Multi-agent Negotiation in Electricity Markets

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Abstract. The electricity industry throughout the world, which has long been dominated by vertically integrated utilities, has experienced major changes. Basically, liberalization has separated the contestable functions of electricity generation and retail from the natural monopoly functions of transmission and distribution. This, in turn, has led to the establishment of electricity markets (EMs)—systems for effecting the purchase and sale of electricity using supply and demand to set energy prices. Ideally, competition and innovation would lead to lower prices and better uses of energy resources. However, the analysis of important EMs yields the main observation that they are still far from liberalized. Stated simply, tariffs do not reflect the pressure of competition. This article addresses the challenge of using software agents with negotiation competence to help manage the complexity of EMs towards ensuring the full benefits of deregulation. Specifically, it presents a multi-agent electricity market composed of a collection of autonomous agents and describes a generic framework for bilateral negotiation. Market participants equipped with the framework are able to enter into fixed price forward contracts and to reach (near) Pareto-optimal agreements.

Keywords: Electricity markets, multi-agent systems, intelligent software agents, automated negotiation, bilateral contracts.

1 Introduction

The electrical power industry provides the production and delivery of electricity to businesses and households through a grid. Electricity is most often produced at power stations, transmitted at high-voltages to multiple substations near populated areas, and distributed at medium and low-voltages to consumers. Traditionally, electric power companies owned the whole infrastructure from generating stations to transmission and distribution infrastructures. Deregulation began in the earlier nineties and has basically separated the contestable functions of electricity generation and retail from the natural monopoly functions of transmission and distribution. This, in turn, has led to the establishment of a wholesale market for electricity generation and a retail market for electricity retailing.

C. Huemer and T. Setzer (Eds.): EC-Web 2011, LNBIP 85, pp. 114–123, 2011.

Practically speaking, electricity markets (EMs) are systems for effecting the purchase and sale of electricity using supply and demand to set energy prices. Two primary motives for restructuring are ensuring a secure and efficient operation and decreasing the cost of electricity utilization. To achieve these goals, three major market models have been considered [16]: pools, bilateral contracts, and hybrid models. A pool, or power exchange, is a market place where electricity-generating companies submit production bids and corresponding market-prices, and consumer companies submit consumption bids. A market operator uses a market-clearing tool, typically a standard uniform auction, to set market prices. Bilateral contracts are negotiable agreements on delivery and receipt of power between two traders. These contracts are very flexible since the negotiating parties can specify their own terms. The hybrid model combines several features of pools and bilateral contracts.

Ideally, opening up the electrical power industry to competition would be an important tool to improve efficiency and benefit energy customers. Competitive forces would drive companies to innovate and operate in more efficient and economic ways. Innovation would lead to lower prices and better uses of energy resources. However, the analysis of important EMs yields the main observation that they are still far from liberalized. Today there is still a lack of both theoretical and practical understanding and important challenges are still waiting to be addressed more thoroughly. Chief among these are the additional complexities to coordinate technical and economic issues, and the technical difficulties to understand EMs internal dynamics. Stated simply, tariffs do not reflect the pressure of competition.

Multi-agent systems (MAS) have generated lots of excitement in recent years because of their promise as a new paradigm for designing and implementing complex software systems (see, e.g., [18]). MAS can deal with complex dynamic interactions and support both artificial intelligence techniques and numerical algorithms. Agent technology has been used to solve real-world problems in a range of industrial and commercial applications. Accordingly, this work looks at using software agents with negotiation competence to help manage the complexity of EMs, particularly retail markets, towards ensuring long-term capacity sustainability. Specifically, the purpose of this paper is twofold:

1. to design a multi-agent electricity market composed of a collection of autonomous agents, each responsible for one or more market functions, and each interacting with other agents in the execution of their responsibilities;
2. to equip agents with a negotiation framework enabling them to enter into forward bilateral contracts and to reach (near) Pareto-optimal agreements.

This paper builds on our previous work in the areas of automated negotiation [6,7,8,10,11] and electricity markets [9]. In particular, it tries to present an integrated and coherent view of bilateral negotiation in electricity markets. It also describes a case study involving interaction between a retailer agent and an industrial customer agent—results show that market participants can enter into efficient bilateral contracts, helping to protect them from price risks (related to high prices volatilities, mainly at times of peak demands and supply shortages).

The remainder of the paper is structured as follows. Section 2 describes a multi-agent electricity market, placing emphasis on the individual behavior of autonomous agents. Section 3 presents a negotiation framework for market participants, focusing on the social behavior of agents. Section 4 illustrates how autonomous agents equipped with the framework operate in a negotiation setting—a simplified retail market. Finally, related work and concluding remarks are presented in sections 5 and 6 respectively.

2 Multi-agent Electricity Market

Multi-agent systems are essentially loosely coupled networks of software agents that interact to solve problems beyond the capabilities of each individual agent. Conceptually, a multi-agent approach in which autonomous agents are capable of flexible action in order to meet their design objectives is an ideal fit to the naturally distributed domain of a deregulated electricity market. Accordingly, we consider the following types of agents:

1. *system operator*: maintains the system security, administers transmission tariffs, and coordinates maintenance scheduling [12];
2. *market operator*: regulates pool negotiations, and thus, is present only in a pool or hybrid market [12];
3. *sellers and buyers*: sellers represent entities able to sell electricity and buyers represent distribution companies or electricity consumers.
4. *virtual power players*: responsible for managing coalitions of producers [17];
5. *traders*: promote liberalization and competition, and simplify dealings either between sellers/buyers and the market operator or between sellers and buyers.

The agents are autonomous computer systems capable of flexible problem solving and able to communicate, when appropriate, with other agents. They are equipped with a generic model of individual behavior [6]. Specifically, each agent has the following key features:

A1 a set of *beliefs* representing information about the agent itself and the market; beliefs are formulae of some logical language (the precise nature of the language is not relevant to our model);

A2 a set of *goals* representing world states to be achieved; goals are also formulae of some logical language;

A3 a library of *plan templates* representing simple procedures for achieving goals; a plan template *pt* has an header and a body; the header defines a name for *pt*; the body specifies either the decomposition of a goal into more detailed subgoals or some numerical computation;

A4 a set of *plans* for execution, either immediately or in the near future; a plan is a collection of plan templates structured into a hierarchical and temporally constrained And-tree.

The generation of a plan *p* from the plan templates stored in the library is performed through an iterative procedure involving four main tasks:

1. *plan retrieval*: searching the library for any plan template whose header unifies with the description of a goal;
2. *plan selection*: selecting the preferred plan template *pt* (from the set of retrieved plan templates);
3. *plan addition*: adding the preferred plan template to *p*;
4. *plan interpretation*: selecting a composite plan template from *p*, say *pt*, establishing a temporal ordering for the elements of its body, and picking the first ordered element (which is interpreted as a new goal).

Now, in order to move towards the benefits of deregulation, we put forward the following requirements for market design:

- market participants should be able to enter into hedge contracts to protect themselves from volatility, notably price volatility;
- participants should be able to effectively negotiate various issues at the table (e.g., three-rate tariffs or even hour-wise tariffs);
- participants should be capable of exhibiting strategic behaviour and considering Demand Response (DR), with the objective of distributing demand over time.

The structure of hedge contracts varies due to different conventions and market structures. However, the two simplest and most common forms are fixed price forward contracts and contracts for differences. A forward contract is an agreement to buy or sell electricity at a specified point of time in the (near) future. A contract for differences is similar to a forward contract, but considers a strike price and allows refunds. For instance, if the actual electricity price in a given period of time is higher than the strike price, a generator will refund the difference to a retailer. Similarly, a retailer will refund the difference when the actual price is less than the strike price.

Energy consumption is typically distributed unevenly along a day—consumers have similar and time synchronous behaviors leading to different energy peaks. Utility companies need to guarantee that they can supply electrical power to all customers, regardless of the amount of energy demanded. Furthermore, they need to be prepared for not only the usual, predictable demand-peaks, but also for any possible peak loads. To this end, there have been a number of initiatives, grouped under the general term of demand-side-management (DSM), to distribute demand over time to avoid peak loads. In particular, many companies have already presented a two-rate tariff to smooth the daily demand profile (cheaper night tariff). This dual peak/off-peak tariff can easily be extended and refined if companies can offer a three-rate tariff (a peak/medium/off-peak tariff) or even an hour-wise DSM-tariff (an hourly-rate tariff). Furthermore, there is still another mechanism that refines the preference elicitation of agents: dynamic pricing tariffs. Specifically, Demand Response has been implemented in several markets and has proved to bring relevant benefits to market players [1].

3 Multi-agent Negotiation

Negotiation, like other forms of social interaction, often proceeds through several distinct phases, notably a beginning or initiation phase, a middle or problem-solving phase, and an ending or resolution phase. This paper concentrates on the operational and strategic process of preparing and planning for negotiation (usually referred to as pre-negotiation), and the central process of moving toward agreement (usually referred to as actual negotiation).

3.1 Pre-negotiation

Pre-negotiation involves mainly the creation of a well-laid plan specifying the activities that negotiators should attend to before actually starting to negotiate. More specifically, negotiators who carefully prepare and plan will make efforts to perform a number of activities, including [4,15]:

- defining the agenda and prioritizing the issues;
- defining the limits and targets;
- selecting an appropriate protocol.

Effective preparation requires that negotiators establish a negotiating agenda—a final set of issues to be deliberated. This task often involves interaction with the opponent. Specifically, every negotiator discloses its list of issues in order to reach agreement about what will be discussed during actual negotiation. The next step is to prioritize the issues at stake. Prioritization usually involves two steps: (i) determining which issues are most important and which are least important, and (ii) determining whether the issues are connected or separate. Priorities can be set in a number of ways (e.g., to rank-order the issues, or to use standard techniques, such as the nominal group technique). For the sake of simplicity, we consider that negotiators set priorities by ranking-order the issues.

Effective preparation also requires that negotiators define two key points for each issue at stake: the *resistance point* or *limit*—the point where every negotiator decides to stop the negotiation rather than to continue, because any settlement beyond this point is not minimally acceptable, and the *target point* or *level of aspiration*—the point where every negotiator realistically expects to achieve a settlement.

Additionally, effective preparation requires that negotiators agree on an appropriate protocol that defines the rules governing the interaction. The protocol can be simple, allowing agents to exchange only proposals. Alternatively, the protocol can be complex, allowing agents to provide arguments to support their negotiation stance. However, most sophisticated protocols make considerable demands on any implementation (see, e.g., [8]). Therefore, we consider an alternating offers protocol. Two agents bargain over the division of the surplus of $n \geq 2$ issues by alternately proposing offers at times in $T = \{1, 2, \dots\}$. A proposal (or offer) is a vector specifying a division of the surplus of all the issues. The agents have the ability to unilaterally opt out of the negotiation when responding to a proposal.

The agents' preferences are modelled by the well-known additive model—the parties assign numerical values to the different levels on each issue and add them to get an entire offer evaluation [15]. This model is simple, and probably the most widely used in multi-issue negotiation. However, it is only appropriate when mutual preference independence exists between issues.

3.2 Actual Negotiation

The negotiation protocol defines the possible states, the valid actions of the agents in particular states, and the events that cause states to change. It often marks branching points at which negotiators have to make decisions according to their strategies. Accordingly, this subsection describes two groups of strategies that have attracted much attention in negotiation research, namely [14]:

1. *concession making or yielding*: negotiators reduce their demands or aspirations to accommodate the opponent;
2. *problem solving or integrating*: negotiators maintain their aspirations and try to find ways of reconciling them with the aspirations of their opponent.

Concession strategies are functions that model significant opening positions and typical patterns of concessions. Practically speaking, three different opening positions (extreme or high, reasonable or moderate, and modest or low) and three levels of concession magnitude (large, substantial, and small) have attracted much attention in negotiation research. They may be associated with a number of strategies, including [13]:

1. *starting high and conceding slowly*: negotiators adopt an optimistic opening position and make small concessions throughout negotiation;
2. *starting reasonable and conceding moderately*: negotiators adopt a realistic opening position and make substantial concessions during the course of negotiation.

Lopes et al. [6,10] present a formal definition of these and other relevant concession strategies.

Problem solving behaviour aims at finding agreements that appeal to all sides, both individually and collectively. The host of existing problem solving strategies includes [3]:

1. *logrolling*: two parties agree to exchange concessions on different issues, with each party yielding on issues that are of low priority to itself and high priority to the other party;
2. *nonspecific compensation*: one party achieves its goals and pays off the other for accommodating its interests.

The formal definition of relevant logrolling strategies and other important problem solving strategies appears elsewhere [7,11].

4 Case Study: Multi-agent Retail Market

A multi-agent electricity market system, involving a wholesale market and a retail market, is currently being developed using the JAVA programming language and the JADE framework. At present, market participants can exhibit simple goal-directed behavior and interact, when appropriate, with other agents to meet their design objectives. Also, they can enter into simple fixed-price forward bilateral contracts for physical delivery.

In general, retailers operate in a fine zone between profit and loss. Specifically, if the price to end-users is too high then no customer signs on. Also, if the price from producers is higher than prices in contracts with end-users, then retailers will lose money. Therefore, it is essential that retailers select the right strategies to negotiate with end-users, while entering into favorable contracts with producers.

For illustrative purposes, we present below a specific scenario involving negotiation between a retailer and a customer:

> "David Colburn, CEO of N2K Power, and Tom Britton, executive at SCO Corporation, are still at it. Colburn and Britton have already gone through the numbers—N2K has offered a three-rate DSM-tariff in accordance with global demand: peak-load period (45€/MWh), medium-load period (42€/MWh), and off-peak period (40€/MWh). This rating scheme was proposed to incentive SCO to move consumption into cheaper hours. However, Britton saw the offer in a slightly different light and has insisted on 40€/MWh for the medium-load period. Colburn and Britton are discussing and, so far, have accomplished little more than making each other angry. Can they resolve their differences?"

The following key characteristics can be noted from this scenario:

1. negotiation involves two parties (bilateral negotiation) and three issues (multi-issue negotiation); specifically, Colburn (electricity retailer) and Britton (industrial customer) are negotiating a three-rate DSM-tariff: `price#1` (for peak-load period), `price#2` (for medium-load period), and `price#3` (for off-peak period);
2. negotiation involves elements of both competition and cooperation; specifically, negotiation is inter-organizational and thus competitive in nature (the parties want to maximize their individual payoff); however, N2K Power seeks to make SCO Corporation as satisfied as possible to establish a long-term relationship (Colburn is thus concerned with Britton's outcome).

Table 1 shows the negotiation issues, the (normalized) weights, and the limits of the Retailer agent. The weights are numbers that express the preferences of Colburn for the issues at stake. As noted, Colburn has set the hourly rates in accordance with the global demand, and thus the first issue (`price#1`) is the most important to N2K Power.

Figure 1 shows the joint utility space for Colburn and Britton. The abscissa represents the utility to Colburn, and the ordinate the utility to Britton. The

Table 1. Issues, preferences and limits (Retailer agent)

Negotiation Issue	Time Period	Weight	Limit
`price#1`	07 − 12 14 − 20	0.40	35
`price#2`	12 − 14	0.35	35
`price#3`	00 − 07 20 − 24	0.25	35

solid line OCO' represents the Pareto optimal or efficient frontier *i.e.*, the locus of achievable joint evaluations from which no joint gains are possible [15]. The small squares depict a few options for settling the issues at stake.

Now, we take up a few strategies and examine their impact on the negotiation outcome. Practically speaking, negotiators who demand too much will often fail to reach agreement. Those who demand too little will usually reach agreement but achieve low benefits. The most successful negotiators are often those who are moderately firm. However, if negotiators do not try to devise new alternatives by means of problem solving, the result will probably be a compromise agreement with low benefits to both sides. For instance, Colburn and Britton can agree on the outcome represented by point A in Figure 1.

Suppose now that it is of higher priority for Britton to settle the medium-load rate, rather than the off-peak rate. Colburn and Britton have the makings of a logrolling deal. Accordingly, the two agents can reach the agreement represented by point B in Figure 1. This agreement is better for both agents than the compromise agreement represented by point A. Noticeably, logrolling strategies can permit negotiators to fully exploit the differences in the valuation of the issues and to capitalize on Pareto optimal agreements. In this way, Colburn and Britton can pursue specific logrolling strategies and agree on the optimal agreement represented by point C in Figure 1. This agreement lies along the efficient frontier.

5 Related Work

Multi-agent energy markets have received some attention lately and a number of prominent tools have been proposed in the literature, notably EMCAS—software agents with negotiation competence use strategies based on machine-learning and adaptation to simulate electricity markets [2], and AMES—open-source computational laboratory for studying wholesale power markets, restructured in accordance with U.S. Federal Energy Regulatory Commission [5].

Also, worthy to mention is the work of Vale et al. [12,17]. They developed the MASCEM system, a multi-agent simulator of EMs supporting a diversity of market models and capturing relevant features of market players. Specifically, it includes a market operator, a system operator, virtual power producers,

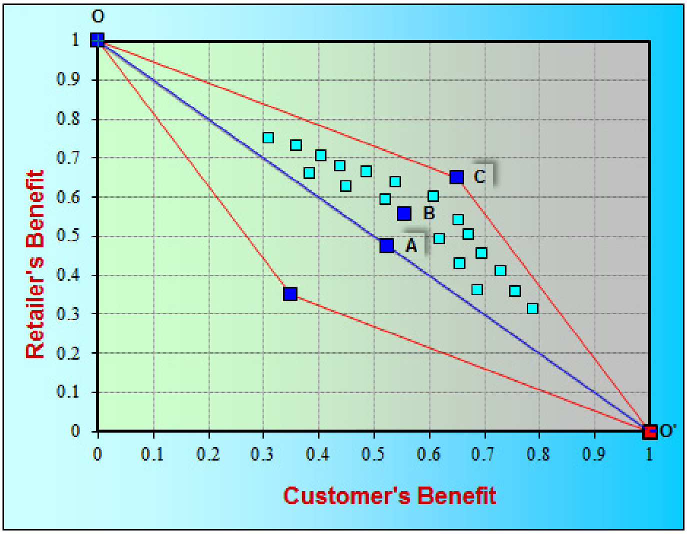

Fig. 1. Joint utility space for the Retailer-Customer negotiation situation

buyers, sellers, and traders. Additionally, it can simulate pool markets, forward markets, balancing markets, complex markets, and bilateral contracts. Furthermore, it integrates (real) data from the Iberian Market, allowing users to define realistic scenarios.

Nevertheless, despite the power and elegance of MASCEM and other existing EM simulators, they often lack generality and flexibility, mainly because they are limited to particular market models, specific types of market participants, and particular features of market players. Currently, there is a pressing need to go a step forward in the development of EM simulators, since they are crucial for tackling the complex challenges posed by electricity markets.

6 Conclusion

This article has addressed, at least partially, the challenges created by competitive energy markets towards ensuring the benefits of deregulation. Specifically, it has presented a multi-agent electricity market composed of multiple software agents and described a generic framework for automated negotiation. Results from a simplified multi-agent retail market, involving interaction between a retailer and an industrial customer, shown that a computational negotiation approach can help protect market participants from price volatility, without making use of significant computational resources.

As this research progresses, we aim to tackle increasingly more complex and realistic scenarios. We also aim to develop agents capable of both entering into various concurrent bilateral negotiations and negotiating more complex bilateral contracts, helping them to transfer financial risks between different market participants.

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