Energy 116 (2016) 128–139

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

# Generation of realistic scenarios for multi-agent simulation of electricity markets

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A R T I C L E  I N F O

*Article history:*
Received 5 April 2016
Received in revised form
9 August 2016
Accepted 16 September 2016

*Keywords:*
Data-Mining
Electricity markets
Knowledge discovery
Machine learning
Multi-agent simulation
Scenarios generation

A B S T R A C T

Most market operators provide daily data on several market processes, including the results of all market transactions. The use of such data by electricity market simulators is essential for simulations quality, enabling the modelling of market behaviour in a much more realistic and efficient way. RealScen (Realistic Scenarios Generator) is a tool that creates realistic scenarios according to the purpose of the simulation: representing reality as it is, or on a smaller scale but still as representative as possible. This paper presents a novel methodology that enables RealScen to collect real electricity markets information and using it to represent market participants, as well as modelling their characteristics and behaviours. This is done using data analysis combined with artificial intelligence. This paper analyses the way players' characteristics are modelled, particularly in their representation in a smaller scale, simplifying the simulation while maintaining the quality of results. A study is also conducted, comparing real electricity market values with the market results achieved using the generated scenarios. The conducted study shows that the scenarios can fully represent the reality, or approximate it through a reduced number of representative software agents. As a result, the proposed methodology enables RealScen to represent markets behaviour, allowing the study and understanding of the interactions between market entities, and the study of new markets by assuring the realism of simulations.



## 1. Introduction

The restructuring of Electricity Markets (EM) has created a new design of the electricity sector, becoming a new global trend. The monopoly model gave way to a non-vertical structure that allows the development of a free competition market, as it allows the liberalization of potentially competitive segments, such as production, transportation and distribution [1]. These changes provide conditions for the establishment of a more competitive market but also more complex, where the laws of supply and demand stimulate the quality of service, reduce costs and increase efficiency. The growth of complexity creates new challenges, namely the difficulty in decision making due to markets unpredictability and the high number of associated variables [2].

Simulation started to play a key role in supporting decision-making in the electricity sector. It allows studying and analysing the profiles and strategies of market participants and, thus, model market behaviour and forecast proposals [3]. Such characteristics enable the establishment of conditions conductive to decision making, turning the simulators into essential tools to support the necessary decisions on major investment environments.

Simulation tools applied to EM are designed to help market entities to respond efficiently to market unpredictability. Each one of the surrounding entities may present different behaviours resulting from the context and its goals, having an immediate impact on the results obtained in the market [4]. Therefore, simulators allow to perform a study of new types of participating entities, their behaviour, market models, types of market trading mechanisms, among others, to understand the impact of these variables on system performance and, therefore, to react in order to achieve the best possible results.

Although multi-agent simulation tools present many advantages, most are not able to present results that can be applied to reality [5]. In order to deal with this problem, it is necessary to

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http://dx.doi.org/10.1016/j.energy.2016.09.096

create realistic scenarios that consider real data about the behaviour and characteristics of market participants as well as the specifications of the markets [6,7]. Although data is available on the website of the different market players (e.g. online platform of Nord Pool market operator [8]), the extraction of these data is a very laborious procedure due to their size, diversity and availability mode. When this problem is surpassed, the real challenge arises: the analysis and extraction of useful information based on these data so that it becomes possible to create realistic scenarios and thereby improve the performance of multi-agent simulators.

This paper presents a novel methodology that generates realistic scenarios for multi-agent simulation of EM. Artificial Intelligence (AI) and Data Mining (DM) techniques are used to perform data analysis and extract the information needed for modelling the characteristics and behaviour of market participants. In order to simplify the simulation, reducing the required computational effort, when necessary, an adjustment of the size of the desired scenario is performed, using fuzzy logic and clustering techniques. The fuzzy logic process determines the number of representative agents of the entities participating in the market, while the clustering approach decides how to divide the players by the determined number of representative agents, taking into account each of their characteristics and respective importance. Artificial Neural Networks (ANN), Support Vector Machines (SVM) and a Simple Average technique are also used in order to forecast, based on the history of the player, the price and quantity of energy that each market player will negotiate in the market. In addition, there is a VPP (Virtual Power Player) creation mechanism that allows agents to form coalitions, by grouping together in order to increase their competitiveness in the market.

The proposed scenario generation model is integrated in RealScen (Realistic Scenario Generator), a tool that is directed to supporting the creation of realistic simulation scenarios for different electricity markets multi-agent simulators. A very important contribution to this tool's development was one of the previous works that is related to a tool able to handle, store and dynamically update real electricity markets data [9]. With access to that data, it was possible to develop a preliminary version of RealScen that was focused in the data aggregation component [5]. The next step was to evolve the tool in order to make it more complete and accurate, which resulted in a new version, presented in Ref. [10]. One of the main aspects of the new release was the inclusion of a graphical user interface that eases the whole process of creating a scenario.

After this introductory chapter, chapter 2 presents a contextualization of EM – the target environment that is modelled by the proposed method, including the presentation of the main models, with special focus to the Day-ahead Spot Model. Chapter 2 also introduces some of the main multi-agent EM simulators. Chapter 3 describes the proposed scenario generation model, and the RealScen tool. This includes the model architecture and operating mode, where the main steps in the generation of a scenario are defined. Chapter 4 presents a case study that demonstrates the quality of results of the proposed model, by presenting a comparison between the scenarios generated by the proposed model and the actual market results for the same days. Finally, chapter 5 presents the main conclusions of the developed work.

## 2. Electricity markets and simulation

The conjuncture in the electricity sector has been changing over the years. Currently, most countries have their own market or participate jointly with other countries in a regional markets [2]. Each EM is usually composed by several market types, which are usually made from three basic models: Day-Ahead Spot, Intraday or Balancing Market and Bilateral Contracts model. The differences between them lie under their rules, objectives and how they operate. The Day-Ahead Spot Market aims to negotiate energy for the following day, the Intraday/Balancing Market allows players to negotiate almost in real-time in order to adjust their needs and compensate possible forecast errors. Negotiation by means of Bilateral Contracts is based on trading power for an extended time horizon, directly between players [11].

The Spot Market is usually where the larger amount of energy is traded, and it is characterized by an enhancement of competitiveness, given that the likelihood of selling in this market increases when the bid value is lower, which gets more buyers to compete in the bidding. This process lowers the selling prices and motivates buyers to submit bids with higher values to increase their chances of buying as well.

### 2.1. Electricity market simulators

Due to the great complexity and dynamism inherent to EM and to their constant evolution, the use of multi-agent simulators applied to EM is increasing. There are several simulators available, each one of them with their own goals and limitations. The market regulators are especially interested in this kind of tools in order to test new rules and detect inefficiencies that are occurring in the system. On the other hand, the players also benefit from these tools because they allow the study of players' behaviour, in order to maximize their profit [12]. Some of the most relevant simulators are EMCAS (The Electricity Market Complex Adaptive System) [13], AMES (Agent-based Modelling of Electricity Systems) [14], MASCEM (Multi-agent Simulator for Competitive Electricity Markets) [15,16] and MAN-REM (Multi-Agent Negotiation and Risk Management in Electricity Markets).

The Electricity Market Complex Adaptive System (EMCAS) [13] uses an agent based approach with agents' strategies based on learning and adaptation. Different agents are used to capture the restructured markets heterogeneity, including generation, demand, transmission, and distribution companies, independent system operators, consumers and regulators. It allows undertaking Electricity Markets simulations in a time continuum ranging from hours to decades, including several Pool and Bilateral Contracts markets.

Agent-based Modelling of Electricity Systems (AMES) [14] is an open-source computational laboratory for the experimental study of wholesale power markets restructured in accordance with U.S. Federal Energy Regulatory Commission (FERC)'s market design. It uses an agent-base test bed with strategically learning electric power traders to experimentally test the extent to which commonly used seller market power and market efficiency measures are informative for restructured wholesale power markets. The wholesale power market includes independent system operator, load-serving entities and generation companies, distributed across the busses of the transmission grid. Each generation company agent uses stochastic reinforcement learning to update the action choice probabilities currently assigned to the supply offers in its action domain.

Simulator for Electric Power Industry Agents (SEPIA) [17] is a Microsoft Windows platform oriented simulator. It is based on a Plug and Play architecture, allowing users to easily create simulations involving several machines in a network, or in a single machine, using various processing units. SEPIA allows specifying the number of participating agents, as well as their behaviours, interactions, and changes during the simulation. The simulation developments can be followed and oriented by mechanisms for that purpose.

Power Web [18] is a Web-based market simulator, allowing the various participants to interact from very distinct zones of the