Negotiating Bilateral Contracts
in a Multi-Agent Electricity Market: A Case Study

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Abstract—Electricity markets are systems for effecting the purchase and sale of electricity using supply and demand to set energy prices. Three major market models are often distinguished: pools, bilateral contracts, and hybrid models. This article addresses the challenge of using software agents with negotiation competence to help manage the complexity of electricity markets, particularly the issues associated with the negotiation of bilateral contracts. Specifically, it presents a multi-agent energy market and describes a case study on forward bilateral contracts.

Keywords—electricity markets; bilateral contracts; intelligent software agents; automated negotiation;

I. INTRODUCTION

Electricity markets (EMs) are systems for effecting the purchase and sale of electricity using supply and demand to set energy prices. EMs differ from their more traditional counterparts because energy is difficult to store or keep in stock—unlike other products, it is not efficient to keep energy in stock. Market participants must generate energy on-demand and, as a result, work with consumption prognoses. This limitation creates a number of risks, notably price risk (related to a high price volatility at times of peak demand and supply shortages) and volume risk (associated with uncertainty in consumption or production).

Three major market models are often distinguished [12]: pools, bilateral contracts, and hybrid models. A pool 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 frequently used to hedge against pool price volatility. The hybrid model combines several features of pools and bilateral contracts.

Opening up electrical energy production to competition is an important tool to improve the efficiency of the electricity industry and therefore to benefit all customers. However, the analysis of important EMs yields the main observation that they are still far from liberalized. In particular, tariffs do not reflect the pressure of competition. Clearly, there is a pressing need for both modeling approaches simulating how market participants react to economic and regulatory changes, and energy management tools supporting key market activities. Against this background, an ongoing study is looking at using software agents with negotiation competence to help manage the complexity of EMs. It intends to go a step forward in the development of EM simulators, by developing a tool able to simulate the negotiation of bilateral contracts in a more realistic way.

In particular, this paper presents a multi-agent energy 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. It also describes a case study on forward bilateral contracts—a retailer agent (a seller) and an industrial customer agent (a buyer) negotiate a three-rate DSM-tariff, i.e., negotiation involves three major issues: price#1 (for peak-load period), price#2 (for medium-load period), and price#3 (for off-peak period). The two agents have a choice between three different negotiation strategies involving a relatively consistent, coherent effort to move toward agreement. Accordingly, we will take up all the possible pairs of strategies, one at a time, and examine their impact on the negotiation outcome.

The remainder of the paper is structured as follows. Section II describes a multi-agent electricity market, placing emphasis on both the individual and the social behavior of autonomous software agents. Section III presents a case study and illustrates how agents equipped with a negotiation framework operate in a simplified retail market. Finally, related work and concluding remarks are presented in sections IV and V respectively.
II. MULTI-AGENT ELECTRICITY MARKET

The electrical power industry, which has long been dominated by vertically integrated utilities, has evolved into a distributed and competitive industry in which market forces drive electricity prices and reduce the net costs through increased competition. Liberalization has led to the establishment of a wholesale market for electricity generation and a retail market for electricity retailing. Practically speaking, the role of the wholesale market is to allow trading between generators and retailers—competing generators can offer their electricity output to retailers. The role of the retail market is to allow trading between energy consumers and retailers—end-use customers can choose their supplier from competing electricity retailers.

Multi-agent systems (MAS) are essentially loosely coupled networks of software agents that interact to solve problems that are beyond the individual capabilities of each agent. MAS represent a relatively new and rapidly expanding area of research and development. Agent technology has been used to solve real-world problems in a range of industrial and commercial applications (see, e.g., [9]). 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 energy market.

This work focuses on bilateral contracts, either physical or financial, between a buyer and a seller pair. Accordingly, we are currently working on the following types of agents:

- **generator or producer agents**: represent utility companies and operate in a wholesale market;
- **retailer or supplier agents**: represent electricity retailers and operate in both a wholesale and a retail market;
- **customer or consumer agents**: represent end-use customers and operate in a retail market.

In the near future, we intend to work on the following types of agents:

- **system operator**: maintains the system security, administers transmission tariffs, and coordinates maintenance scheduling; it analyzes the technical feasibility of all negotiated contracts;
- **market operator**: regulates pool negotiations, and thus, is present only in a pool or hybrid market; it uses a market-clearing tool, typically a standard uniform auction, to set market prices.
- **virtual power players (VPPs)**: responsible for managing coalitions of producers, including the role of negotiating on behalf of such coalitions;
- **traders**: promote liberalization and competition, and simplify dealings either between sellers/buyers and the market operator or between sellers and buyers.

The agents are computer systems capable of flexible, autonomous action and able to communicate, when appropriate, with other agents to meet their design objectives. They are currently being developed using the JAVA programming language and the JADE platform [1]. We chose this platform for two main reasons:

1) it is an agent-oriented platform offering a framework for multi-agent system development; this framework can support different agent models;
2) it is built on top of and fully integrated with the Java programming language; it includes all components of Java and it offers specific extensions to implement agents’ behaviours.

The agents are implemented as Jade agents, i.e. they inherit from the basic “Agent” class. Agent communication is done by sending and receiving messages. Figure 1 shows the different agents operating in a deregulated electricity market and the main interactions between them.
A. Autonomous Software Agents

The agents are equipped with a generic model of individual behavior [4]. Specifically, each agent has the following key features:

A-1 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).

A-2 A set of goals representing world states to be achieved. Goals are also formulae of some logical language.

A-3 A library of plan templates representing simple procedures for achieving goals. A plan template has an header and a body. The header defines a name for the template. The body specifies either the description of a goal into more detailed subgoals or some numerical computation.

A-4 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 nodes of the tree are instantiated plan templates retrieved from the library. The header of each instantiated plan template is referred to as intention.

The generation of a plan from the simpler plan templates stored in the library is performed through an iterative procedure involving four main tasks: (i) plan retrieval, (ii) plan selection, (iii) plan addition, and (iv) plan interpretation. In brief, plan retrieval consists of searching the library for any plan template whose header unifies with the description of a goal. Plan selection consists of selecting the preferred plan template (from the set of retrieved plan templates). Plan addition consists of adding the preferred plan template to . Plan interpretation consists of selecting a composite plan template from , establishing a temporal order for the elements of its body, and picking the first ordered element (which is interpreted as a new goal).

B. Computational Negotiation

The agents are equipped with a negotiation framework that handles two-party and multi-issue negotiation (see also [4, 5] and [6]). The framework enables them to:

1) enter into hedge contracts to protect themselves from financial risks, notably high price volatility;
2) negotiate various issues at the table, particularly different rates for different periods of a day (e.g., a three-rate tariff or even an hour-wise tariff);
3) exhibit strategic behavior, with the objective of distributing demand over time.

This section presents the key features of the framework, focusing 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).

1) Pre-Negotiation: Effective preparation and planning involves mainly the creation of a well-laid plan specifying the activities that negotiators should attend to before actually starting to negotiate. These activities include:

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

Let be the set of autonomous agents (negotiating parties). Let be the negotiating agenda—the set of issues to be deliberated during negotiation. Let be the set of issue domains. For each issue , the range of acceptable values is represented by the interval .

Prioritization involves deciding which issues are most important and which are least important. Target setting involves defining two key points for each negotiation issue: 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.

The negotiation protocol is an alternating offers protocol [8]. Two agents bargain over the division of the surplus of issues (goods or “pies”) by alternately proposing offers at times in . This means that one offer is made per time period , with an agent offering in odd periods and the other agent offering in even periods. A proposal is a vector specifying a division of all the goods. Once an agreement is reached, the agreed-upon allocations of the goods are implemented.

The agents have continuous utility functions. Specifically, we consider that each agent has a utility function . The outcome is interpreted as one of the agents opting out of the negotiation in a given period of time. Perpetual disagreement is denoted by . The players’ preferences are modelled by the well-known additive model—the parties determine weights for the issues at stake, assign scores to the different levels on each issue, and take a weighted sum of them to get an entire offer evaluation [11].

2) Actual Negotiation: The heart of negotiation is the exchange of offers and counter-offers—the nature, timing, and pattern of offers, and the concessions they elicit, constitute the very essence of negotiation. Negotiation is iterative—negotiators’ offers usually contain changes in position and suggest alterations to the opponent’s position. There is an unstated assumption that the parties will show their commitment to the process of finding a solution by making concessions, and not simply by rejecting the offers of the others out of hand.
Concession making involves reducing negotiators’ demands or aspirations to (partially) accommodate the opponent. A reduction in demands usually involves a reduction in the level of benefit underlying these demands, which is called a concession. Specifically, a concession is a change of offer in the supposed direction of the other party’s interests that reduces the level of benefit sought [10]. Concessions ordinarily result from the belief that they will hasten agreement, prevent the other party from leaving the negotiation, or encourage the other to make reciprocal concessions.

The negotiation protocol marks branching points at which agents have to make decisions according to their strategies. Clearly, negotiation strategies can reflect a variety of behaviours and lead to strikingly different outcomes. In this work, we consider the following three groups of concessions strategies:

1) Starting reasonable and conceding moderately (SRCM): negotiators adopt a realistic opening position and make substantial concessions during the course of negotiation;

2) Low-priority concession making (LPCM): involves changes of proposals in which larger concessions are made on low-priority than on high-priority issues;

3) Energy dependent concession making (EDCM): negotiators concede strategically throughout negotiation, by considering the amount or quantity of energy traded in each period of the day.

The formal definitions of these and other relevant concession strategies appear elsewhere [7].

### III. A Case Study on Bilateral Contracts

Our case study illustrates how software agents negotiate forward bilateral contracts in the multi-agent electricity market. The two negotiating parties are David Colburn, CEO of N2K Power—a retailer agent—and Tom Britton, executive at SCO Corporation—a customer agent. The agents negotiate a three-rate DSM-tariff, i.e., negotiation involves three major issues: price#1 (for peak-load period), price#2 (for medium-load period), and price#3 (for off-peak period).

The 24 hours of every day are divided into three periods as follows:

- **period 1 (peak-load):** 10:30–13:00h and 19:30–21:00h;
- **period 2 (medium-load):** 8:00–10:30h, 13:00–19:30h and 21:00–22:00h;
- **period 3 (off-peak):** 22:00–8:00h.

David Colburn sets the hourly rates in accordance with the global demand, i.e., more expensive in periods where the demand is higher, cheaper when it is lower. Accordingly, this agent proposes the following rating scheme: period 1 (56.70€/MWh), period 2 (48.93€/MWh), and off-peak period (27.72€/MWh). This scheme can be seen as a communication tool between Colburn and Tom Britton. On the one hand, Colburn “advises” Britton when to place consumption. From the point of view of Britton, the increment of the price at certain hours constitutes an incentive to move consumption into cheaper hours.

Table I shows the initial offers and the price limits for the two agents. Negotiation involves an iterative exchange of offers and counter-offers. We consider the following:

- the first agent to submit a proposal is the retailer agent;
- the agents are allowed to propose only strictly monotonically—the customer’s offers increase monotonically and the retailer’s offers decrease monotonically;
- the acceptability of a proposal is determined by a negotiation threshold—an agent $a_i \in A$ accepts a proposal $p^t_{j-1}$, submitted by $a_j \in A$ at period $t-1$, when the difference between the benefit provided by the proposal $p^t_{j-1}$ that $a_i$ is ready to send in the next time period $t$ is lower than or equal to the negotiation threshold;
- the agents are allowed to exchange only a maximum number of proposals, denoted by $\max_p$—failure to reach agreement after $\max_p$ proposals results in a deadlock.

The negotiation strategies are the three concession strategies presented earlier: SRCM, LPCM and EDCM. These strategies involve a relatively consistent, coherent effort to move toward agreement and the agents can pursue any of them.

### Table I

<table>
<thead>
<tr>
<th>Agent</th>
<th>Time Period</th>
<th>Price (€/MWh)</th>
<th>Limit (€/MWh)</th>
<th>Energy (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer</td>
<td>1</td>
<td>51.30</td>
<td>55.62</td>
<td>12.32</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>44.27</td>
<td>48.00</td>
<td>27.00</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>25.08</td>
<td>27.19</td>
<td>03.90</td>
</tr>
<tr>
<td>Retailer</td>
<td>1</td>
<td>56.70</td>
<td>51.84</td>
<td>—–</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>48.93</td>
<td>44.74</td>
<td>—–</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>27.72</td>
<td>25.34</td>
<td>—–</td>
</tr>
</tbody>
</table>
Now, Colburn operates in a fine zone between profit and loss. In particular, if the price to Britton is too high then this agent may summarily reject the offer—starting high frequently communicates an attitude of toughness that can be reciprocated by the opponent, thus making negotiation difficult to resolve. Also, if the price from producers is higher than the price in the contract with Britton, then Colburn will lose money. Therefore, it is essential that Colburn selects the “right” strategy to negotiate with Britton, while entering into favorable contracts with producers. The main point here is that strategic choice is a critical activity in negotiation.

We have taken up the possible pairs of strategies, one at a time, and examined their impact on the negotiation outcome. The main response measure was the benefit of each agent in the final agreement. The experimental results are shown in Table II. The results indicate that the following strategies yielded superior outcomes:

- Customer agent: energy dependent concession making (EDCM);
- Retailer agent: low-priority concession making (LPCM) and starting reasonable and conceding moderately (SRCM).

It is important to note, however, that these are initial (and partial) results in a simple bargaining scenario. There is a need to conduct extensive experiments to evaluate the effect of the aforementioned strategies on both the outcome of negotiation and the convergence of the negotiation process.

### IV. RELATED WORK

Multi-agent energy markets have received some attention lately and a number of prominent tools have been proposed in the literature, including EMCAS [2], AMES [3], and MASCEM [13]. Despite their power and elegance, they often lack generality and flexibility, mainly because they are limited to particular features of market players.

Lopes et al. [6] present an extensive review and highlight some of the major challenges for future automated negotiation research. The authors are aware of no similar efforts to formalize important negotiation strategies motivated by rules-of-thumb distilled from good behavioral practice in real-life negotiations.

### V. CONCLUSION

This article has presented a multi-agent electricity market and described a case study on bilateral contracts. Results from a simplified retail market, involving interaction between a retailer and a customer, shown that a computational negotiation approach can help protect market participants from price volatility. As this research progresses, we aim to tackle increasingly more complex and realistic scenarios.

### REFERENCES