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An intelligent negotiator agent design for bilateral contracts of electrical energy

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ABSTRACT

In this paper, an intelligent agent (using the Fuzzy SARSA learning approach) is proposed to negotiate for bilateral contracts (BC) of electrical energy in Block Forward Markets (BFM or similar market environments). In the BFM energy markets, the buyers (or loads) and the sellers (or generators) submit their bids and offers on a daily basis. The loads and generators could employ intelligent software agents to trade energy in BC markets on their behalves. Since each agent attempts to choose the best bid/offer in the market, conflict of interests might happen. In this work, the trading of energy in BC markets is modeled and solved using Game Theory and Reinforcement Learning (RL) approaches. The Stackelberg equation concept is used for the match making among load and generator agents. Then to overcome the negotiation limited time problems (it is assumed that a limited time is given to each generator–load pairs to negotiate and make an agreement), a Fuzzy SARSA Learning (FSL) method is used. The fuzzy feature of FSL helps the agent cope with continuous characteristics of the environment and also prevents it from the curse of dimensionality. The performance of the FSL (compared to other well-known traditional negotiation techniques, such as time-dependent and imitative techniques) is illustrated through simulation studies. The case study simulation results show that the FSL based agent could achieve more profits compared to the agents using other reviewed techniques in the BC energy market.

1. Introduction

Due to the increase of information and intelligence for decision making in uncertain systems (especially financial systems), intelligent energy markets are also of interest for many supplying and consuming firms. One of these markets is the bilateral contract (BC) energy market in which, both buyers and sellers submit their bids and offers to the market operator and a contract is made if a buyer and a seller agree on the price-quantity-duration of the contract, simultaneously. The high price volatility of spot electricity markets is not usually seen in BC energy markets (due to its forward temporal nature), that makes it financially safer than spot energy markets (Shahidehpour, Yamin, & Li, 2002). Due to the existing IT/ICT infrastructures in advanced countries (like USA and EU countries), energy trading via bilateral contracts for large energy firms could be preferred.

Shahidehpour et al. (2002) modeled a market environment as a bargaining game and used the Pareto optimal solution to identify the price-quantity of contracts. They assumed a cooperative game with complete information for all players. A Nash bargaining solution for a bilateral contract between players with incomplete information is discussed. David and Wen (2001) and Song, Liu, and Lawarrée (2002) presented a Nash equilibrium type bidding strategy for bilateral contracts in BC electricity market where the generators would submit their offers to the BC market then loads would analyze the supply offers and accept the best offered price (if it was lower than their marginal benefits). Since all loads need to choose the minimum price simultaneously, the conflict of interest could happen. Therefore, they solved the problem by minimizing the total cost of power generation to handle the match making process among generators and loads. Son, Baldick, and Siddiqi (2004) showed that the proposed solution in the work of Song et al. (2002) does not satisfy the Nash inequality conditions. The Stackelberg equation solution in a leader–follower game could be used to handle the match making process among the supplier and consumer agents. The generators and loads introduce two representatives to the ISO (the independent system operator) to do the match making by means of the leader–follower game on their behalves (Kebriaei, Kian, & Majd, 2011). This work does not have limitations of the previous works; but since in the Stackelberg equation solution only one load is assigned to one generator in the match making process, there will be no outside options for other players in the negotiation process.

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Besides the match making process, the negotiation process is the other important basis of bilateral contract markets. The authors Gerding, Van Bragt, and La Poutrfie (2000) and Jennings et al. (2001) presented two good surveys on the methods, techniques, tactics and challenges in the negotiation process. Bilateral negotiation could be done over single attribute (issue) or multi attributes. Although both multi-attribute and single attribute are in the field of negotiation, they have major differences. (Zheng, Chakraborty, Dai, Sycara, & Lewis, 2013). This makes it difficult to use the designed agent for multi-attribute to single attribute. The complexity and importance of the utility function in multi-attribute is superior to that in single attribute negotiations. The agreement zone is the lowest price at which the seller is willing to sell is less than the highest price the buyer is willing to pay. In a negotiation over a single issue (e.g., price of a car), if the agreement zone is non-empty, there is no deadline for the negotiations and there are no outside options which cause one of the agents ignores the negotiation before deadlines, always an agreement will be made. Thus, if the agreement zone is not empty the main problem in single issue negotiation is designing a negotiator agent to make most profitable agreements while the deadline and outside options exist in the environment of the negotiations. However, for two agents negotiating over two or more attributes, even if an agent makes an offer with the utility equal to its reservation utility, the offer may not be acceptable to its opponent. Therefore, developing methods to find offers that provably lie in the zone of agreement without any information about opponents' utility functions is a challenging problem. Some researchers worked in recent years on the challenge of multi attribute negotiation (Chen & Weiss, 2012; Hao & Leung, 2012; Williams, Robu, Gerding, & Jennings, 2011; Zheng et al., 2013). Nevertheless, in this work, we focus on single issue negotiation and try to cope with the main problem of this kind of negotiations using Reinforcement Learning method.

Learning is one of the favorite techniques studied by researchers in bilateral negotiations. The Bayesian learning method, in which an agent uses Bayesian rule to update its belief about reservation price (RP) of the opponent to submit an appropriate offer in the next round of the negotiation (Zeng & Sycara, 1998). The agent must have some prior knowledge to use Bayesian rule and make decision about its offer/bid price. The main bottleneck of this method is gathering information, which is usually difficult in real energy markets. Takadama, Kawai, and Koyama (2008) tried to simulate human behavior in negotiation with an agent using a single dimension state Q-learning method. In that paper, only the opponent's previous proposal was considered as the agent's state in the QL. Therefore, the proposed method could not hedge against some important issues in a negotiation such as deadline time. Lao and Zhong (2010) proposed an agent using discrete Q-learning. Two parameters were used to define the agent's state vector at each step of the negotiation; the first parameter was the distance between the last offers of the agent and its opponent, and the second parameter was the time elapsed from the beginning of the negotiation until the current step. Since the market is a continuous environment, using discrete method would enlarge the number of states and make convergence of the algorithm difficult. Some authors presented a Q-learning method that defined the belief of the agent about its offer/bid as its state vector to learn the optimal decision (Qu & Chen, 2010). Huang and Lin (2008) proposed a temporal difference (TD) learning method for multi agent bargaining problem and four years later, Jamali and Faez (2012) improved the proposed method by applying Simulated Annealing (SA) to overcome the challenge of finding a balance between exploration and exploitation. Both works used neural network (NN) as a function approximator for Q-value function in TD method. The learning process of the NN, which is inside the loop of the learning process of TD, would enlarge the number of required iterations for the TD learning and makes the convergence of the algorithm difficult.

In this paper, agent-based bilateral contracts of energy in the BFM environment are considered. All generators and loads are supposed to submit their offers and bids, respectively. Since each generator/load attempts to negotiate with the best offer/bid, the conflict of interest might happen. Due to the capability of Game Theory to cope with this problem, two representative agents for the generators and loads in a leader–follower game are designed and implemented. Then, the Stackelberg equation solution is used to handle the match making process in a way that each agent/player finds at least two trading agents to start negotiation with Osborne and Rubinstein (1994).

In this paper, it is assumed that if the primary submitted prices of a generator–load pair are not matched, a limited time is given to them to negotiate and make an agreement. The main focus of this paper is on the negotiation process in bilateral contracts. The negotiation could be modeled as a game with incomplete information, which could be reinforced by Artificial Intelligence (Gerding et al., 2000). Here a Fuzzy SARSA learning (FSL) method is proposed for negotiation, which has the advantage of considering effective elements of decision making in a negotiation via appropriate definition of state vector and rewards; the FSL method has the advantages of preventing the curse of dimensionality, and capability to cope with incomplete information games. Through a comparative case study, the advantages and capabilities of the FSL method are shown with respect to the time-dependent imitative tactics introduced by Faratin, Sierra, and Jennings (1998).

The rest of this paper is organized as follows: Section 2 introduces the assumed model of the BC market. In Section 3, the match making process is discussed in details and the Stackelberg equation solution for the new proposed match making process is presented. Section 4 contains the negotiation process and the common negotiation tactics. In Section 5, the Fuzzy SARSA learning agent is designed. Section 6 introduces the proposed definition of states and rewards for the learning algorithm in this paper. Different simulation studies of the BC market with the proposed FSL agents are presented and analyzed in Section 7. Finally, the concluding remarks and a discussion of future work are given in Section 8.

2. Market model

A bilateral contract forward energy (BCFE) market contains buyers (loads) and sellers (generators) trading energy with each other forward in time. As mentioned before, here, it is assumed that if the primary submitted prices of a generator–load pair are not matched, a limited time is given to them to negotiate and make an agreement. Therefore, each round of the market has two steps. The first step is assigning a buyer to a seller to start a negotiation, called "match making", and the second step is the negotiation process between them to make an agreement and sign a contract, called "negotiation". Assume that there are m generators and n loads in the market. Each generator/load usually submits an offer/bid to the market according to its cost/utility function. In this paper, it is assumed that both generators and loads are levied for transmission usage, losses and system services. Therefore, due to variety of services or distances between a generator/load and loads/generators, the generator/load may submit different offers/bids to the market for different loads/generators. The submitted offers/bids get evaluated by other loads/generators based on their objective functions. Let us define the economic objectives of typical generators and loads as follows:

$$O_{g_i}(q, p_{l_j \to g_i}) = p_{l_j \to g_i} \cdot q - C_{g_i}(q) \quad (1)$$

$$O_{l_j}(q, p_{g_i \to l_j}) = U_{l_j}(q) - q \cdot p_{g_i \to l_j} \quad (2)$$