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Keywords
power, selection, supplier, strategy, fuzzy, market, constraints, relaxation

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A Relaxation Strategy with Fuzzy Constraints for Supplier Selection in a Power Market

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Abstract. A power market is a special kind of e-markets. In a power market, all trading processes are related to three parties: buyers, suppliers and brokers. A broker acts as middlemen between buyers and suppliers in a trading process. In a power market, how to select a potential supplier for a buyer through a broker based on the buyer's requirements is a challenging research problem. This paper proposes relaxation strategy with fuzzy constraints for supplier selection. The strategy includes three components, i.e., a supplier selection, a fuzzy constraint relaxation, and a decision making. The major contributions of this paper are that (1) the trading process between buyers and suppliers through brokers is modeled by using fuzzy constraints through the consideration of multiple attributes of the buyer's requirements as well as potential power suppliers; and (2) a buyer can utilize a relaxation with fuzzy constraints to change its requirements in difficult situations when a broker cannot find any supplier to satisfy a buyer's requirements. Experimental results show that our approach is successfully applied in a simulated power market.

Keywords: Supplier selection, relaxation strategy, fuzzy constraints, power market.

1 Introduction

E-markets are virtual marketplaces where buyers and suppliers meet to exchange information about price, products and service offerings, and to negotiate and carry out business transactions [1]. A power market is a kind of e-markets with specifications. In a power market, a buyer cannot reach a contract with a supplier directly and any supplier selection must go through a broker. Thus, in a power market involving three parties, it is hard to apply game theory-based negotiation approaches, which have been successfully applied in many e-markets, to reach an agreement in trading processes. In addition, because of electricity energy's constraints from policies of companies or organizations, it is difficult for buyers and suppliers to use automated negotiation approaches [3],[8],[9] or auction mechanisms [7],[12]. Due to the involvement of third party (brokers) [5], a broker in a power market acts as middlemen between buyers and suppliers to help a buyer identify a potential supplier in order to reach an electricity supply contract.

The study of brokers, acting as the third party of a trading process in e-markets, has been examined by many researchers in recent years. Sarma et al. [11] provided an efficient algorithm to compute the equilibrium for a related game of price in a trading process between buyers and sellers through brokers. Blume et al. [2] studied the trading process in general e-markets between buyers and sellers through a layer of intermediaries. Rubenstein et al. [10] proposed a market model with three types of agents, i.e., sellers, buyers, and middlemen, and analyzed steady state conditions in such markets. Gale et al. [4] analyzed a network model of exchange, in which trading is intermediated. Due to the special features of power markets, these approaches are facing two main challenges in power markets: (1) every trading process between buyers and suppliers in a power market is related to a broker, so a broker plays an important role in the supplier selection; and (2) due to policies of organizations or companies, suppliers cannot make any concession to a buyer.

To address the above challenges, we develop a relaxation strategy with fuzzy constraints to select a potential power supplier to agree on an electricity supply contract through a broker. In particular, our approach uses prioritized fuzzy constraints to present trade-offs between the different possible values of attributes and to indicate how relaxations should be made when they are necessary. The major contributions of this paper are that (1) the trading process between buyers and suppliers through brokers is successfully addressed based on fuzzy constraints for multiple attributes of buyer's requirements as well as potential power suppliers; and (2) a buyer utilizes a relaxation strategy with fuzzy constraints to change its requirements when a broker cannot find any supplier to meet a buyer's requirements. Experimental results demonstrate the good performance of the proposed approach in terms of satisfaction of buyer's requirements.

The rest of this paper is organized as follows. The problem description and definitions are presented in Section 2. A relaxation strategy with fuzzy constraints to select a potential power supplier is introduced in Section 3. An experiment is presented in Section 4. Section 5 concludes this paper and points to our future work.

2 Problem Description and Definitions

In general, there are three parties involving in a power market, i.e., suppliers, buyers and brokers. One objective of the trading process between a buyer and suppliers through a broker is to select a potential supplier for the buyer. To achieve the objective, the three parties in the trading process have to follow certain rules. (1) multiple suppliers provide their electricity to the power market; (2) due to policies of companies or organizations, suppliers cannot make any concession to buyers; and (3) a buyer's requirements must be satisfied by suppliers. Before elaborating the details of the approach, it is necessary to define the scope of this research and provide some necessary definitions.

A buyer agent is considered as an electricity consumer who would like to find a potential power supplier and agree on a contract.

Definition 1. *A buyer agent B_i is defined as a 4-tuple $B_i =< ID, EER, \alpha, \lambda >$, where ID is the buyer agent's identification, EER indicates the electricity energy request (see Definition 2), α is the acceptability threshold of B_i, and λ is the concession threshold of B_i.*

Definition 2. *An electricity energy request is represented by EER and is defined by the following format.*

$$EER = \begin{pmatrix} A_1 & A_2 & \dots & A_n \\ C_1 & C_2 & \dots & C_n \\ W_1 & W_2 & \dots & W_n \end{pmatrix}, \tag{1}$$

where A_i indicates the i^{th} attribute name, C_i is the constraint value of A_i and W_i is the priority value of A_i, $1 \leq W_i \leq n$. W_i=*1* indicates the lowest priority and $W_i = n$ indicates the highest priority.

A supplier agent is considered as a company or an organization and its responsibility is to sell electricity to buyer agents in a power market.

Definition 3. *A supplier agent S_i is defined as a 3-tuple $S_i =< ID, ER, BO >$, where ID is the identification of S_i, ER indicates an electricity resource (see Definition 4) provided by S_i, and BO is a bonus value which a supplier agent may use to attract a buyer agent to purchase electricity.*

The electricity resource is provided by a supplier agent. Due to company or organization policies, an offer from a supplier agent contains some constraints to electricity resource such as constraints of price and time.

Definition 4. *An electricity resource provided by a supplier agent S_i is presented by ER and is defined by the following format.*

$$ER = \begin{pmatrix} A_1 & A_2 & \dots & A_n \\ C_1 & C_2 & \dots & C_n \end{pmatrix}, \tag{2}$$

where A_i is the i^{th} attribute name and C_i is the constraint value of A_i provided by S_i.

A broker agent acts as the third party in a trading process between a buyer agent and supplier agents. A broker agent's responsibility is to select the most suitable supplier agent to meet a buyer agent's requirements.

Definition 5. *A broker agent BR_i is defined as $BR_i =< \mathbf{S}, B_i, r >$, where $\mathbf{S}$ is a set of supplier agents, which sell electricity to a buyer agent B_i, r is a reward that BR_i can get from a supplier agent.*

3 A Relaxation Strategy with Fuzzy Constraints for Supplier Selection

Our relaxation strategy includes the three main components: (1) the supplier selection; (2) the relaxation with fuzzy constraints; and (3) the decision making. In this section, the principle of the whole trading process is introduced in subsection 3.1. Then the three main components are presented in details in three subsections, respectively.

3.1 The principle of the whole trading process

Background A trading process between a buyer agent and supplier agents is conducted through a broker agent to achieve an agreement by using certain strategies. In our strategy, a buyer agent utilizes the relaxation with fuzzy constraints to change its requirement in difficult situations. The broker agent relies on a reward from supplier agents to select the most suitable supplier agent for the buyer agent. Supplier agents use a bonus policy to attract the buyer agent to purchase their electricity. The principle of the whole trading process between a buyer agent and supplier agents through a broker agent in our approach is presented in Fig. 1.

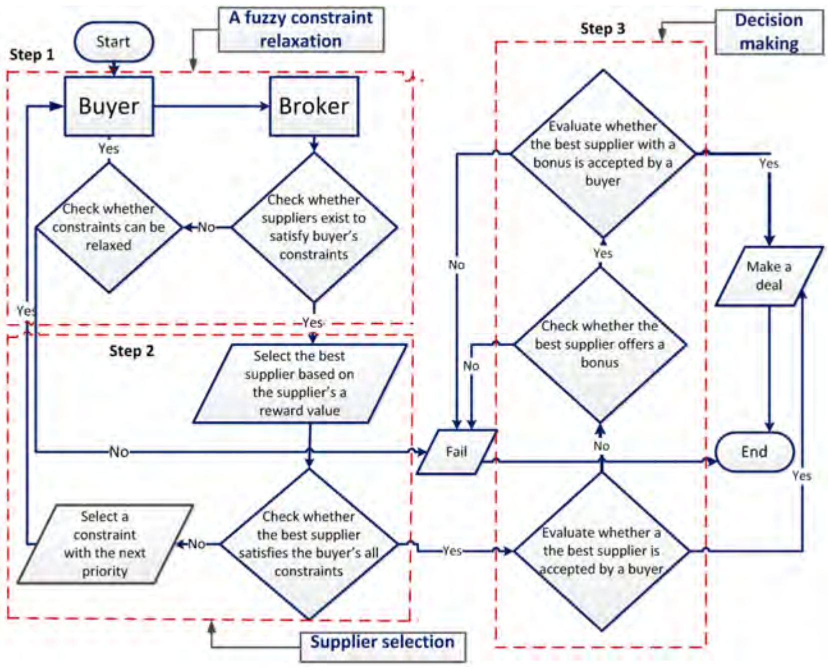

Fig. 1. Diagram of the principle

Step 1: The buyer agent selects a constraint of attributes with the highest priority from its requirements and sends the constraint to the broker agent. Based on the buyer agent's constraint, the broker agent searches for supplier agents. If the broker agent cannot find any supplier agent, the broker agent checks whether the buyer agent's constraints can be relaxed. If the relaxation is not applied, the trading process is terminated. Otherwise, the buyer agent selects a relaxed constraint and sends it to the broker agent again. This procedure will be repeated until the broker agent finds supplier agents to satisfy the buyer agent's constraints or the trading is terminated.
Step 2: Once the broker agent finds suitable supplier agents, it will select the most suitable supplier agent based on the suitable supplier agents' rewards and

send the selected supplier agent to the buyer agent. The buyer agent checks whether the most suitable supplier agent satisfies the buyer agent's other constraints. If there are more constraints, the buyer agent selects the next highest priority constraints and sends it to the broker agent again, and the process goes to step 1. Otherwise, the buyer agent evaluates whether the most suitable supplier agent is acceptable.

Step 3: If the buyer agent accepts the most suitable supplier agent, the trading process makes a deal. Otherwise, the buyer agent requires the broker agent to check whether the most suitable supplier agent offers a bonus. If the most suitable supplier agent does not offer a bonus, the trading process between the buyer agent and the broker agent is terminated. Otherwise, the buyer agent evaluates the most suitable supplier agent with a bonus again to make a decision.

Formal description A formal representation of the process of potential supplier selection is described by Algorithm 1.

Algorithm 1: A principle algorithm of potential supplier selection

```
1  Input: S = {S_i | i = 1,n}, B_i =< ID, EER, α, λ >. Threshold α, λ ∈ [0, 1];
2  Output: Return the decision of making a deal or fail;
3  Initialization: Initialize submitted-constraint-set C* and constraint set C to ∅;
4  begin
5      for ∀ i in EER do
6          C_i ← determine(f(C_i) ≥ α);
7          C ← C ∪ {C_i}
8      C_new ←argmax_C(W_i);
9      BR_i ← send(C_new);
10     while ¬stopCriterion() do
11         C*=C* ∪ {C_new};
12         S'← find(C*,S);
13         if S' ≠ Null then
14             B_i ← send(S');
15             if check(C*,S') and evaluate(C*,S',0) then
16                 success();
17             else
18                 if check(C*,S') and ¬ evaluate(C*,S',0) then
19                     if B_i ← offer-bonus(S') and evaluate(C*,S',BO) then
20                         success();
21                     else fail() ;
22                 else
23                     C_new ← argmax_{C\C_new}(W_i);
24                     BR_i ← send(C_new)
25         else
26             if B_i ← relax(C*) then
27                 B_i ← update(EER);
28                 Go to line 5;
29             else fail() ;
```

The algorithm shows all cases of the trading process between a buyer agent B_i and a set of supplier agents $\mathbf{S}$ through a broker agent BR_i based on the B_i's requirements, an acceptability threshold and a concession threshold (line 1). The output of the algorithm can be either *'deal'* or *'fail'* (line 2).

First, B_i uses its acceptability threshold to determine each constraint value of an attribute in EER (lines 6-7). Then B_i selects a constraint of an attribute in EER with the highest priority and sends it to BR_i (lines 8-9). BR_i finds the most suitable supplier agent to satisfy B_i's requirements (line 12) by using

'*find*' function described in subsection 3.2. The results from BR_i are presented as follows.

If BR_i finds the most suitable supplier agent, BR_i sends the most suitable supplier agent to B_i (line 14). Then, B_i verifies whether the most suitable supplier agent satisfies B_i's requirements and evaluation (line 15) by using *'evaluation'* function described in Subsection 3.4. There are three cases in this situation. (1) if B_i's requirements and evaluation are acceptable, a deal is made (line 16). (2) if B_i's requirements are satisfied but B_i's evaluation is not acceptable, B_i verifies whether the most suitable supplier agent offers a bonus. If the most suitable supplier agent offers the bonus and B_i's evaluation with a bonus is acceptable, the trading process between B_i and BR_i makes a deal. (lines 18-20). Otherwise, the trading process between B_i and BR_i is terminated (line 21). (3) if B_i's requirements are not satisfied, B_i selects a constraint of attributes with the next highest priority in the EER and sends it to BR_i (lines 23-24). Thus, BR_i has to find suitable suppliers again with the new constraints.

If BR_i does not find any suitable supplier agent, which satisfies B_i's requirements, B_i has to relax its requirements (line 26) by using *'relaxation'* function described in Subsection 3.3. In particular, if a constraint of an attribute is relaxed by B_i, B_i has to update its EER and the algorithm runs again with the updated EER (lines 27-28). Otherwise, the trading process is terminated (line 29).

The three major components of the proposed approach are introduced in detail in the following three subsections, respectively.

3.2 Supplier selection

When a broker agent receives the buyer agent's requirements, the broker agent starts to find the most suitable supplier agent for a buyer agent. The *'find'* function, displayed in line 12 of Algorithm 1, is shown in Algorithm 2 as follows.

Algorithm 2: find($\mathbf{C}^*, \mathbf{S}$)

```
Input: S = {S_i | i = 1,n}, a set of constraints C*;
Output: return the most suitable supplier or null ;
begin
    foreach S_i in S do
        add← true;
        foreach C_i in C* do
            if f(S_i.C) ≤ f(C_i) then
                add← false;
        if add=true then
            SS ← SS ∪ {S_i};
    if SS is not ∅ then
        return argmax_{S_i ∈ SS}(S_i.r);
    else
        return Null;
```

The algorithm 2 shows how to select the most suitable supplier agent based on a set of suppliers $\mathbf{S}$, a set of constraints called $\mathbf{C}^*$ which has been submitted

to BR_i during the selection stage (line 1). The output of the algorithm can be either *'the most suitable supplier'* or *'null'* (line 2). First, BR_i selects a suitable supplier set, which satisfies B_i's requirements (lines 4-10). Then, the most suitable supplier agent is selected from the supplier set based on a maximal reward value from supplier agents. If BR_i finds the most suitable supplier agent, BR_i sends it to B_i (line 12). Otherwise, BR_i cannot find any supplier agent which satisfies B_i's requirements (line 14).

3.3 A fuzzy constraint relaxation

If BR_i cannot find any S_i, which satisfies B_i's requirements, BR_i requests B_i to consider relaxing its requirements. The *'relaxation'* function, displayed in line 26 of Algorithm 1, will be activated. The relaxation function is shown in Algorithm 3.

The algorithm shows how to carry out the relaxation based on a set of constraints called $\mathbf{C}^*$, which has been submitted to BR_i so far and the concession threshold λ (line 1). The output of the algorithm can be either *'a selected constraint for the relaxation'* or *'false of the relaxation'* (line 2). The algorithm proceeds as follows.

Algorithm 3: relax(C^*)

```
1  Input: a set of constraints C*, the concession threshold λ;
2  Output: return a selected constraint for a relaxation or null ;
3  begin
4      k ← argmax_EER(W_i);
5      l ← inf;
6      C^k ← Null;
7      foreach C in C* do
8          if f(C^R) ≥ λ then
9              d ← f(C_i) − f(C^R);
10             p ← W_i/k;
11         if d*p<l then
12             l ← d * p;
13             C^k ← C_i;
14     return C^k;
```

After determining the highest priority in EER (line 4), B_i checks whether each constraint of an attribute in C^* is satisfied for the relaxation. This means that B_i determines the degrees of satisfaction for the relaxation of each constraint. When constraint C of an attribute is decreased to the next highest satisfaction degree, the decreased constraint is named C^R. If a satisfaction degree of a relaxed constraint $f(C^R)$ is less than its concession threshold λ, the relaxation of the constraint is not permitted. Otherwise, the constraint is considered for a relaxation. The process of the relaxation is illustrated as follows. First, B_i calculates a decreased satisfaction degree (line 9) and a relative priority degree (line 10) for each constraint of an attribute in C^*. Then, a lost benefit value for each constraint after relaxation is calculated from a decreased satisfaction degree and a relative priority degree. Based on a lost benefit value for each relaxed constraint, B_i selects a constraint for a relaxation with the smallest lost benefit to B_i (lines 12-13).

3.4 Decision making

The *'evaluation'* function, displayed in line 15 of Algorithm 1, is shown in Algorithm 4. Algorithm 4 presents how to evaluate the most suitable supplier agent based on B_i's updated EER, the acceptability threshold, the bonus from the most suitable supplier agent (line 1). The output of the algorithm can be either *'acceptability'* or *'unacceptability'* (line 2). The algorithm proceeds as follows.

Algorithm 4: evaluate($\mathbf{C}^*$,S',BO)

```
1  Input: constraint set C*, the most suitable supplier S', and a bonus BO;
2  Output: return true if satisfaction or false if unsatisfaction ;
3  begin
4      k ← argmax_EER(W_i);
5      δ ← inf;
6      foreach C_i in C* do
7          p ← W_i/k;
8          t ← (f(C_i) − 1) ∗ p + 1;
9          if t < δ then
10             δ ← t;
11     Δ_ap ← Δ(α, γ, δ);
12     return (Δ_ap > α);
```

B_i calculates an acceptability degree called Δ_{ap} to compare to α. The acceptability degree is related to three parameters δ, γ, and α [6]. Parameter $\delta \in [0,1]$ is called the overall satisfaction degree and is calculated from B_i's updated EER. To calculate δ value, we calculate corresponding suitable degree t_i for each constraint C_i (lines 7-8). Then, δ value is $min\{t_i\}$ (line 10). Parameter $\gamma \in [0,1]$ is the satisfactory degree of a bonus from S'. Parameter α is the acceptability threshold of B_i. Based on δ, γ, and α [6], Δ_{ap} is calculated from Equation 3 as follows (line 11).

$$\Delta(\alpha,\gamma,\delta) = \frac{(1-\alpha)\delta((1-\alpha)\gamma+\alpha)}{(1-\alpha)\delta((1-\alpha)\gamma+\alpha)+\alpha(1-\delta)(1-((1-\alpha)\gamma+\alpha))} \quad (3)$$

If Δ_{ap} is more than α, the most suitable supplier agent is acceptable. Otherwise, the most suitable supplier agent is unacceptable (line 12).

4 Experiment

In this section, we illustrate our experimental results on relaxation strategy with fuzzy constraints for supplier selection in the power market. Subsection 4.1 introduces the experimental setting. Subsection 4.2 demonstrates the experimental results.

4.1 Experiment setting

The experiment settings include the settings for the buyer agent, supplier agents and the broker agent.

Supplier setting: The simulation contains six supplier agents and considers four attributes: price, electricity usage on weekdays, electricity usage on weekends and early withdrawal penalty. The detail contents of each supplier are presented in Table 1. Supplier agents use a bonus to attract buyer agents to purchase their electricity. In particular, five of the six supplier agents offer a bonus for the buyer agent and the satisfaction degrees of a bonus for 'gift' and 'free sign up fee' are set as 80% and 10%, respectively.

Supplier	Price (AUD/KW)	Electricity usage on weekdays (Kw)	Electricity usage on weekends (Kw)	Early withdrawal penalty	Sale off
S1	1.40	270	360	No	No bonus
S2	0.70	200	290	Yes	Gift
S3	0.71	240	400	No	Free sign up fee
S4	0.80	245	320	No	Free sign up fee
S5	0.89	229	350	No	Gift
S6	0.98	248	420	No	Free sign up fee

Table 1: Some electricity suppliers

Broker setting: All supplier agents agree that if their electricity is bought by B_1 through BR_1, BR_1 will receive a reward value called r from supplier agents. In this experiment, the reward is calculated as

$$r = price \times 10\% \tag{4}$$

It can be seen that if there are more than one supplier agent, which satisfy B_1's requirements, BR_1 will choose a supplier with the largest reward to BR_1.

Buyer setting: The buyer agent B_1's requirements are presented as follows. B_1's concession threshold λ is set to a value (50%) and four considered attributes in B_1's EER are price, electricity usage on weekdays, electricity usage on weekends and early withdrawal penalty. B_1's acceptability threshold is as 95% and based on B_1's acceptability threshold, each constraint value of attributes is displayed in 2-5, respectively. In addition, the priority degrees of price, electricity usage on weekdays, electricity usage on weekends and early withdrawal penalty are set to 3, 2, 1, and 4, respectively. Thus, B_1's EER is shortly presented as follows.

$$EER = \begin{pmatrix} & \textit{Electricity usage} & \textit{Electricity usage} & \textit{Early withdrawal} \\ \textit{Price} & \textit{on weekdays} & \textit{on weekends} & \textit{penalty} \\ ---- & ----- & ----- & ----- \\ \textit{under } 0.7 & \textit{under } 200 & \textit{under } 300 & \textit{no} \\ 3 & 2 & 1 & 4 \end{pmatrix} \tag{5}$$

4.2 Experiment results

In this subsection, we illustrate the experimental results on the trading process between a buyer agent and supplier agents through a broker agent for supplier selection in the power market.

Price (AUD/KW)	Satisfaction degree
under 0.7	100%
0.7-1.0	90%
1.0-1.3	80%
1.3-1.6	70%
1.6-1.9	60%
1.9-2.2	50%
above 2.2	40%

Table 2: Satisfaction degree of price

Electricity usage on weekdays (KW)	Satisfaction degree
under 200	100%
200-220	90%
220-240	85%
240-260	80%
260-280	70%
280-300	60%
above 300	50%

Table 3: Satisfaction degree of electricity usage on weekdays

Electricity usage on weekends (KW)	Satisfaction degree
under 300	100%
300-400	70%
above 400	30%

Table 4: Satisfaction degree of electricity usage on weekends

Early withdrawal penalty	Satisfaction degree
No	100%
YES	0%

Table 5: Satisfaction degree of early withdrawal penalty

In the experiment, B_1's acceptability threshold is set at a high value (95%). This means that it is difficult for the trading process between B_1 and **S** through BR_1 to achieve an agreement without any relaxation of requirements. Thus, our approach is useful for overcoming this difficulty. In particular, B_1 uses a relaxation when BR_1 cannot find any supplier agent, which satisfies B_1's requirements. Supplier agents offer a bonus program to attract B_1 to purchase their electricity and BR_1 selects the most suitable supplier for B_1.

The experimental result is illustrated in Fig. 2. From Fig. 2, we can see that the agreement was achieved through using 8 rounds. The relaxation was applied in rounds 2, 4, and 5 because BR_1 could not find any supplier agent, which could satisfy B_1's requirements. After the relaxation was used in round 5, BR_1 found that S_5 could meet B_1's requirements and required B_1 to verify whether S_5 was acceptable. Although S_5 satisfied all constraints of B_1, the agreement was not achieved because B_1's acceptability degree was 92.5% for S_5 which was less than B_1's required acceptability threshold of 95% in round 6. So, B_1 required BR_1 to find other supplier agent. Then, BR_1 found S_5 again with offered bonus and required B_1 to verify whether S_5 could be acceptable in round 7. B_1 calculated the acceptability degree for S_5 with the offered bonus. The acceptability degree of S_5 was acceptable and the agreement was achieved in round 8.

The explanation of such results is (1) The buyer agent used relaxation three times to achieve an agreement with the acceptability threshold α=95%. If the relaxation was not carried out, the trading process was terminated in round 2. (2) Supplier agents used a bonus policy to attract the buyer agent to purchase their electricity in round 7. Thus, the experimental result convinces us that the buyer's relaxation strategy, suppliers' bonus policy and the broker's supplier selection are able to successfully achieve a trading process.

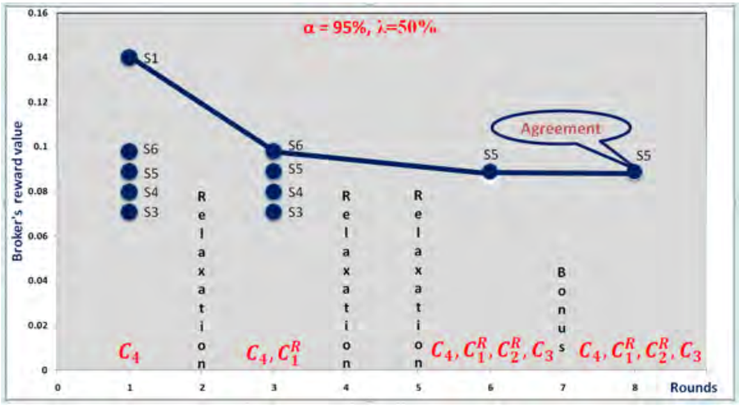

Fig. 2. The experimental result

4.3 Discussions

There has been a lot of previous work on regarding the indirect interaction between buyer agents and seller agents through broker agents in e-markets. Sarma et al [11] analyzed market behavior in large networks where buyer agents do not know seller agents and vice-versa. All trading processes between seller agents and buyer agents depend on broker agents. Although they proposed polynomial time algorithms to compute equilibria in networks, their proposed algorithms are only suitable for simple situations in e-markets. The difference between Sarma's work and our work is that all trading processes in our approach are related to three parties involving buyer agents, supplier agents and broker agents. Supplier agents offer a bonus policy to attract buyer agents to purchase their electricity supply. In our approach, broker agents will achieve supplier agents' reward if broker agents sell supplier agents' electricity supply to buyer agents, while Sarma's work does not pay attention to a bonus policy from seller agents to buyer agents and broker agents. Blume et al. [2] modeled the trading phenomenon related to buyer agents, seller agents and trader agents. In their model, trader agents set price strategies, and then buyer agents and seller agents react to the proposed price. Although their model proposed price strategies, it did not incorporate in many features of real markets. The novelty of our approach is that broker agents act as middlemen to find a potential supplier agent to meet the buyer agents' requirements, while Blume's work does not pay attention to how to match buyer agents and seller agents through broker agents.

5 Conclusion and Future work

This paper proposed a relaxation strategy with fuzzy constraints to select a potential supplier agent for a buyer agent in the power market through a broker agent. The strategy contains three main components: supplier selection, a fuzzy constraint relaxation and decision making. The proposed approach is novel

because (1) the trading process between the buyer agent and supplier agents through the broker agent is successfully solved based on fuzzy constraints for multiple attributes of the buyer agent's requirements and power supplier agents; and (2) the buyer agent's relaxation is applied to select a potential supplier agent through the broker agent when the buyer agent's requirements cannot be met by any supplier agents. Also, the experimental results demonstrate the good performance for supplier selection in the power market.

Further work is needed to test the proposed strategy in a real world application and to develop comprehensive strategies with fuzzy constraints to consider the relationships of the buyer agents and the broker agents.

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