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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