the message includes the content language and the ontology. The former specifies the syntax, while the latter provides the semantics of the message [44]. This way the correct interpretation of the meaning of the message is assured, removing the ambiguity about the content. The FIPA-SL content language is the only one that reached a stable standard. Ontologies are used by agents for exchanging information, ask questions, and request the execution of actions related to their specific domain.

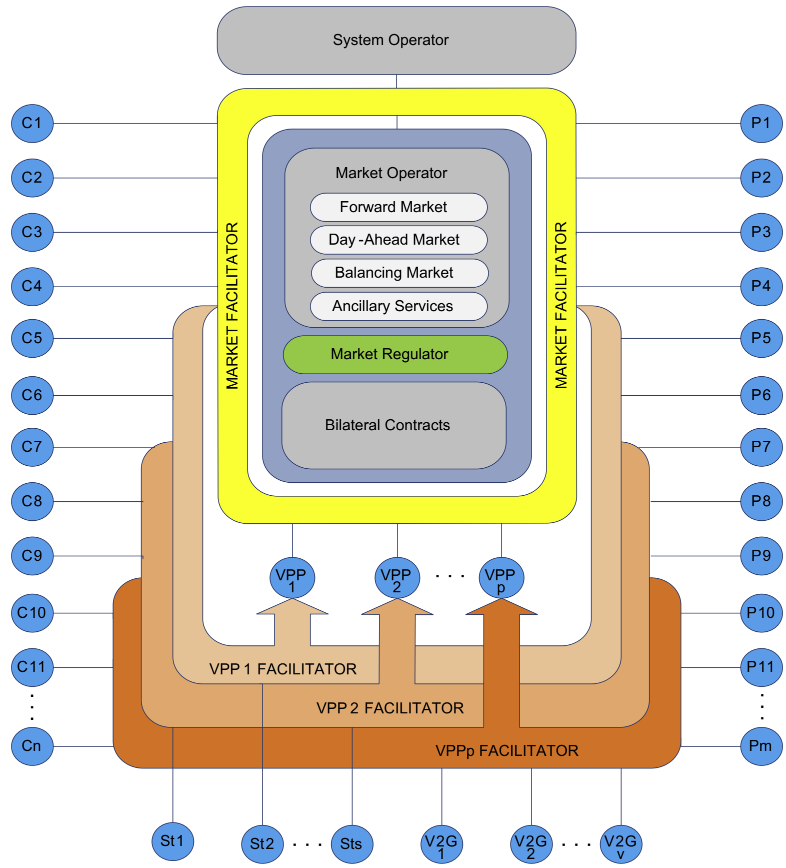

Fig. 1. MASCEM's global structure [38].

Presently, multi-agent systems in the power system's domain are developed with their own specific ontologies. These systems share common concepts, which are differently represented between ontologies. Translating these concepts automatically is not as straightforward as it seems. To solve the problem of multiple ontologies, FIPA proposes the use of an ontology agent that provides some related services [45]. This is still an experimental standard and mappings between ontologies still must be performed by ontologies' designers, which increases the human effort required and costs of implementation.

Alternatively, [26] proposes the use of an upper ontology representing the general concepts of the domain, ensuring a common basis for the representation of those concepts and their relations between systems while reducing the complexity of ontology mapping.

5.2. Upper ontology

This paper proposes the use of an upper ontology which contains the most important concepts for the integration of electricity market and power system simulation platforms. Fig. 2 presents the proposed approach to co-relate the real electricity markets and power system with simulators.

The ontologies regarding the three systems used in the present paper are represented in purple within the image. The analysis of electricity markets and power systems operation resulted in the extraction of the main concepts and relations that must be present in the upper ontologies of Power Systems Operation and Electricity Markets. These concepts and relations must be validated and accepted by the power systems community, so that they can be extended or mapped by developers of power systems' simulators.

After defining our Power System Operation Ontology and Electricity Markets Ontology, we extended the respective concepts and relations needed for defining our platforms' ontologies. MASCEM ontology extends the Electricity Markets Ontology while MASGriP ontology extends the Power Systems Operation Ontology. Regarding the ALBidS ontology, it extends some concepts present in both Power Systems Operation Ontology and Electricity Markets Ontology in order to be able to perform correctly the decision support to MASCEM and MASGriP's players. Other simulators like the AMES, EMCAS or Power Matcher can be integrated in the proposed ontology. Fig. 3 illustrates the existing communications between the three platforms, and the agents responsible for such interoperability.

The systems communicate with each other according to their needs and trying to make the best possible negotiations. MASCEM's players interact with ALBidS' Main Agent, sending him information about the market in which they are presenting bids. The Main Agent spreads this information among its agents that process data from the past accordingly to this information and present a proposal for the market. The best of all proposals is returned to the player. Similarly, VPPs in MASGriP can also communicate with the ALBidS to support the decision on which is the best offer to present in the market. Communication between MASCEM and MASGriP happens when the VPPs in MASGriP decide to present offers in the market in order to buy or sell energy. For that, VPPs have to communicate with the Market Operator.

Each of the multi-agent systems has an internal ontology shared among its agents. However, sharing their ontology is not enough to allow proper communication between systems. The upper-ontology must be abstract enough to allow inter-communication between the systems. In Fig. 4 is shown part of MASCEM ontology extended from the proposed upper ontology.

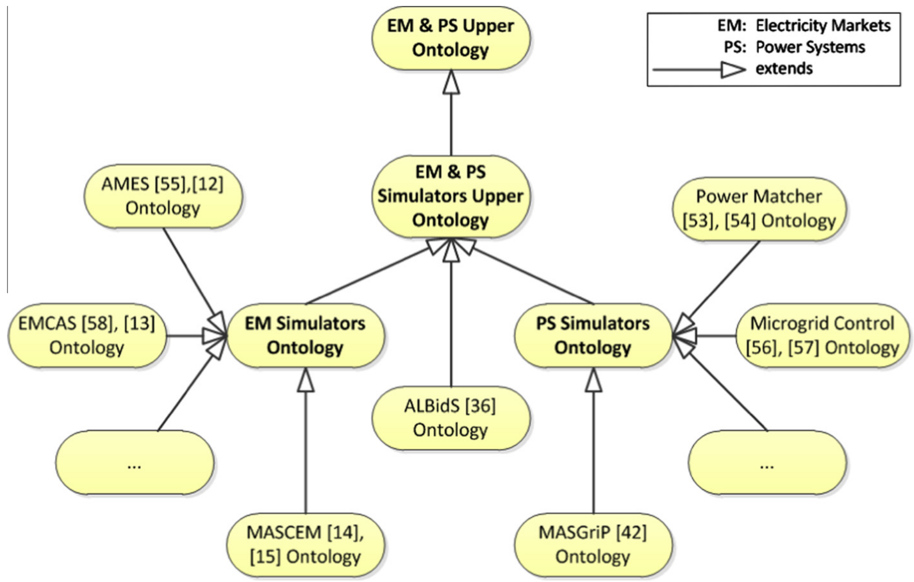

Fig. 2. Ontology representation to relate real Electricity Markets And Power Systems with simulators.

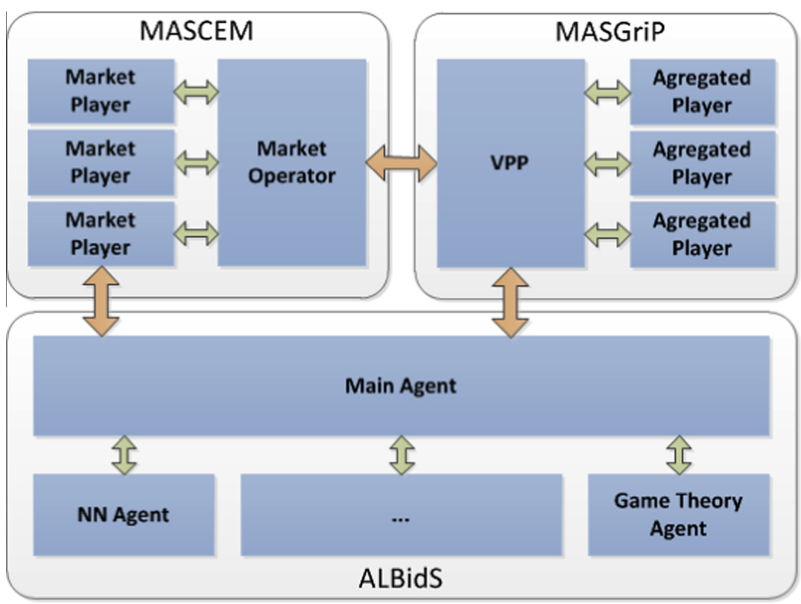

Fig. 3. Main communications between MASCEM, ALBidS and MASGriP.

In the MASCEM ontology it is possible to verify some of the extensions made from the Electricity Markets upper ontology, such as the concepts of Market-Type, Market Algorithm and Electricity Market. MIBEL, EPEX and NordPool are individuals of MASCEM ontology representing some of the electricity markets supported by the simulator. Relations between classes and individuals are discriminated in the legend. Different simulators extending the Electricity Markets Upper Ontology can have different individuals from MASCEM, representing different Electricity Markets that can be simulated. Each Electricity Market can have more than one market types, and each one has a specific market algorithm. In the case of MASCEM, as can be seen by Fig. 4, there are four market types: (a) Day-Ahead; (b) Balancing; (c) Intraday; and (d) Bilateral Contract. The first three make use of a Market Algorithm that can be Symmetric or Asymmetric.

Using the proposed ontology it becomes possible for agents of the different systems to communicate among each other, hence integrating the several multi-agent simulators in a way that the models offered by one system can be used by agents of other systems. Fig. 5 presents a schematic example of a series of communications between agents of the three systems that are possible due to the use of the proposed ontology.

Fig. 5 shows an example in which a VPP agent (aggregator) of MASGriP participates in two electricity markets provided by MASCEM, while using the decision support capabilities of ALBidS. The internal communications inside MASGriP, between the VPP and the small consumers and producers, is performed naturally, using the MASGriP ontology, so that agents of MASGriP can understand each other. However, when the VPP desires to participate in the electricity market, a market offer, or bid, is required. The term “bid” is, however, vague, since it obviously represents a bid for market participation, but the characteristics that define a bid are different in different electricity markets. By using the proposed ontology, the VPP understands that, despite both the participation

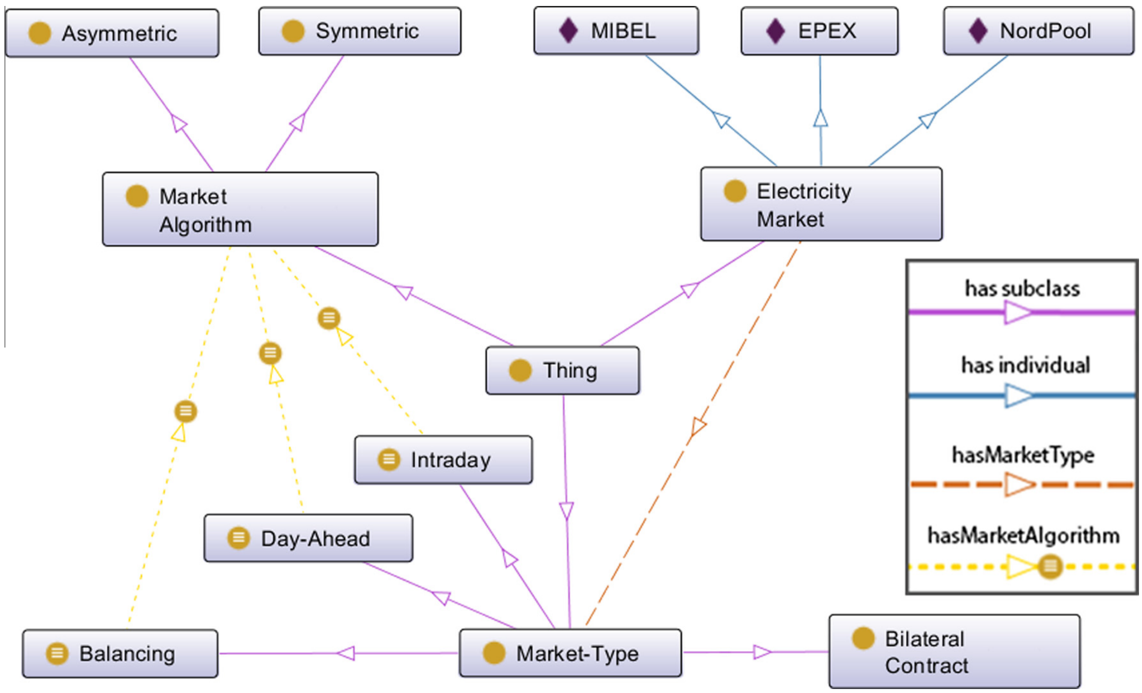

Fig. 4. Excerpt of Electricity Markets Simulator ontology.

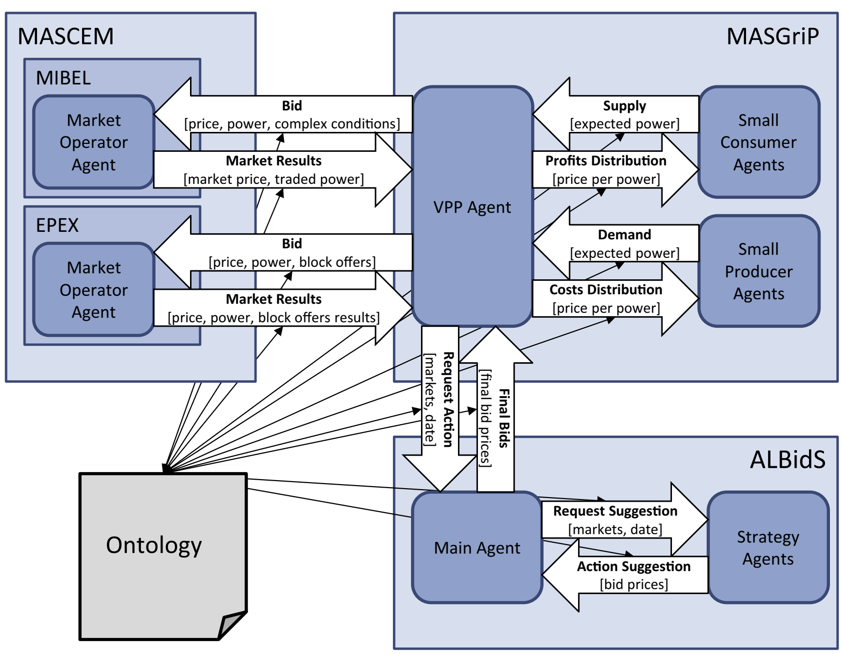

Fig. 5. The role of the proposed ontology in the integration of MASCEM, ALBidS and MASGriP.

in MIBEL and in EPEX require a bid, the type of bid that must be presented to the MIBEL market operator agent includes complex conditions, while the bid that must be sent to the EPEX market operator agent can include block offers. By using the ontology, which contains all of these terms and specifications, the VPP is able to participate in different markets and understand how to do it, and how to interpret the achieved results. Fig. 6 presents a sequence diagram, which represents the timings of the communications performed in the given example.

From Fig. 6 it is visible that communications between agents of different systems occur in different timings. In the considered example the VPP starts by receiving the expected consumption and generation amounts from the aggregated agents, which are used by the VPP to perform an internal dispatch of its aggregated units. After determining the amount that is needed to be bought or sold in the market, the VPP makes a request to the main agent of ALBidS, in order to get decision support for its participation in the market. The main agent of ALBidS executes ALBidS' strategies, and after reaching the best suggested action for the VPP to perform in the market, this market action suggestion is sent to the VPP agent. Using the actions suggested by ALBidS, the VPP submits the market bids to the MIBEL and EPEX market operator agents,

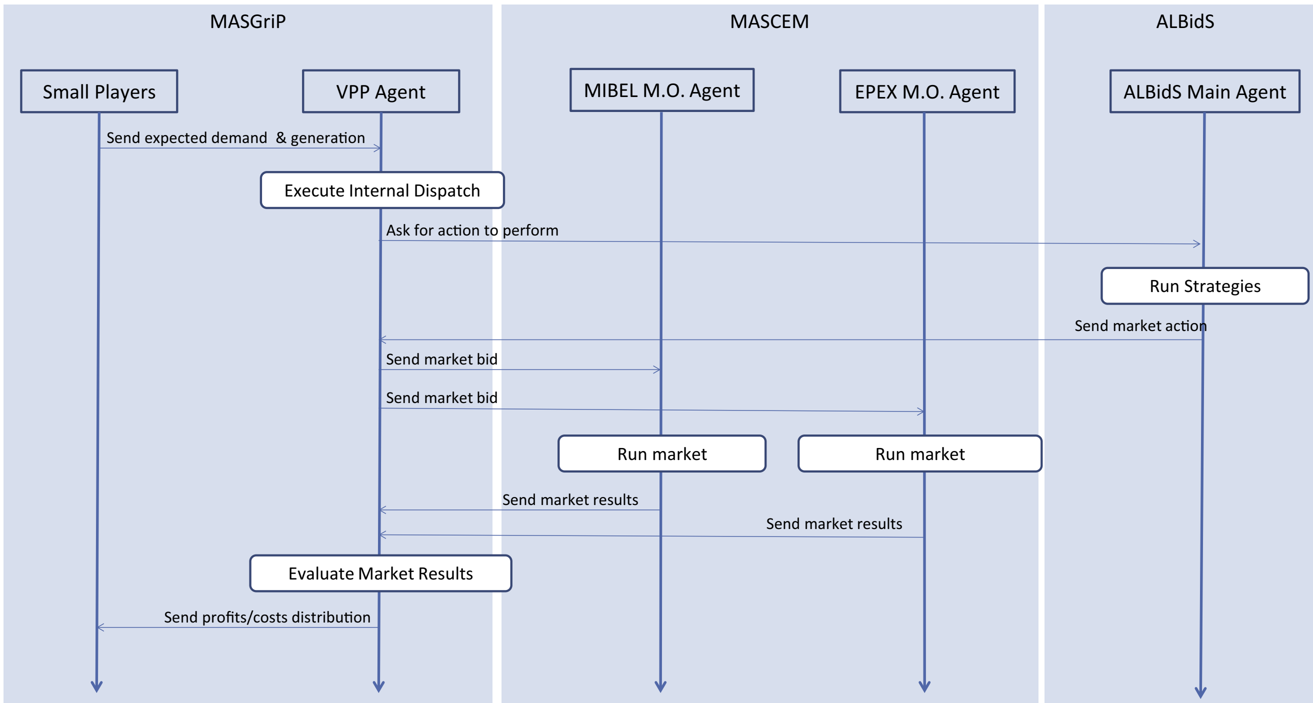

Fig. 6. Sequence diagram of the communications performed between the VPP agent (of MASGriP), the market operator agents of MIBEL and EPEX, of MASCEM, and the main agent of ALBidS.

which in turn run the market mechanisms, and send back the market results. Finally, the VPP evaluates these market results, and sends information to its aggregated players regarding the costs and profits distribution, which depend on the achieved market results. These communications between agents of the different systems make it possible for the three systems to be integrated, working together for common simulations, which is possible due to the proposed ontology.

The inter-operability between systems brings added value to all of power systems' research, allowing to take a better advantage of the various developed platforms, for the study of power systems and competitive electricity markets. This also provides the basis for the interconnection of MASCEM with other systems, allowing MASCEM agents to participate in different types of markets, different perspectives of smart grids, and vice versa.

6. Case study

This case study is based on four scenarios created using real data extracted from the several European regional market operators. These scenarios, created to represent the European reality through a summarized group of market negotiation agents, include seller and buyer players, representing the numerous areas that compose each regional market (e.g., in the Iberian Market, each of the two areas represents one country: Portugal and Spain; while in some regional markets, e.g. Nord Pool, these areas represent different zones, such as several parts of different countries.

The simulation includes two agents for each area (one seller and one buyer), practicing the average prices that are usually found in each particular area in the particular chosen cases, and transacting the total amounts of power that were sold or bought in each of these areas in the reality.

The selected cases are four: two during the summer, and two during the winter, and for each, one case during a business day and another on a weekend (Sunday). The selected dates were: 25th July, 2012 (Wednesday, in the summer); 29th July, 2012 (Sunday, in the summer); 16th January, 2013 (Wednesday, in the winter); and 20th January, 2013 (Sunday, in the winter). These dates have been selected because represent the average days, concerning the power volume transacted and market price in each season.

All players, representing the entire European Continent, negotiate in a common market environment, simulating the PAN-European Electricity Market. The considered market mechanisms are three, all regarding day-ahead negotiations: the MIBEL spot market; the EPEXSPOT; and the Elspot market from Nord Pool. All players will negotiate using each of these three market mechanisms, for each of the four considered cases. Players' behavior is assumed like they are participating in their origin market, e.g. players from markets where complex conditions are permitted will use the particularities of each market mechanism to transpose the condition as best as possible (a good example is the indivisibility complex condition from MIBEL described [47], which can be easily replaced with a ELSPOT or EPEXSPOT block offer described in [48,49], respectively, and vice versa). The demonstration of an individual illustrative player participating in the three market types and using the proposed ontology to transpose the acting opportunities from one market to another, as to preserve its strategic behavior, is also presented. The price strategy for this seller is determined by ALBidS. ALBidS has 20 different algorithms to determine the best offer in each period. Each algorithm is based in a different principle requiring different information. Afterwards, an agent will be responsible to identify the algorithm to be used in each period based in their performance in similar market conditions (context and efficiency/effectiveness requirements) [36].

Fig. 7 presents the market results for each of the four considered dates, using each of the three market mechanisms.

From Fig. 7 it is visible that the market prices in each day are, most of the times, very similar when using the three market mechanisms. In the case of 29th July, 2012, presented in Fig. 7b), the market prices in MIBEL and the Nord Pool market mechanisms are identical throughout all day. Regarding the case of 16th January, 2013 – Fig. 7 c), all three market prices are very close in all 24 periods of the day.

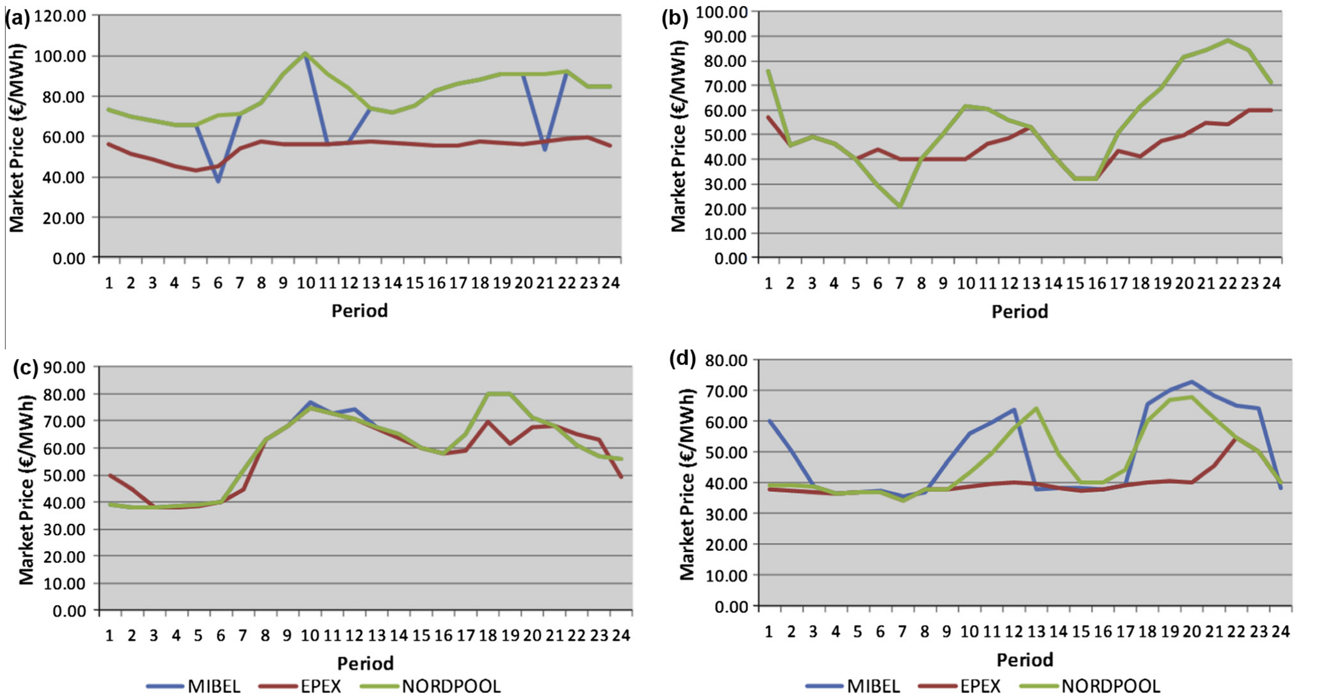

Fig. 7. Electricity market prices for the conjunct participation of all European countries, in: (a) 25th July, 2012; (b) 29th July, 2012; (c) 16th January, 2013; (d) 20th January, 2013.

These small differences, as well as the bigger disparity in some prices of the other days, are due to the fact that, in spite of the three market mechanisms being based on a symmetric auction (i.e. the basis of the markets is identical), all markets present particularities that distinguish them. The possibility of presenting complex conditions, block offers and flexible offers, give the participant players the chance to adapt their behavior to the specificities of each market. This means that the way players act in each market has a direct influence on the outcomes of the market, therefore the use of simulation tools, which allow them to test new approaches in order to learn how to act in a new environment, is a critical issue.

Considering the results of each player in the three different electricity markets, it is possible to determine the social welfare (SW) (1) to evaluate the global players' benefits in each one [46].

$$SW = \sum_{t=1}^{T}\left[\begin{array}{l}\displaystyle\sum_{Seller=1}^{N_{Seller}}\sum_{Bid=1}^{N_{Bid}} P_{(Seller,Bid,t)} \times (MP_{(t)} - BP_{(Seller,Bid,t)}) \times BA_{(Seller,Bid,t)} + \\ \displaystyle\sum_{Buyer=1}^{N_{Buyer}}\sum_{Bid=1}^{N_{Bid}} P_{(Buyer,Bid,t)} \times (BP_{(Buyer,Bid,t)} - MP_{(t)}) \times BA_{(Buyer,Bid,t)} + \end{array}\right] \tag{1}$$

where $P_{(Player,Bid,t)}$ and $BP_{(Player,Bid,t)}$ are the power and price offered by the player (Seller or Buyer) in a specific bid for the period t, respectively. $MP_{(t)}$ is the market clearing price in period t and the $BA_{(Player,Bid,t)}$ is a binary variable which indicate if the bid for period t was accepted. The results are presented in Fig. 8.

As it is possible to see in Fig. 8 the SW is similar in the three markets. However large differences can happen in different days. In all days, the Nord Pool presents a higher SW, with an average difference of 0.3%. The differences of social welfare are marginal for the different markets in the same day because all the markets use a symmetric clearing mechanism. Additionally, the values represent the sum of the social welfare of all periods, absorbing the differences existing in the individual periods. In contrast, the social welfare changes significantly in different days due to the difference in the demand requirements and mainly in the resources (production) availability. In fact, in systems with high penetration of distributed generation based in natural resources (wind and solar), the availability of this resources have high impact in the market prices. With these results it is possible to conclude the importance of the use of a decision support tool with context identification like the ALBidS. The results of each player can change significantly every day and its strategy should be adapted to increase the benefits in the market participation.

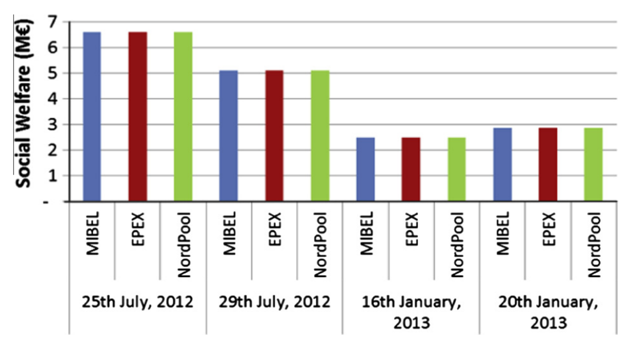

Fig. 8. Social welfare.

In order to illustrate the impact of using different types of offers, available in the different markets, the outcomes of one particular seller player (Seller 22) are analyzed when participating in the PAN-European Market scenario, with the three different market mechanisms. This player uses the proposed ontology to participate in the different market mechanisms while maintaining, as possible, its strategic approach for market negotiations.

Fig. 9 presents the results of Seller 22 during the daily market session, in the case using the MIBEL market mechanism. This player uses the Indivisibility complex condition, to ensure that the whole production amount is sold. Given that Seller 22 is in need of selling a certain amount of energy, the price set was very low when compared to the average, expected, market price. As a result, all of the energy available for sale was indeed negotiated in the market.

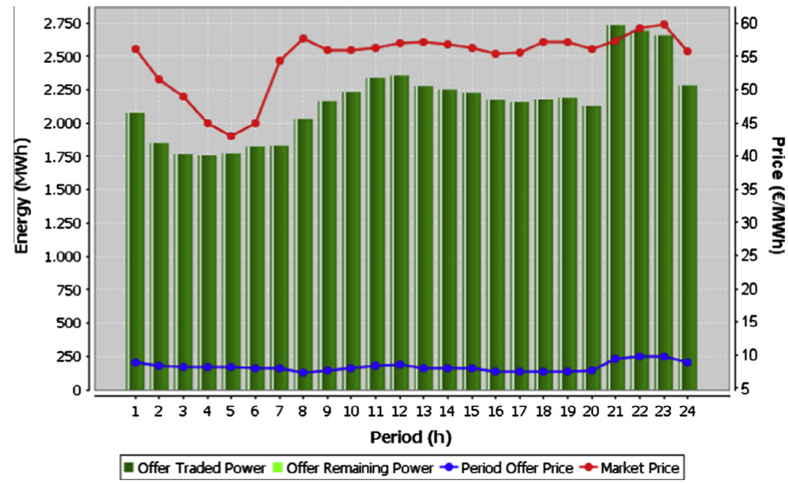

Fig. 9. Market results of Seller 22 when participating in the MIBEL market mechanism, with the *Indivisibility* complex condition.

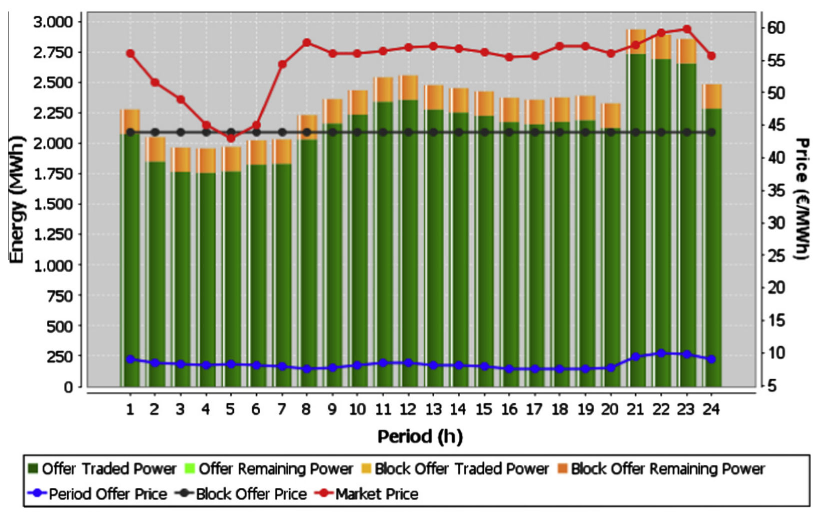

Fig. 10. Market results of Seller 22 when participating in the EPEX market mechanism, using block orders.

Analyzing the chart of Fig. 9, it is possible to observe that there are no light green bars (meant to indicate the amount of energy that was not sold during the session). Fig. 10 presents the market results for Seller 22, this time when participating in the EPEX spot market, using block orders. This type of order can be seen as a group of single hourly orders, where each order can have a different amount of energy, but all must obey to the same price. All of the orders comprising the block must belong to three or more consecutive hours.

These orders have a fill-or-kill condition, which means that all of the orders comprising the block must be accepted in the market, for the block to be negotiated. If only block offers were used, this type of offer would be very similar to the use of the Indivisibility complex condition of MIBEL. The use of the agents' ontologies allows players to be aware of this. However, since the main objective of this player is to sell as much power as possible, Seller 22 will offer the majority of its available power at low prices, but using the block offers to try optimizing the price on a smaller amount of power, assuming that risk.

The block order submitted by Seller 22 is comprised of 24 individual orders, one for each of the 24 hourly periods of the market session. The same energy volume was defined for all of the orders (200 MW h). The price set for the block is 44 €/MW h.

It is possible to observe in the chart of Fig. 8, that the block was not accepted, despite the block price being inferior to the established market price in 23 of the 24 hourly periods of the market. The market price of the 5th period was set at 42 €/MW h, which caused the entire block being refused in the market, after failing the fill-or-kill condition.

Fig. 11 presents the results of Seller 22 when participating in the European Market scenario, using the Nord Pool – Elspot mechanism. In this market mechanism, Seller 22 uses three flexible hourly orders. These flexible hourly orders (available only to seller agents), allow the players to specify a fixed price and volume. The hour is not specified. The order will be accepted in the hour that optimizes the overall socioeconomic welfare of the market. A maximum of five flexible hourly orders is available per agent during a market session. In this scenario three orders were submitted with the volume of 2000 MW h each, all three at the price of 40 €/MW h.

It is possible to observe from the chart of Fig. 11 that during the first nine periods (hours) none of the orders was accepted in spite of the bid price being below the established market price. The orange bars indicate a total of 6000 MW h of unsold energy during these periods (referring to the total of the three flexible offers, of 2000 MW h each). The flexible hourly orders were accepted in the 10th, 11th and 15th periods. In these three periods the total amount of energy of the order was sold. As can be seen by the graph of Fig. 9, since the first flexible offer is accepted in period 10, only 4000 MW h remain to be negotiated in the 11th period. From these, 2000 MW h are accepted, and the remaining 2000 MW h, referring to the third and final flexible offer are

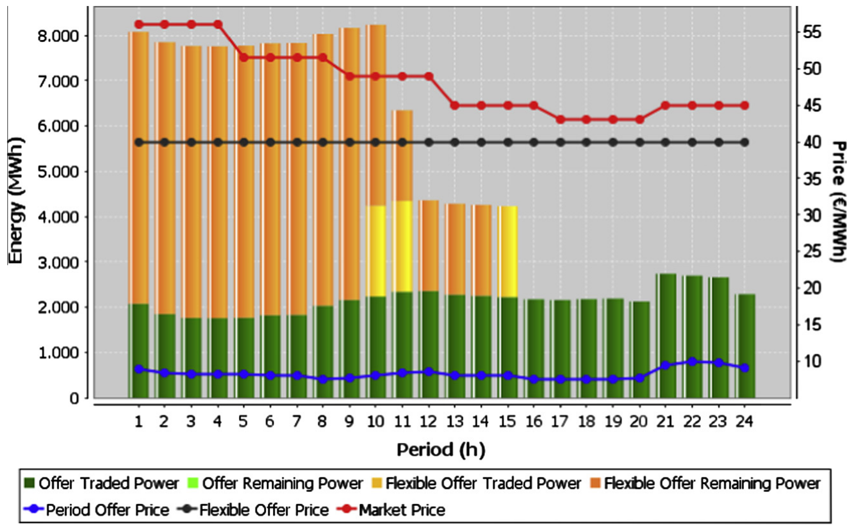

Fig. 11. Market results of Seller 22 when participating in the Elspot market mechanism, using flexible orders.

negotiated in the following periods, being finally accepted in the 15th period. As mentioned before, the condition for the acceptance of each (or all) flexible offer is not only the proposed bid price, but also the maximization of the overall socioeconomic welfare of the market session, from the market operator's perspective.

When comparing the performance of Seller 22 when participating in each one of the three markets, it is possible to observe that it is vital for an agent to have a full understanding of all the different conditions that each market presents. The possibility of using different types of offers, such as complex conditions, and flexible and block orders can make a colossal difference both in an individual player's profits, and also in the overall socioeconomic welfare of the market. The flexible orders allow a player to sell an extra volume of energy, at a higher price, in hours when that energy is most demanded. By defining a lower price for a block order, a player can sell a predetermined amount of energy throughout the whole market session. In that case, the risk is not very high. However, if the player tries to maximize its profit, by setting a higher price, such as Seller 22 when participating in the EPEX spot market, the risk of the whole block being rejected increases exponentially because of the fill-or-kill condition.

The use of the proposed ontology, which contains the characteristics and specifications of each different market, allows inferring market rules from the contained information. Taking these rules into account, behaviors can be modeled and adapted. In this case study, Seller 22 has used block orders in its participation in the EPEX market. These block orders are not available in MIBEL, however, the Indivisibility complex condition that is supported by MIBEL, allows specifying a similar behavior, as it forces the total amount of offered power to be accepted, otherwise, none is. This is similar to the fill-or-kill condition, which characterizes the block orders. The inference on the information contained in the ontology allows players to use similar behaviors in different markets, taking advantage on the opportunities and particularities of each market. Once the use of a specific order or complex condition is determined by the inference process, the way the condition or order is used is defined by ALBidS, resulting in the player's behavior in the market.

7. Conclusions and future work

This paper presented MASCEM, a multi-agent simulator of competitive electricity markets and power systems. MASCEM includes a close cooperation with two other systems developed by the authors' research group – ALBidS and MASGriP. Although these systems are independent platforms, to achieve better results in the study of these systems and from the interaction between the involved agents, the need to connect them arises. For this it is necessary that the agents involved are able to interpret messages from other platforms. The need for connecting different simulators highlights this need, for the cooperation between the models existing in different platforms can benefit in a large scale the realism and depth of electricity markets and power systems' studies.

To achieve systems interoperability an upper-ontology has been developed, from which the ontologies of each platform must be extended. Although this approach does not avoid the need for mapping, it significantly reduces the effort expended for this purpose. It also aims to enable communication from external systems with ours, allowing a much more complete study of this domain.

The proposed Upper-Ontology facilitates the integration of different multi-agent systems, by providing a way for communications to be understood by agents from all systems. In the specific case of the integration between MASCEM, ALBidS, and MASGriP, the common concepts that are necessary for all three systems are extended from the Upper-Ontology, avoiding the necessity for mapping in order to understand requests made by agents from a different system. By "speaking the same language", agents from different communities can understand each other perfectly and communicate efficiently, without the need for spending unnecessary computational resources and execution time (which is an essential issue in a simulation process), in converting the messages from others so that they can become understandable enough to be processed.

The new enhanced electricity markets simulator resulting from the integration of several market mechanisms in MASCEM provides a solid platform to study and explore the implications and consequences of new and already existing approaches in electricity markets. Tools with this type of capabilities are essential for researchers of the power systems area in order to be prepared to deal with the constant changes in the electricity markets environment. Additionally, market negotiating players, regulators, and operators can fruitfully use the simulation capabilities of MASCEM to test negotiation alternatives in order to maximize their goals.

The simulation results, comparing the probable competitive scenario of all European players negotiating under the same electricity market mechanism, suggest that the implemented markets mechanisms will influence the outcomes of the market. This means that players acting in such a new environment can take huge advantages from using combinations of tools, such as presented in this paper, in order to test and adapt their behavior to better suit the characteristics of the new markets. Aspects such as the types of offers, and their constraints (such as the possibility to submit complex conditions, flexible offers or block offers) obligate players that are not accustomed to such particularities to adapt and understand how to take the most advantages of the new reality. The decision support in this scope is, besides the obvious advantages for studies of regulators and operators, the main contribution of this work.

These different types of offers, each one with specific rules will allow many further studies, mainly regarding the inclusion of intelligent techniques for supporting the players' actions taking into account this market's characteristics. Taking into account, and acknowledging the differences in different electricity markets operation becomes essential for players to be prepared to deal with different negotiation contexts, mainly with the ongoing unification of the European electricity market, and the consequential changes that it will bring to the electricity negotiation process.

As future work, the adaptation of MASCEM to accommodate the inclusion of EUPHEMIA algorithm can be referred. This will allow the study and experimentation of new potential alternatives and improvements, which are facilitated by the use of the proposed ontologies.

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