Nord Pool Ontology to Enhance Electricity Markets Simulation in MASCEM

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Abstract. This paper proposes the use of ontologies to enable information and knowledge exchange, to test different electricity market models and to allow players from different systems to interact in common market environments. Multi-agent based software is particularly well fitted to analyse dynamic and adaptive systems with complex interactions among its constituents, such as the complex and dynamic electricity markets. The main drivers are 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. An ontology to represent the concepts related to the Nord Pool Elspot market is proposed. It is validated through a case study considering the simulation of Elspot market. Results show that heterogeneous agents are able to effectively participate in the simulation by using the proposed ontologies to support their communications with the Nord Pool market operator.

Keywords: Electricity Markets, Multi-agent Simulation, Nord Pool Elspot Market, Semantic Interoperability.

1 Introduction

Real-world restructured electricity markets (EM) are sequential open-ended games with multiple participants trading for electric power. EM are extremely complex and dynamic environments due to 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 [1,2].

With this restructuring EM became more competitive, posing new challenges to its participants and regulators, forcing them to rethink their behaviour and market strategies. Regulators need to experiment new market rules to detect inefficiencies before implementing them. Market players are very interested to understand its behaviour and operation to maximize their profits [1,3].

Decision support simulation tools to address the new challenges became essential to these entities. Simulation and Artificial Intelligence techniques are required under this context. Simulators in this area must be able to deal with the dynamic and rapid evolution of EM and adopt new models and constraints of the market, providing players with adequate tools to adapt themselves to this changing environment. Multi-agent based simulators are particularly well suited for the analysis of complex interactions in dynamic and complex systems such as the EM [3].

Some of the main advantages that multi-agent approaches provide are the facilitated inclusion of new models, market mechanisms, player types, and different types of interactions [4]. In this domain some reference modelling tools have emerged, such as AMES (Agent-based Modelling of Electricity Systems) [5], EMCAS (Electricity Market Complex Adaptive System) [6] and MASCEM (Multi-Agent Simulator of Competitive Electricity Markets) [7,8].

MASCEM [7,8] is a modelling and simulation tool developed to study the complex and restructured EM. It supplies players with simulation and decision-support resources, providing them with competitive advantage in the market. It's multi-agent architecture models EM's complex entities, with their distinct characteristics, aims, and interactions.

Although several works have confirmed the adequate applicability of multi-agent simulation to the study of EM, they have a common limitation: the lack of interoperability between the various systems to allow 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. Current tools are directed to the study of different EM mechanisms and to the analysis of the relationships between market entities, but they do not enable the interoperability with external systems.

These limitations point out the need for the interaction between agent-based simulators in the scope of EM. These simulators could gain significant added value by sharing their knowledge and market models with other agent societies. Such tools would provide the means for an actual improvement in current EM studies and development [9,10]. To overcome this issue the *Electricity Markets Ontology* (EMO) has been proposed in [11].

This article introduces the *Nord Pool Ontology* (NPO), an extension from EMO [11], developed to provide MASCEM with interoperability in the simulation of Nord Pool Elspot market.

After this introductory section, section 2 presents related work on multi-agent interoperability, Nord Pool Spot market model, and agent-based EM simulation. Section 3 introduces the *Nord Pool Ontology* and section 4 features a case study based on real data. Finally, section 5 exposes the most relevant conclusions.

2 Related Work

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 [7]. 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 [7,11].

2.1 Multi-agent interoperability

There are inherent difficulties in the integration of independently developed agent-based systems, especially to access and map private ontologies. This work has the purpose of disseminating the development of interoperable multi-agent simulators in the EM research area, 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 heterogeneous systems. For that purpose EMO has been proposed [11]; a general ontology that gathers the main concepts of EM, so that it can be imported and extended by lower-level domain ontologies, facilitating mappings between them and the share of knowledge between systems.

EMO 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. It was kept as simple as possible to facilitate its reuse and extension independently of the markets features and/or rules. However, some markets constraints were also defined, given that the suggested ontologies were developed considering its use by agent based simulation tools.

It is publicly available [3] to third-party developers who wish to reuse or extend it for new agent-based EM simulation tools; or even to integrate their agent-based simulators with MASCEM, taking advantage of its simulation capabilities and market models.

Two additional modules have been developed to enable semantic communications between the market operator and player agents [12]: (i) the *Call for Proposal* (CFP) ontology and (ii) the *Electricity Markets Results* (EMR) ontology. EMO defines the main concepts and axioms of EM, while CFP and EMR ontologies define *Requests*, *Responses* and *Informs* enabling a semantic interaction between the participating agents. CFP and EMR ontologies are also available online[4]. Further details about them can be found in [12].

2.2 Nord Pool Elspot market

The Elspot market from Nord Pool is an auction based market, where both buyers and sellers present offers (symmetrical pool). The offers must be contained

[3] `http://www.mascem.gecad.isep.ipp.pt/ontologies/electricity-markets.owl`

[4] `http://www.mascem.gecad.isep.ipp.pt/ontologies/call-for-proposal.owl`, `http://www.mascem.gecad.isep.ipp.pt/ontologies/electricity-markets-results.owl`

in the price range set by Nord Pool Spot. Elspot enables three types of offers [13], namely:

- **Hourly Orders**: simple orders, which may contain up to 64 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.
- **Flexible Hourly Orders**: give the opportunity to present sale offers only, 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.

Nord Pool [13,14], supports the submission of *Flexible hourly orders* in addition to *Block orders*. The supported *Block orders* intend to connect several periods on an all-or-none basis, meaning that the order is accepted in all periods or rejected altogether. *Block orders* have low priority when compared with *Hourly orders*. In turn, a *Flexible hourly order* is a single sale offer (purchases are not allowed) where sellers specify only the price and amount of energy to trade. The period is not indicated as this type of order is accepted in any period of the day, depending on the optimization of the overall socio-economic welfare of the market.

For flexible offers, trading occurs in the same way as with the hourly orders, and these deals will apply in the period when its use maximizes the overall markets social welfare. Regarding 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, for selling offers; or if the market price of the block periods is equal to, or less than, the price of the block, for purchasing bids. This condition is called *fill-or-kill*.

2.3 MASCEM Overview

MASCEM [7,8] is a modelling and simulation tool developed to study and simulate 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. Is responsible for the system's security as well as to assure that all conditions are met within the system.

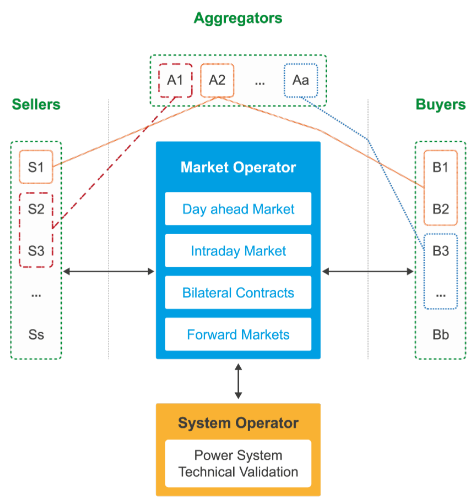

Fig. 1. MASCEM's multi-agent model [11]

Buyer and Seller agents are the key elements of EM. 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.

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. MASCEM allows the simulation of three of the main European EM: MIBEL[5], EPEX[6] and Nord Pool[7].

[5] `http://www.mibel.com/`
[6] `https://www.epexspot.com/`
[7] `http://www.nordpoolspot.com/`

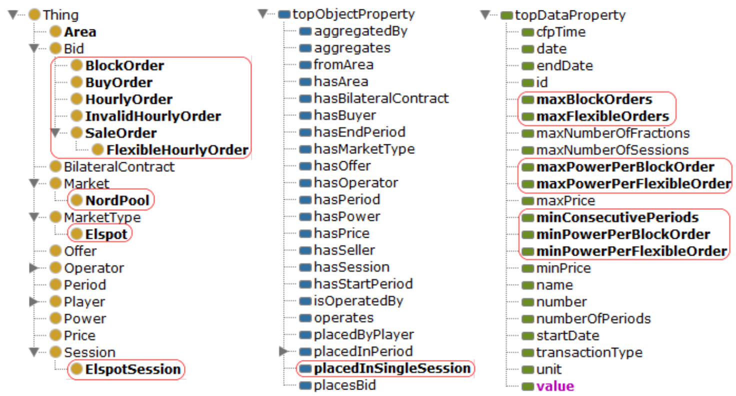

Fig. 2. *Nord Pool Ontology* classes, object and data properties

3 Nord Pool Ontology

The Nord Pool Ontology (NPO) imports EMO, extending its concepts and including some new classes, object and data properties. It is publicly available for reuse and extension[8]. Figure 2 highlights the classes (in yellow), object (in blue), and data properties (in green) included in NPO.

NPO extends only concepts from EMO. The **BLockOrder**, **BuyOrder**, **HourlyOrder**, **InvalidHourlyOrder** and **SaleOrder** concepts are extended from **EMO:Bid**; in the same way as **NordPool**, **Elspot** and **ElspotSession** extend from **EMO:Market**, **EMO:MarketType** and **EMO:Session**, respectively. It is also possible to observe in Figure 2 the **FlexibleHourlyOrder** concept (on the left column), included as a subclass of **SaleOrder**, meaning that it is only allowed as a sale bid. A new object property - placedInSingleSession - and seven new data properties (maxBlockOrders, maxFlexibleOrders, maxPowerPerBlockOrder, maxPowerPerFlexibleOrder, minConsecutivePeriods, minPowerPerBlockOrder and minPowerPerFlexibleOrder) were also included.

Figure 3[9] exposes the classes, object properties and data properties of NPO. The EMOs concepts are illustrated in yellow, and the prefix *"EMO:"* identifies EMOs object and data properties. The object properties of both EMO and NPO are identified in blue. As is possible to observe, in NPO, the **EMO:Area** is redefined including the new seven data properties of NPO.

NPO is used by players willing to participate in **Elspot** simulations through its market operator. Tables 1, 2 and 3 provide the description logic[10] (DL) syntaxes of its object and data properties, and classes. Similarly to EMO, NPO has expressiveness *ALCHIQ(D)* [11].

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[8] `http://www.mascem.gecad.isep.ipp.pt/ontologies/nordpool.owl`
[9] `http://www.mascem.gecad.isep.ipp.pt/ontologies/paper/epia/17/npo.png`
[10] `http://www.obitko.com/tutorials/ontologies-semantic-web/owl-dl-semantics.html`

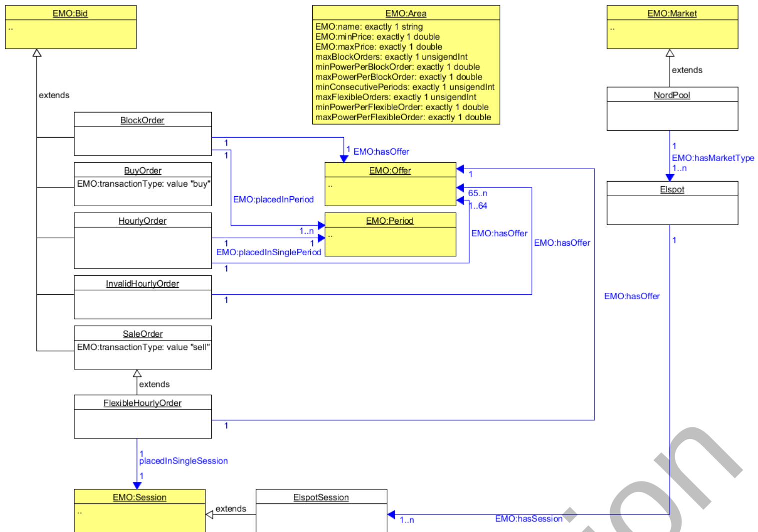

Fig. 3. *Nord Pool Ontology*

Table 1. *Nord Pool Ontology* object property DL syntax

Object Property
placedInSingleSession $\sqsubseteq R$ $\top \sqsubseteq \leq 1$ placedInSingleSession

Table 2. *Nord Pool Ontology* data properties DL syntax

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

Table 3. *Nord Pool Ontology* classes DL syntax

Classes
Area $\sqsubseteq$ **EMO:Area** $\sqcap$ 1 maxBlockOrders $\sqcap$ 1 maxPowerPerBlockOrder $\sqcap$ 1 minPowerPerBlockOrder $\sqcap$ 1 minConsecutivePeriods $\sqcap$ 1 maxFlexibleOrders $\sqcap$ 1 maxPowerPerFlexibleOrder $\sqcap$ 1 minPowerPerFlexibleOrder
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 ≤ 64 **EMO:Offer** $\sqcap$ $\exists$ EMO:placedInSinglePeriod 1 **EMO:Period**
InvalidHourlyOrder $\sqsubseteq$ **EMO:Bid** $\sqcap$ $\exists$ EMO:hasOffer ≥ 65 **EMO:Offer**
FlexibleOrder $\sqsubseteq$ **SaleOrder** $\sqcap$ $\exists$ EMO:hasOffer 1 **EMO:Offer** $\sqcap$ $\exists$ placedInSingleSession 1 **EMO:Session**
ElspotSession $\sqsubseteq$ **EMO:Session**
Elspot $\sqsubseteq$ **EMO:MarketType** $\sqcap$ $\exists$ EMO:hasSession **ElspotSession**
NordPool $\sqsubseteq$ **EMO:Market** $\sqcap$ $\exists$ EMO:hasMarketType **Elspot**

The **Area** is redefined to include new data properties related with the Nord Pool Elspot EM, namely maxBlockOrders, maxPowerPerBlockOrder, minPowerPerBlockOrder, minConsecutivePeriods, maxFlexibleOrders, maxPowerPerFlexibleOrder and minPowerPerFlexibleOrder. Each area 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:Period**s, using the EMO:hasOffer and EMO:placedInPeriod respectively.

The **HourlyOrder** is also subclass of **EMO:Bid** but including a maximum number of 64 **EMO:Offer**s; and it only can be related to a **EMO:Period**, making use of the EMO:placedInSinglePeriod *Functional*[11] object property. In turn, an **InvalidHourlyOrder** is defined as a **EMO:Bid** with 65 or more **EMO:Offers**.

The **FlexibleHourlyOrder** is subclass of **SaleOrder** and only accepts one **EMO:Offer** which can be only assigned to a **EMO:Session**, using the object properties EMO:hasOffer and placedInSingleSession, respectively. The placedInSingleSession object property is also *Functional*. The **FlexibleHourlyOrder** may be seen as a complex condition only available for sellers, similarly to the day-ahead complex conditions of MIBEL, which are only allowed for seller agents [12].

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

[12] `http://www.omie.es/en/home/markets-and-products/electricity-market/our-electricity-markets/daily-market`

```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:nordpool="http://www.mascem.gecad.isep.ipp.pt/ontologies/nordpool.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="nordpool.owl#iMO-NORDPOOL_2012_07_25">
    <emo:name>NORDPOOL 2012 07 25</emo:name>
    <rdf:type rdf:resource="electricity-markets.owl#MarketOperator"/>
  </rdf:Description>
  <rdf:Description rdf:about="nordpool.owl#iPrice1-P22-ElspotSession2012-07-25-0">
    <emo:value rdf:datatype="http://www.w3.org/2001/XMLSchema#double">9.86
    </emo:value>
    <emo:unit>EUR</emo:unit>
    <rdf:type rdf:resource="electricity-markets.owl#Price"/>
  </rdf:Description>
```


Fig. 4. Proposal sent by Seller 22

The **ElspotSession** is subclass of **EMO:Session**; and **Elspot** is subclass of **EMO:MarketType**, including the **ElspotSession** using the object property EMO:hasSession. The **NordPool** concept is subclass of **EMO:Market** and includes the **Elspot** market type with the object property EMO:hasMarketType.

The next section presents a case study to demonstrate NPO's use to support players participation in Elspot market.

4 Case Study

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

As the simulation starts, MASCEM's Main Agent reads the input file to generate the involved players and their knowledge base (KB) files. After being created, each agent receives a message from MASCEM's Main Agent with its KB represented in RDF/XML[13].

The market session begins with the market operators sending the call for proposals (CfP) to all registered players. After, each player queries its KB in order to send its proposal to the market operator. Figure 4 shows a snippet of the market proposal sent by Seller 22. The complete version is available online[14].

After receiving all the proposals and validating 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. Figure 5 presents

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

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

```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:nordpool="http://www.mascem.gecad.isep.ipp.pt/ontologies/nordpool.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#iFlexibleResult-2">
    <emo:hasPrice rdf:resource=
    "electricity-markets-results.owl#iMarketPrice-FlexibleResult-2"/>
    <emo:hasPower rdf:resource=
    "electricity-markets-results.owl#iTradedPower-FlexibleResult-2"/>
    <emr:periodNumber rdf:datatype="http://www.w3.org/2001/XMLSchema#unsignedInt">2
    </emr:periodNumber>
    <rdf:type rdf:resource="electricity-markets-results.owl#FlexibleResult"/>
  </rdf:Description>
  <rdf:Description rdf:about=
  "electricity-markets-results.owl#iTradedPower-FlexibleResult-11">
    <emo:unit>MW</emo:unit>
    <emo:value rdf:datatype="http://www.w3.org/2001/XMLSchema#double">0.0</emo:value>
    <rdf:type rdf:resource="electricity-markets-results.owl#TradedPower"/>
  </rdf:Description>
```


Fig. 5. Result sent to Seller 22 by Elspot's market operator

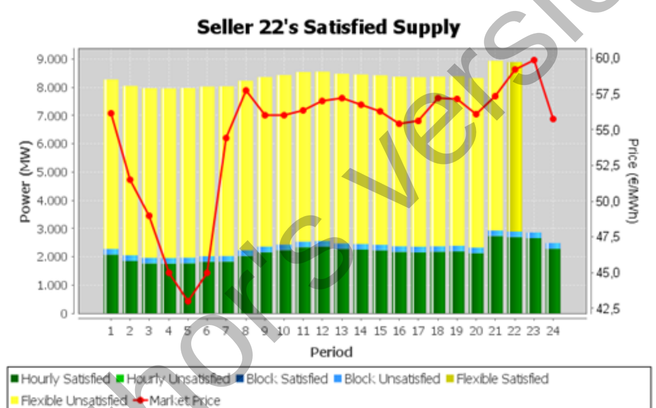

Fig. 6. Result achieved by Seller 22

the result sent by the market operator to Seller 22 (in RDF/XML); also available online[15].

Figure 6 illustrates the market result for Seller 22. In this market, 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 socioeconomic welfare of the market. In this scenario three orders were submitted with the volume of 2000MWh each, all at the same price of 40€/MWh.

It is possible to observe from the chart of Figure 6 that during the first twenty one periods none of the orders was accepted although bid price being below the

[15] `http://www.mascem.gecad.isep.ipp.pt/ontologies/paper/epia/17/result.rdf`

established market price. The light yellow bars indicate a total of 6000MWh of unsold energy during these periods (referring to the total of the three flexible offers, of 2000MWh each). All flexible hourly orders were accepted in the 22^{nd} period. Only the block orders were unsatisfied in all of the 24 hourly periods. As mentioned before, the condition for the acceptance of each (or all) flexible offer(s) is not only the proposed bid price, but also the maximization of the socioeconomic welfare of the market session, from the market operators perspective. Additionally, the use of the proposed ontology allows inferring market rules from the contained information. Taking these rules into account, behaviours can be modelled and adapted.

5 Conclusions

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 systems.

Opening the simulation environment to other systems enables the integration of different market models and allows agents, from heterogeneous systems, 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 realism and depth of EM and power systems' studies can benefit in a large scale from the cooperation between the different platforms.

The *EMO* has been developed to achieve systems interoperability. It is the base ontology from which other domain specific ontologies were extended, such as the *CFP*, *EMR* and *NPO*. The first two are common ontologies for EM operation, while the last one is related to the Nord Pool EM model included in MASCEM. The developed ontologies are publicly available to be easily reused and extended by ontology engineers EM scope.

The integration of the proposed ontologies provides an enhanced platform to study and explore the implications and consequences of new and already existing approaches in 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.

Acknowledgments. This work has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 641794 (project DREAM-GO) and from FEDER Funds through COMPETE program and from National Funds through FCT under the project UID/EEA/00760/2013.

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