EPEX Ontology: Enhancing Agent-based Electricity Market Simulation

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***Abstract*—Electricity markets worldwide are complex and dynamic environments with very particular characteristics. The markets' restructuring and evolution into regional and continental scales, along with the constant changes brought by the increasing necessity for an adequate integration of renewable energy sources are the main drivers. Multi-agent based software is particularly well fitted to analyse dynamic and adaptive systems with complex interactions among its constituents, such as electricity markets. This paper proposes the use of ontologies to enable the exchange of information and knowledge, to test different market models and to allow market players from different systems to interact in common market environments. Focusing, namely, on the EPEX electricity market.**

***Index Terms*—Electricity Markets, Multi-agent Simulation, Semantic Interoperability.**

I. Introduction

Electricity markets (EM) worldwide are extremely complex and dynamic. Their restructuring and evolution into regional and continental scale markets, along with the constant changes brought by the increasing necessity for an adequate integration of renewable energy sources, were the main drivers for this progression [1], [2].

This restructuring made the market more competitive, but also more complex, posing new challenges to its participants. Real-world restructured electricity markets are sequential open-ended games with multiple participants trading for electric power. Therefore, the involved entities are forced to rethink their behavior and market strategies. Market players and regulators are very interested in foreseeing market behaviour: market players to understand market behaviour and operate in order to maximize their profits; regulators to test rules before they are implemented and detect market inefficiencies [1], [3].

The use of simulation tools became essential to give entities decision support to address the new challenges. EM simulators must be flexible to deal with the constantly evolving reality of EM and grant actors with appropriate solutions to adapt themselves to the new reality, gaining experience to act in the context of a changing economic, financial, and regulatory environment. Simulation and Artificial Intelligence techniques are essential under this context. Multi-agent based simulation is particularly well fitted to analyse dynamic and adaptive systems with complex interactions among its constituents [3].

Some relevant tools in this domain are: Agent-based Modelling of Electricity Systems (AMES) [4]; Electricity Market Complex Adaptive System (EMCAS) [5]; and Multi-Agent Simulator of Competitive Electricity Markets (MASCEM) [6], [7], amongst several others.

MASCEM [6], [7] is a modeling and simulation tool developed to study the complex and restructured EM. It provides players with competitive advantage in the market by supplying them with simulation and decision-support resources. A multi-agent architecture is used since players are complex entities with distinct characteristics and goals, making their decisions and interacting with each other.

Available EM simulation tools are focused on the study of different market mechanisms and models, and on the analysis of the relationships between market entities. However, interoperability between heterogeneous systems in this scope is still an utopia. Significant added value could be gained by sharing knowledge and market models with other agent societies. Such tools would provide the means for an actual improvement in current EM studies and development [8], [9]. To overcome this issue the *Electricity Markets Ontology* (EMO) has been proposed in [10].

This paper presents the *EPEX Ontology* (EPX), a module extended from EMO [10], developed to provide interoperability in MASCEM's simulations, more specifically in the simulation of EPEX market models.

After this introductory section, section II overviews the most relevant work concerning agent-based EM simulation and EPEX EM. Section III presents the *EPEX Ontology* and section IV exposes a case study based on real data. Finally, section V features the most relevant conclusions.

II. Related Work

EM are evolving to regional markets and some to continental scale. Transaction of huge amounts of electrical energy are already supported by EM, enabling the efficient use of renewable based generation in places where it exceeds the local needs [1]. Nowadays a wide range of negotiation opportunities is available, turning the EM sector into a highly demanding and complex environment, through auction based markets, intraday and balancing negotiations, bilateral contracts, forwards and futures markets, among others [3]. The shared interest of regulators and market players in foreseeing the market's behaviour required a clear understanding of EM principles, and the impact of power systems physics on market dynamics and vice-versa [3], [11]. Additionally, a suitable understanding of the diversity of market types and regulatory models that

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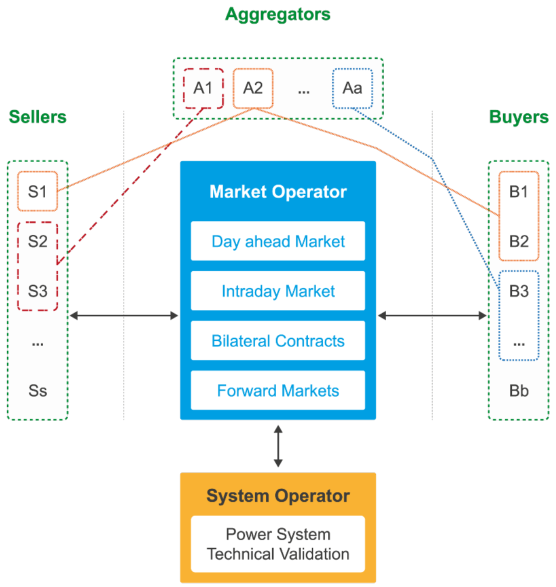

Fig. 1. MASCEM's multi-agent model [10]

have been introduced is critical for the success of all involved players. In this scope arises MASCEM.

A. MASCEM Overview

MASCEM [6], [7] is a modelling and simulation tool developed aiming at the study of EM operation. It models the main market entities and their interactions. Medium/long-term gathering of data and experience is also considered to support players decisions in accordance with their characteristics and goals. The main market entities are implemented as software agents, such as: market and system operators, buyer and seller agents (consumers, producers and/or prosumers), and aggregators. Figure 1 illustrates MASCEM's multi-agent model.

The Market Operator regulates pool negotiations by validating and analysing the players bids depending on the type of negotiation, and determines the market price, the accepted and refused bids, and the economical dispatch that will be sent to the System Operator.

The System Operator examines the technical feasibility from the power system point of view and solves congestion problems that may arise. It is responsible for the system's security as well as to assure that all conditions are met within the system.

The key elements of EM are the Buyer and Seller agents. A Buyer agent may be a consumer or distribution company which participates in the EM in order to buy certain amounts of power. On the other hand, a Seller agent may simulate electricity producers or other entities able to sell energy in the market.

The Aggregators, represent alliances of small independent players, enabling their participation in the wholesale EM and to compete with big players. They manage their aggregates'information and are seen from the market's point of view as buyer or seller agents.

The main types of negotiations normally present in EM included in MASCEM are: day-ahead and intraday pool (symmetric or asymmetric, with or without complex conditions) markets, bilateral contracts and forward markets. By selecting a combination of these market models, it is also possible to perform hybrid simulations.

For each scenario, the user must input the market and market type to simulate, the number of simulation days, the number of participating players and their strategies considering each type of agent, with their own decision-support resources, assuring them competitive advantage in the market. It should also be noticed that MASCEM allows the simulation of three of the main European EM, namely, MIBEL[1], EPEX[2] and NordPool[3]. Subsection II-B details the EPEX Spot market as it is the focus of this work.

B. EPEX Spot

The EPEX Spot market is a symmetric market, where the minimum and maximum bid prices are -500 and 3000 € respectively. It allows two types of offers [12]:

- **Individual hours**: simple orders, which may contain up to 256 combinations of price/amount of energy for each hour of the auction;
- **Block orders**: with the purpose of connecting various periods. The offer is accepted in all periods or is rejected altogether. These present a lower priority when compared to simple orders.

In the case of EPEX [12], [13] no complex conditions are defined. For assuring some restrictions market players may use Block orders. Block orders are intended to connect several periods on an all-or-none basis, meaning that either the offer is accepted in all periods or it is rejected altogether. These offers have a lower priority when compared with the regular hourly offers. A block order is executed or not by comparing its price with the volume-weighted average of the hourly market prices related to the hours contained in the block. There are packages of block offers defined by standard, such as: *Baseload Block*, covering hours 1 to 24; *Peakload Block*, covering hours 9 to 20; *Morning Block*, covering hours 7 to 10; *Evening Block*, covering hours 19 to 24; *Off-Peak Block*, covering hours 1 to 8 and 21 to 24; among others.

There is also the possibility of defining custom blocks from linking a minimum of 2 consecutive periods. A maximum of 40 block orders per player per day can be submitted and the maximum volume for a block order is 400 MW.

C. Multi-agent interoperability

Accordingly to the Foundation for Intelligent Physical Agents (FIPA), multi-agent systems should be able to interoperate. However, it does not mean that agents are able to exchange any useful information due to the use of different languages and vocabularies, specific to each domain, developer team and development platform [6]. It is required that they share a common vocabulary so the messages may be interpreted correctly among agents. Ontologies are used to this end, enabling the standardization of communications and interpretation of concepts between independent systems [6], [10].

[1]http://www.mibel.com/
[2]https://www.epexspot.com/
[3]http://www.nordpoolspot.com/

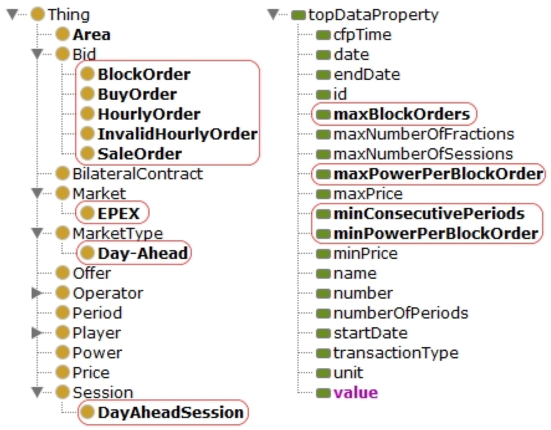

Fig. 2. *EPEX Ontology* classes and data properties

MASCEM agents use EMO to enable interoperability with other agent-based simulators that intend to participate in MASCEM's simulations [6], [10], [14]. It incorporates abstract concepts and axioms referring to the main existing EM, with the aim of being as inclusive as possible in order to be extended and reused in the development of market specific ontologies. To facilitate its reuse and extension independently of the markets features and/or rules, the EMO was kept as simple as possible. However, some markets constraints were also defined, given that the suggested ontologies were developed considering its use by agent based simulation tools.

EMO is publicly available[4] in order to be used by third-party developers who wish to integrate their agent-based simulators with MASCEM, taking advantage of its simulation capabilities and market models. It may also be reused and extended for the development of new multi-agent simulation tools in the context of wholesale EM.

To enable semantic communications between the market operator and player agents, two additional modules have been developed [14]: (i) the *Call for Proposal* (CFP) ontology and (ii) the *Electricity Markets Results* (EMR) ontology. The CFP and EMR ontologies define *Requests*, *Responses* and *Informs* enabling a semantic interaction between the participating agents, while EMO defines the main concepts and axioms of EM. CFP and EMR ontologies are also available online[5]. Further details about them can be found in [14].

III. EPEX Ontology

The EPEX Ontology (EPX) imports EMO, extending its concepts and including some new data properties. It is publicly available for reuse and extension[6]. Figure 2 highlights the classes and data properties included in EPX.

EPX ontology extends only concepts from EMO. The **BuyOrder**, **SaleOrder**, **HourlyOrder** and **InvalidHourlyOrder** are extended from **EMO:Bid**; as well as the concepts extended from **EMO:Market**, **EMO:MarketType** and **EMO:Session**.

TABLE I
EPEX Ontology DATA PROPERTIES DL SYNTAX

Data Properties	
maxBlockOrders $\sqsubseteq \cup$ $\top \sqsubseteq \leq 1$ maxBlockOrders	minPowerPerBlockOrder $\sqsubseteq \cup$ $\top \sqsubseteq \leq 1$ minPowerPerBlockOrder
maxPowerPerBlockOrder $\sqsubseteq \cup$ $\top \sqsubseteq \leq 1$ maxPowerPerBlockOrder	minConsecutivePeriods $\sqsubseteq \cup$ $\top \sqsubseteq \leq 1$ minConsecutivePeriods

TABLE II
EPEX Ontology CLASSES DL SYNTAX

Classes
Area $\sqsubseteq$ **EMO:Area** $\sqcap$ 1 maxBlockOrders $\sqcap$ 1 maxPowerPerBlockOrder $\sqcap$ 1 minPowerPerBlockOrder $\sqcap$ 1 minConsecutivePeriods
BuyOrder $\sqsubseteq$ **EMO:Bid** $\sqcap$ EMO:transactionType "buy"
SaleOrder $\sqsubseteq$ **EMO:Bid** $\sqcap$ EMO:transactionType "sell"
BlockOrder $\sqsubseteq$ **EMO:Bid** $\sqcap \exists$ EMO:hasOffer 1 **EMO:Offer** $\sqcap \exists$ EMO:placedInPeriod 1 **EMO:Period**
HourlyOrder $\sqsubseteq$ **EMO:Bid** $\sqcap \exists$ EMO:hasOffer ≤ 256 **EMO:Offer** $\sqcap \exists$ EMO:placedInSinglePeriod 1 **EMO:Period**
InvalidHourlyOrder $\sqsubseteq$ **EMO:Bid** $\sqcap \exists$ EMO:hasOffer ≥ 257 **EMO:Offer**
DayAheadSession $\sqsubseteq$ **EMO:Session**
Day-Ahead $\sqsubseteq$ **EMO:MarketType** $\sqcap \exists$ EMO:hasSession **DayAheadSession**
EPEX $\sqsubseteq$ **EMO:Market** $\sqcap \exists$ EMO:hasMarketType **Day-Ahead**

The novelty here is the **BlockOrder** which can be seen as a complex condition or constraint.

The classes, the object properties and data properties defined in EPX are shown in Figure 3[7].

EMOs classes are presented in yellow, while its data and object properties have the prefix *"EMO:"*. As can be seen by Figure 3, the **EMO:Area** is redefined in EPX, including the new four data properties of EPX.

This ontology is used both by players and the market operator. The market operator detains a knowledge base defining the markets features. This knowledge base is created from the users input file. The same input file also determines the players knowledge bases. The market operator gathers the players proposals using the ontology's conceptualization.

The EPX ontology data properties and classes, in Description Logic[8] (DL) syntax, are presented in Table I and Table II respectively. Its expressivity is the same as EMO: *ALCHIQ(D)*.

An **Area** is here redefined to include new data properties that relate to the EPEX EM, namely maxBlockOrders, maxPowerPerBlockOrder, minPowerPerBlockOrder and minConsecutivePeriods. Each area in EPEX determines these values considering its particular constraints. On the other hand, enabling a greater flexibility of parameterizations enables more valuable and richer simulations.

BuyOrder and **SaleOrder** are subclasses of **EMO:Bid**, being defined by the transactionType data property, which is equal to buy or sell respectively. **BlockOrder** is also subclass of **EMO:Bid** but only comprises an **EMO:Offer** valid for an interval of **EMO:Periods**, using the EMO:hasOffer and EMO:placedInPeriod respectively. The **HourlyOrder** is another subclass of **EMO:Bid** but including a maximum number of 256 **EMO:Offers**; and it only can be related to a

[4]http://www.mascem.gecad.isep.ipp.pt/ontologies/electricity-markets.owl
[5]http://www.mascem.gecad.isep.ipp.pt/ontologies/call-for-proposal.owl, http://www.mascem.gecad.isep.ipp.pt/ontologies/electricity-markets-results.owl
[6]http://www.mascem.gecad.isep.ipp.pt/ontologies/epex.owl
[7]http://www.mascem.gecad.isep.ipp.pt/ontologies/paper/isap/17/epx.png
[8]http://www.obitko.com/tutorials/ontologies-semantic-web/owl-dl-semantics.html

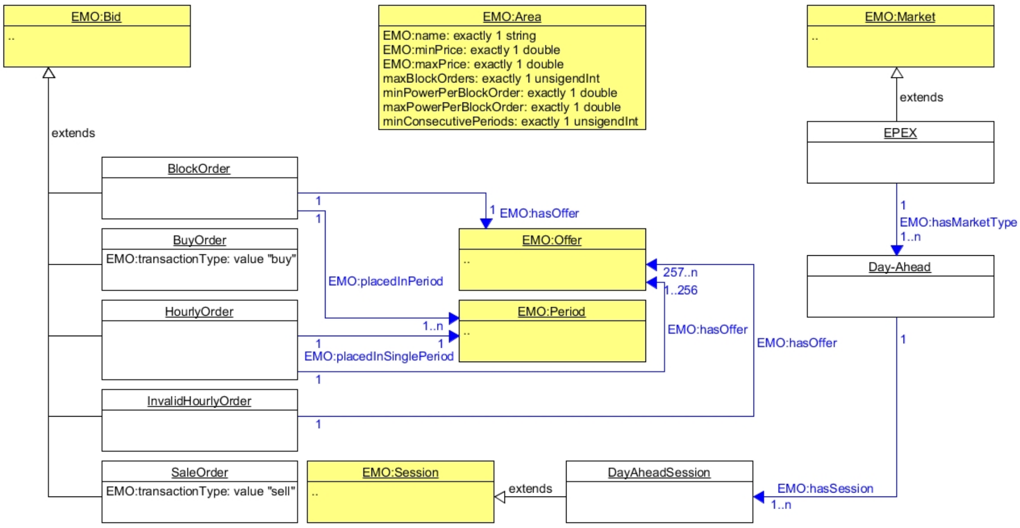

Fig. 3. *EPEX Ontology* classes and data properties

EMO:Period, making use of the EMO:placedInSinglePeriod *Functional*[9] object property. On the other hand, an **InvalidHourlyOrder** in EPX ontology is defined as a **EMO:Bid** with more than 256 **EMO:Offer**s.

DayAheadSession is subclass of **EMO:Session**; and the **Day-Ahead** is subclass of **EMO:MarketType**, including the **DayAheadSession** using the object property EMO:hasSession. The **EPEX** concept is subclass of **EMO:Market** and includes the **Day-Ahead** market type with the object property EMO:hasMarketType.

IV. Case Study

This case study is based on a scenario generated by RealScen (Realistic Scenarios Generator) [15], a scenarios generation tool developed in GECAD, using real data extracted from several European market operators, through an extraction tool [16]. The scenario was created with the intention of representing the EPEX reality through a summarized group of players, considering data of 25th July 2012. It includes 41 buyers and 41 sellers, resulting in a total of 82 players.

As the simulation starts, MASCEMs Main Agent reads the input excel file to generate the players involved in the simulation and their respective knowledge base (KB) files. After being created, each agent receives a message from the MASCEMs Main Agent with their KB represented in RDF/XML[10].

The simulation begins with the market operators sending the call for proposals to all the registered players. After receiving the CfP, each player queries its KB in order to send its proposal to the respective market operator. Figure 4 shows a snippet of the market proposal sent by Seller 22. The complete version is available online[11], where the prices and amount of power to trade are more easily perceptible.

After receiving the proposals and validating all incoming offers, the market operator analyses the bids, executes the market algorithm, and generates the result RDF/XML files to be sent to the participating players. The result achieved by Seller 22 is illustrated in Figure 5 (in RDF/XML) where the hourly results for the periods 12 and 24 (between lines 11 and 22) are presented. The result may be observed with better insight online[12].

Figure 6 presents the market result for Seller 22. In addition to the hourly offers, this player also decided to present block offers. This type of offer can be seen as a group of single hourly offers, where each order can have a different amount of energy, but all have the same price. The orders included in 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 must be accepted in the market for the block to be negotiated. However, since the main objective of this player is to sell as much power as possible, Seller 22 offers the majority of its available power at low prices, but using the block offers trying to optimize the price on a smaller amount of power, assuming that risk.

The block order submitted by Seller 22 is composed 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 MWh) and the price set for the block is 44€/MWh.

As it is possible to observe in Figure 6, the block order was not accepted, despite its price being lower than the market price on 23 of the 24 hourly periods. The market price of the 5^{th} period was set at 42€/MWh (below the block offer price), which caused the entire block being refused in the market, according with the fill-or-kill condition.

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

[9]A functional property is a property that only relates the same subject to one single object/value.

[10]XML syntax to represent a Resource Description Framework (RDF) graph.

[11]http://www.mascem.gecad.isep.ipp.pt/ontologies/paper/isap/17/proposal.rdf

[12]http://www.mascem.gecad.isep.ipp.pt/ontologies/paper/isap/17/result.rdf

```xml
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<rdf:RDF
 xmlns:cfp="http://www.mascem.gecad.isep.ipp.pt/ontologies/call-for-proposal.owl#"
 xmlns:emo="http://www.mascem.gecad.isep.ipp.pt/ontologies/electricity-markets.owl#"
 xmlns:epex="http://www.mascem.gecad.isep.ipp.pt/ontologies/epex.owl#"
 xmlns:owl="http://www.w3.org/2002/07/owl#"
 xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
 xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
 xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
 xml:base="http://www.mascem.gecad.isep.ipp.pt/ontologies/">
  <rdf:Description rdf:about="epex.owl#iOffer1-P3-DayAheadSession2012-07-25-0">
    <emo:hasPrice rdf:resource="epex.owl#iPrice1-P3-DayAheadSession2012-07-25-0"/>
    <emo:hasPower rdf:resource="epex.owl#iPower1-P3-DayAheadSession2012-07-25-0"/>
    <emo:number rdf:datatype="http://www.w3.org/2001/XMLSchema#unsignedInt">1
    </emo:number>
    <emo:id rdf:datatype="http://www.w3.org/2001/XMLSchema#unsignedLong">
    8611796767900337750</emo:id>
    <rdf:type rdf:resource="electricity-markets.owl#Offer"/>
  </rdf:Description>
  <rdf:Description rdf:about="epex.owl#iPrice1-P12-DayAheadSession2012-07-25-0">
    <emo:value rdf:datatype="http://www.w3.org/2001/XMLSchema#double">8.55
    </emo:value>
    <emo:unit>EUR</emo:unit>
    <rdf:type rdf:resource="electricity-markets.owl#Price"/>
  </rdf:Description>
```


Fig. 4. Proposal sent by Seller 22


```xml
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<rdf:RDF
 xmlns:emo="http://www.mascem.gecad.isep.ipp.pt/ontologies/electricity-markets.owl#"
 xmlns:emr="
 http://www.mascem.gecad.isep.ipp.pt/ontologies/electricity-markets-results.owl#"
 xmlns:epex="http://www.mascem.gecad.isep.ipp.pt/ontologies/epex.owl#"
 xmlns:owl="http://www.w3.org/2002/07/owl#"
 xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
 xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
 xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
 xml:base="http://www.mascem.gecad.isep.ipp.pt/ontologies/">
  <rdf:Description rdf:about="electricity-markets-results.owl#iHourlyResult-24">
    <emo:hasPrice rdf:resource=
    "electricity-markets-results.owl#iMarketPrice-HourlyResult-24"/>
    <emo:hasPower rdf:resource=
    "electricity-markets-results.owl#iTradedPower-HourlyResult-24"/>
    <emr:periodNumber rdf:datatype="http://www.w3.org/2001/XMLSchema#unsignedInt">24
    </emr:periodNumber>
    <rdf:type rdf:resource="electricity-markets-results.owl#HourlyResult"/>
  </rdf:Description>
  <rdf:Description rdf:about="electricity-markets-results.owl#iHourlyResult-12">
    <emo:hasPrice rdf:resource=
    "electricity-markets-results.owl#iMarketPrice-HourlyResult-12"/>
    <emo:hasPower rdf:resource=
    "electricity-markets-results.owl#iTradedPower-HourlyResult-12"/>
    <emr:periodNumber rdf:datatype="http://www.w3.org/2001/XMLSchema#unsignedInt">12
    </emr:periodNumber>
    <rdf:type rdf:resource="electricity-markets-results.owl#HourlyResult"/>
  </rdf:Description>
```


Fig. 5. Result achieved by Seller 22

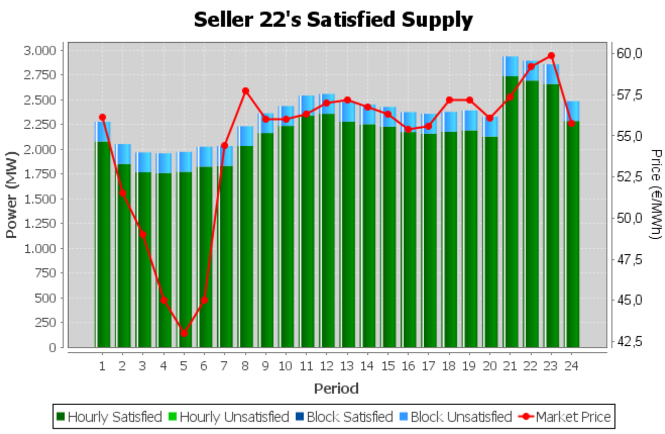

Fig. 6. Result achieved by Seller 22

price, such as Seller 22 did when participating in the EPEX SPOT market, the risk of the whole block being rejected increases because of the fill-or-kill condition.

Additionally, the use of the proposed ontology, which defines the characteristics and specifications of EPEX EM, allows inferring market rules from the contained information.

V. Conclusions

There are inherent difficulties in integrating independently developed agent-based systems, especially to access and map private ontologies. To overcome these difficulties, this work disseminates the development of interoperable multi-agent simulators in the EM research area, thus enabling knowledge exchange between them in order to take full advantage of their functionalities, and promoting the adoption of a common semantic that enables the communication between these heterogeneous systems.

Opening the simulation environment to other systems brings the opportunity of integrating different market models and allows agents, from other systems with very distinct characteristics, to be able to interact in joint simulations. For such, it is mandatory that the messages exchanged by the involved agents may be properly interpreted. The cooperation between the different platforms can benefit in a large scale the realism and depth of EM and power systems'studies.

To achieve systems interoperability the *Electricity Markets Ontology* has been developed. It is the base ontology from which several domain specific ontologies were extended. This is the case of the *Call for Proposal*, *Electricity Markets Results* and *EPEX* ontologies. The first two are common ontologies for EM operation, while the last one is related to the EPEX EM model included in MASCEM. The developed ontologies are publicly available to be easily accessed, reused and extended by Ontology Engineers or Agent-based systems developers in the scope of EM.

The presented case study illustrates the use and usefulness of the developed module, being given emphasis to the communications exchanged between agents instead of the achieved market's results. The integration of the proposed ontologies provides a solid and enhanced platform to study and explore the implications and consequences of new and already existing approaches in EM.

Researchers of the power systems area consider tools with this type of capabilities essential in order to be prepared to deal with the constant changes in the EM environment.

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