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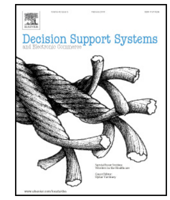

Six thinking hats: A novel metalearner for intelligent decision support in electricity markets

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ABSTRACT

The energy sector has suffered a significant restructuring that has increased the complexity in electricity market players' interactions. The complexity that these changes brought requires the creation of decision support tools to facilitate the study and understanding of these markets. The Multiagent Simulator of Competitive Electricity Markets (MASCEM) arose in this context, providing a simulation framework for deregulated electricity markets. The Adaptive Learning strategic Bidding System (ALBidS) is a multiagent system created to provide decision support to market negotiating players. Fully integrated with MASCEM, ALBidS considers several different strategic methodologies based on highly distinct approaches. Six Thinking Hats (STH) is a powerful technique used to look at decisions from different perspectives, forcing the thinker to move outside its usual way of thinking. This paper aims to complement the ALBidS strategies by combining them and taking advantage of their different perspectives through the use of the STH group decision technique. The combination of ALBidS' strategies is performed through the application of a genetic algorithm, resulting in an evolutionary learning approach.

1. Introduction

The electricity industry has been facing an important challenge since the 1980s—a market environment is replacing the traditional centralised-operation approach, thereby creating a more competitive and complex environment [1]. This deregulation, often accompanied by privatisation processes, has brought many changes. For example, presently the industry is organised in a horizontal way, replacing the previous vertical organisation. Many electricity companies used to be responsible for the complete business chain; now, they are split into several companies, with each one focusing exclusively on one business area: generation, transmission, distribution, and retail. The changes also aim to give consumers a more active role in the market, ensuring their ability to choose their energy supplier [2]. The new electricity market environment is more complex and unpredictable, forcing interveners to rethink their strategies and behaviour. Several market models exist, with different rules and constraints, creating the need to foresee market behaviour. Regulators need to test the rules before they are implemented, and market players need to understand the market so that they can reap the benefits of well-planned actions. The employment of simulation tools is an adequate way to find market inefficiencies and to provide support for players' decisions. The multiagent paradigm is useful for the job because it can represent several constituents with their own individual features, interacting in a dynamic system. Relevant tools in this domain are the Electricity Market Complex Adaptive System (EMCAS) [3] and Agent-based Modelling of Electricity Systems (AMES) [4].

The Multi-Agent Simulator of Competitive Electricity Markets (MASCEM) [5,6] is another simulator, which has been developed by the authors' research team to address the constant changes in the electricity market operation all around the world. With this purpose, MASCEM is always under improvement, updating the existent market mechanisms and integrating new ones to reflect different countries' approaches and realities [7,8]. The different market opportunities, together with the necessity to address the increasing complexity in the electricity market environment, force players to adapt and act strategically to take the most advantage from their negotiations.

To complement the MASCEM simulator with new strategies, learning, and adaptability, a new system was developed in [6]: ALBidS—Adaptive Learning strategic Bidding System. This system implements several new strategies and behaviours along with those originally implemented in MASCEM. The purpose of ALBidS is to provide market players with the capability to act and react accordingly to the different contexts they encounter in the market, which is achieved using several different strategies and adaptive learning techniques to choose the most appropriate way to use each of them, according to the context [9]. The approach generally adopted by ALBidS is to take advantage of the differences and particularities of each strategy, considering them as different options that are most

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suitable for different contexts. However, the different natures of the strategies can provide complementary aspects, which, when combined, can prove to be much more powerful than the simple "sum of the parts." It is in the understanding of these complementarities, and how to combine different approaches, that this paper gives its contribution.

The main goal of a metalearner is to use meta-data to improve the performance of existing learning algorithms [10]. By using meta-data derived from other learning algorithms, a metalearner creates flexibility in solving different types of learning problems [11]. Metalearners are especially useful when dealing with dynamic environments, with a high level of associated uncertainty, as is the case of the electricity market environment. The combination of the meta-data derived from the different existing learning algorithms must be performed appropriately to obtain a valuable output. Six Thinking Hats (STH) is a parallel thinking method built to change the way meetings are run and the way stakeholders work and interact [12]. For each direction of thinking, STH associates a hat with a distinct colour. Using this method, participants discard any conflict that emerges in the meeting. Taking advantage of stakeholders' capabilities should result in better decisions.

Using the principles of the STH method, this paper proposes a new metalearner that combines the different outputs from ALBidS strategies to support the choice of the best possible action for market players. This is performed using a set of different agents reasoning in a distinct STH point of view. Individual answers are then combined using genetic algorithms (GA) [13,14] with the purpose of providing a better and evolutionary overall combination of all the answers. The proposed method, acting as a metalearner, offers the possibility of combining different strategic bidding approaches so that through cooperation they can contribute to an overall better response than individually. The best potential result that can be achieved from the use of different methodologies in parallel is equal to the result of the best individual approach. On the other hand, taking advantage of the cooperation and combination of the individual methodologies, the final result is not limited to the threshold of the best strategy; it is open to the accomplishment of better results, achieved by taking advantage of the best assets of each individual approach. These results are demonstrated by the case study that is presented in Section 4, which shows that the proposed STH-based metalearner is able to achieve better results than the individual strategies by themselves. GA has been applied in diverse fields, such as machine learning [15,16], optimisation [17], scheduling [13], and many others [14]. However, the use of an evolutionary approach as a metalearner, combining the learning processes of different learning algorithms, has not been presented in the literature. Moreover, approaching the different meta-data resulting from the distinct learning processes in a way that each approach is considered dependently of its nature (or way of thinking) by using methods that result from fields that specifically study the interaction of different entities—sociology (such as the STH) is a novelty that complements the development of a GA-based metalearner.

After this introductory section, Section 2 examines the electricity markets simulation thematic, including an overview of the main electricity market models found worldwide and an outline of the main features of MASCEM and ALBidS. The characteristics and particularities of the STH method are addressed in Section 3, including its adaption to decision support by means of metalearning through integration in ALBidS and MASCEM. The results of the proposed method are presented in Section 4, using case studies based on real data from the Iberian Market—MIBEL [18], from which the performance of the STH-based metalearner is compared to other approaches. Finally, Section 5 presents the most relevant conclusions and contributions of this work.

2. Electricity markets simulation

The electricity industry has experienced major changes in the structure of its markets and in its regulation around the world. This transformation is often called the deregulation of the electricity market. The industry is becoming more competitive, as a market environment is replacing the traditional centralised-operation approach; this change allows market forces to drive electricity prices [2]. The liberalised market environment typically consists of a day-ahead spot market, based on a pool, as well as a floor for bilateral contracts. Most electricity markets also include intraday or balancing markets. Additionally, forward negotiations are also often implemented, as well as ancillary services [1]. These markets' operation usually involves a market operator and a system operator. The market operator is responsible for the correct functioning of the market; it manages the pool using a market-clearing tool to establish the market price and the set of accepted bids for each negotiation period. The system operator is responsible for the management of the transmission grid and also analyses the technical feasibility (from the power system point of view) of the trades.

The increasing complexity brought by the conception of such a diversity of market types has resulted in major changes concerning the relationship between the electricity sector entities. The complexity has also resulted in the emergence of new entities, mostly dedicated to the electricity sector and electricity energy trading management [19,20], such as virtual power players (VPP), traders, and brokers. These entities introduce new behaviours, e.g., aggregation of smaller size players and participation in alternative market mechanisms. The new roles of market operators, regulators, and system operators also signify an important change.

In most electricity markets, namely, all seven regional European markets, such as MIBEL—the Iberian electricity market, which is used as a case study in this paper—the regulator does not interfere in the electricity market price establishment [18]. The market price is obtained through a clean auction between the sellers and buyers of energy. This means that only the negotiating entities influence the market prices. However, players' bids are based on several highly volatile factors, such as raw materials' prices, other players' actions, the wind speed, and solar intensity. The variability of the factors that affect the outcomes of the market makes the results non-deterministic; therefore, the market environment cannot be approached as deterministic.

In addition to the dependency of the market price on the variations of raw materials' prices, including those based on renewable sources, such as wind, sun, or water, this volatility results in a greater difficulty in managing the energy resources [21,22]. This may originate due to deficient management of operators and a huge waste of produced power, especially in the case of wind power generation. The excess of production above forecasted values brings the market prices to values of zero, or very near this value, which results in huge losses for the generation units, not only taking into account the inability to cover production costs but also to justify the high investments that are necessary to implement such generation facilities. Complete and realistic electricity market simulators offer the possibility of testing different management alternatives, so that such wastes can be drastically reduced, and the investments made by countries in green energy sources can be monetised [23]. Most importantly, these studies are an extremely important asset for green energy to be harnessed and become an added value to the global population. An example of experiences that can be made is the analysis of scenarios in which high variations occur between the forecasted and real wind speed and solar intensity. When such situations are expected, opportunities should be given to consumers so that they can purchase power at very low prices, or even for free in extreme cases, as long as they "shift" some of their consumption, so that they can take advantage of such moments. This would offer great business opportunities for aggregated consumers and drastically reduce the waste of power.

Realistic electricity market simulators, capable of providing scenarios based on real data are an enormous asset for the study of electricity markets. Market operators and regulators are able to experiment and test new market rules and mechanisms, which could not be tested directly in reality due to the impact that such experiments could have for the global population and to obtain valuable insights regarding the