A preference-based matching mechanism for participants in peer-to-peer energy market

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Abstract

Due to an awareness of the climate change crisis and a cost reduction of renewable energy technology, more residential electricity consumers tend to install renewable energy technology in their homes and become prosumers. Consequently, an alternative energy market called peer-to-peer energy market is introduced allowing these prosumers to trade energy with neighborhoods. This paper proposes a matching mechanism for participants in the peer-to-peer energy market which allows peers to match with preferred neighborhoods. This proposed mechanism can be applied with multiple peers' preferences and also has no difference in matching results whether buyers or sellers start the matching process, which can be implied that equality among participants is secured. A matching mechanism between three buyers and three sellers is simulated in two scenarios. The first one is a scenario in which buyers start the matching process and sellers start the process in the second scenario. The simulation result shows that both matching results are identical.

Keywords: Peer Matching Mechanism, Peer-to-Peer Energy Market, Preference, Prosumer

1. Introduction

A renewable energy technology tends to be increasingly used nowadays due to more awareness of the climate change crisis and the cost reduction of renewable energy technology, e.g., solar PV systems [1]. Consequently, Residential electricity consumers tend to install more renewable energy technology, e.g., Solar PV systems, in their homes [2] changing their role from consumers to prosumers, consumers who can produce power. In recent research, prosumers are allowed to trade energy with neighborhoods through an alternative energy market called the peer-to-peer energy market.

In a traditional energy trading scheme, consumers purchase energy from a utility with a retail price and prosumers sell excess energy to the utility with a buyback price. On the other hand, the peer-to-peer energy market allows prosumers to directly negotiate with neighborhoods to reach a mutual trading agreement which consists of an agreed trading quantity and price between two parties. [3] Since the peer-to-peer energy market helps prosumers to match with the nearby neighborhoods, this market performs a local balancing in a grid which reduces power loss due to a lower power sending from distant power plants. Moreover, prosumers can make more profit due to peer-to-peer trading prices being higher than the buyback price and consumers can also achieve more cost-saving due to peer-to-peer trading prices being lower than the retail price.

There are many challenges in the peer-to-peer energy market. One of them is how to design the matching mechanism considering the preferences of market participants. The previous research associated with this challenge can be found in [4-7]. Guerrero et al. [4] proposed a matching mechanism with the utilization of a deferred-acceptance algorithm and electrical distance concept with buyers as initiators. This method performs a stable matching and allows peers to match with electrically closer neighborhoods. Zhao et al. [5] proposed an iterative-based matching process with social relationship preference consideration. In this scheme, the consumer sends a matching offer to the producer based on social relationship value and the producer reacts to that offer based on the weighted value between social relationship value and the consumer's price. However, both proposed matching mechanisms in [4] and [5] can give different matching results when changing the starter role from buyer to seller. Khorasany et al. [6] proposed a peer matching and negotiation method for prosumers in the peer-to-peer energy market. In the peer matching process, each peer ranks another party with offered prices and transaction fees estimated from loss. Then, each peer iteratively sends a matching offer to another party based on those ranks. This scheme can match peers without different matching results. Nevertheless, the matching mechanism from [4] to [6] consider only single participants' preference. Talari et al. [7] proposed a peer matching process that considers three different preferences, which are location, reputation, and type of resources. Each participant can uniquely adjust the premium price for each preference through premium coefficients. Although this scheme considers more than one preference simultaneously, the preferences of each participant are still limited only to location, reputation, and type of resources. Participants can't freely set their own multiple preferences in the matching process.

To mitigate the aforementioned research gap, this paper proposes a peer matching mechanism for peer-to-peer energy market participants which allows each participant to freely set their unique multiple preferences in a matching process. The proposed matching mechanism is an iterative-based method using multiple preference conditions and offered price to rank willing-to-match neighborhoods. By doing this, not only more participants' preferences can be freely applied in the matching process but also has no difference in matching result whether buyers or sellers start the process which can be implied that the proposed mechanism guarantee equality among participants.

The rest of this paper is organized as follows. Section 2 presents an overview of the preference-based matching process in a peer-to-peer energy market. In Section 3, four

Acknowledgement: The authors would like to thank the CUEE High-Performance Scholarship and Thailand Science Research and Innovation Fund Chulalongkorn University (IND66210021).

available online May 1, 2023.
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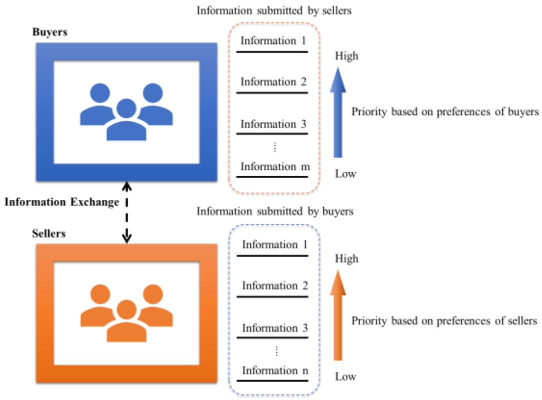

Fig. 1. An example of preference-based matching process

steps of the proposed peer matching mechanism are explained. Section 4 presents simulation results and a discussion. Finally, Section 5 concludes the paper.

2. Preference-Based Matching Process

This section describes the matching process in a peer-to-peer (P2P) energy market based on the preferences of market participants. The P2P energy market enables buyers and sellers to engage in direct energy transactions based on their preferences, without the participation of an intermediary. This removes the need for an intermediary in these transactions.

On a P2P market, participants can typically identify a variety of trading preferences, allowing them to trade energy as they reach an agreement on these preferences. The preferences of participants may include the types and sizes of generators, the total amount of demand, the distance between any two participants, and the trading prices between them.

Furthermore, as depicted in Fig. 1, when one party receives the information submitted by the other, that party has the right to assign priority. They will be matched if the first priority of two participants is identical; otherwise, the lower priority will be considered. This is done so that the most suitable partner for a contract can be selected.

3. Proposed Matching Mechanism

This section describes four steps of proposed peer matching mechanism which are preference conditions setting step, information exchanging and ranking step, scoring step, and matching step respectively.

Before the matching mechanism is performed, each market participant should determine the offered power and price and also identify his/her role as a buyer or seller. This paper assumes that prosumers will do a self-consumption first and then sell excess power as sellers if their power production is higher than demand, otherwise, they will buy power from the market to cover the rest of demand as buyers. For consumers, they always participate in this market as buyers.

A. Step 1: Set Preference Conditions

In this step, each participant determines preference conditions or properties of peers that he/she is willing to match with. After that, each participant sets the order of these conditions based on the level of desire, i.e., if he/she prefers one property the most, he/she will set that property to be the first. Then, the next most desired property will be set in the next order.

B. Step 2: Exchange Information and Ranking

After each participant has a set of ordered preference conditions, he/she starts to exchange information with his/her neighborhoods based on his/her preference conditions and the neighborhoods' preference conditions. After exchanging all necessary information, each participant will consider his/her first priority condition with each neighborhood's information, i.e., if his/her neighborhood satisfies his/her preference condition, his/her neighborhood will be promoted to higher rank and will be validated with the next preference condition. Inversely, his/her neighborhood will stay in the same rank. After ranking all neighborhoods with each preference condition, then he/she will rearrange the order of his/her neighborhood in each rank with his/her neighborhood's offered price. If his/her neighborhood is a seller, the order is ascending If his/her neighborhood is a buyer, the order is descending.

A flowchart of this step is demonstrated in Fig. 2. Note that the description of variables in the flowchart can be seen in the next step's explanation.

C. Step 3: Scoring

In this step, each participant uniquely gives a willing-to-match score to each of their neighborhood based on rank and order from previous step. The higher rank or higher order means higher priority and neighborhood with higher priority will be given a higher score by a certain participant. A score given to each neighborhood by each participant is demonstrated in (1)

$$score_{i\leftarrow j} = \frac{f}{n_j+1}\times(n_j+2-m_{i,j}) - \frac{x_{i,j}-1}{y_{i,j}}\times(\frac{f}{n_j+1}+0.01) \quad (1a)$$

$$score_{j\leftarrow i} = \frac{f}{n_i+1}\times(n_i+2-m_{j,i}) - \frac{x_{j,i}-1}{y_{j,i}}\times(\frac{f}{n_i+1}+0.01) \quad (1b)$$

where,

$i\ ,j$ is ID of seller i (buyer j).

n_i, n_j is Total preference of seller i (buyer j).

f is An identical maximum score that can be given to one participant.

$m_{i,j}$ is Rank of seller i given by buyer j.

$y_{i,j}$ is Total number of sellers who are in the same rank with seller i.

$x_{i,j}$ is Order of seller i compared to other sellers in rank $m_{i,j}$ (After rearranging the order based on prices offered by sellers).

$m_{j,i}$ is Rank of buyer j given by seller i.

$y_{j,i}$ is Total number of buyers who are in the same rank with buyer j.

$x_{j,i}$ is Order of buyer j compared to other buyers in rank $m_{j,i}$ (After rearranging the order based on prices offered by buyers).

$score_{i\leftarrow j}$ is A willing-to-match score given to seller i by buyer j.

$score_{j\leftarrow i}$ is A willing-to-match score given to buyer j by seller i.

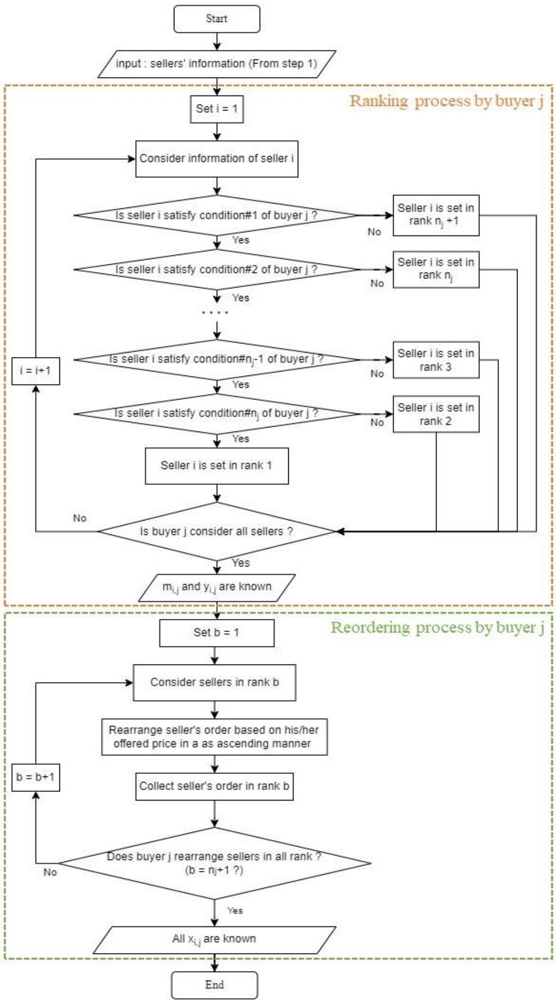

Fig. 2(a) A flowchart of ranking and reordering process by buyer j.

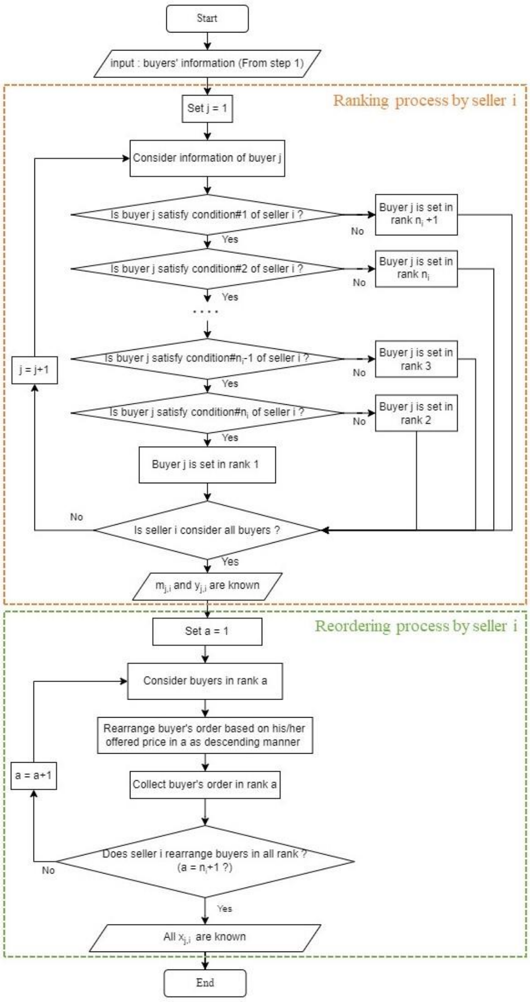

Fig. 2(b) A flowchart of ranking and reordering process by seller i.

After the score determination step ends, each participant will exchange scores with neighborhoods who are different role. That means sellers only exchange scores with buyers.

D. Step 4: Matching

After exchanging score step terminates, each participant will know a score that he/she gives to each neighborhood and also a score that each neighborhood gives to him/her. Next, each participant sums both scores together, as shown in (2)

$$score\_sum_{i,j} = score_{i \leftarrow j} + score_{j \leftarrow i} \tag{2}$$

In the matching process, the proposer and recipient are introduced. The proposer sends a matching offer to a specific recipient and that recipient will consider and then responds to that offer. If the recipient accepts the offer, the proposer and recipient are matched. Otherwise, they will not match, and the proposer will send an offer to another recipient. In this work, the proposer sends a matching offer to a recipient whose summation of scores is highest as possible and the recipient will accept that offer if two conditions are satisfied. That is, the selling price is higher than buying price and a summation of scores from the perspective of this recipient is also highest as possible. If that proposer is rejected, he/she will send an offer to a recipient with the next highest score.

There possibly has multiple rounds in matching process, which one round will end if one-on-one peer matching is done as much as possible. After a certain round ends, each participant will update his/her power and do matching in the next round. The proposed matching process finishes when there is no more possible matching or exceed time.

4. Results And Discussion

The proposed matching mechanism is simulated in two scenarios. That is, when buyers are proposers and when sellers are proposers. This section compares matching results from these two scenarios.

In this simulation, there are three sellers and three buyers participating in the matching process. Table 1 and Table 2 show sellers' information and buyers' information respectively. The offered prices are randomized between utility buyback price which is 2.20 Baht/kWh and time-of-use (TOU) retail price which is 5.80 Baht/kWh. So, the exchanged price in peer-to-peer

Table 1 Sellers' information

Seller's ID	Offered power (kW)	Offed price (Baht/kWh)	Other information		
			Gen.type	%error$_i$	location
i = 1	5	3.37	Solar PV	11	(0,0)
i = 2	4	3.68	Solar PV	14	(3,3)
i = 3	6	4.29	Solar PV	20	(1,1)

Table 2 Buyers' information

Buyer's ID	Offered power (kW)	Offed price (Baht/kWh)	Other information	
			%error$_j$	location
j = 1	7	4.92	2.5	(3,4)
j = 2	5	5.34	1	(7,3)
j = 3	3	3.82	6	(5,2)

Table 3 Preference conditions of each seller

Seller's ID	Preference conditions of sellers		
	#1	#2	#3
i = 1	error_j <= 3%	-	-
i = 2	distance <= 2 km	error_j <= 5%	distance <= 5 km
i = 3	distance <= 3 km	-	-

Table 4 Preference conditions of each buyer

Buyer's ID	Preference conditions of buyers		
	#1	#2	#3
j = 1	gen. type. = wind	gen. type. = solar	distance <= 5 km
j = 2	error_i <= 15%	gen. type. = solar	-
j = 3	error_i <= 13%	-	-

market is bounded between 2.20 and 5.80 Baht/kWh which confirms that market participants will gain more economical benefit compared to a traditional energy trading scheme. Table 3 and Table 4 show preference conditions which are freely set by each seller and each buyer respectively. The preferences of participants include the types of generators, the distance between any two participants, and %error. Note that %error$_i$ is an average error between forecasted power and actual exchange power of seller i. in the past and %error$_j$ is an average error between forecasted power and actual exchange power of buyer j. in the past.

4.1 Simulation Results

After each participant manually selects their unique set of preference conditions with priority consideration as shown in Table 3 and Table 4, each seller exchanges his/her information in Table 1 with buyers. On the other hand, each buyer exchanges his/her information in Table 2 with buyers.

Then, each participant will rank and reorder their neighborhoods based on his/her preference conditions and neighborhoods' price respectively. $m_{i,j}$,$y_{i,j}$, $x_{i,j}$ are used to calculate a willing-to-match score given to all sellers by each buyer and $m_{j,i}$,$y_{j,i}$, $x_{j,i}$ are used to calculate a willing-to-match score given to all sellers by each seller.

Lastly, participants share a willing-to-match score with neighborhoods, calculate score summation of every possibility. Then start a matching process based on a proposed mechanism. The matching results when buyers are proposers and when sellers are proposers are shown in Table 5 and Table 6 respectively.

4.2 Discussion

From Table 5 and Table V, the matching results are identical whether buyers or sellers start the process. These results occur because the participants can be matched when both parties have the highest summation of scores as possible only. Although this proposed method secures equality among sellers and buyers, participants might not match with the most preferred neighborhood. So, there is a trade-off between equality and individual preferred match.

Table 5 Matching result when buyers are proposers

Round	Buyer's ID	Seller's ID	Matched power (kW)
1	1	2	5
1	2	1	4
2	1	3	3

Table 6 Matching result when sellers are proposers

Round	Buyer's ID	Seller's ID	Matched power (kW)
1	1	2	5
1	2	1	4
2	1	3	3

5. Conclusion

This paper presents a matching mechanism for participants in a peer-to-peer energy market with consideration of participants' preferred preferences and the equality among them. From the simulation results, it was found that there was no difference in the matching results, regardless of whether the buyer or seller initiated the matching process. Therefore, it can be confirmed that equality is achieved between buyers and sellers in the market. However, the proposed mechanism requires all participants to choose their matches based on pairs with the highest summation of scores, which may differ from other research that allows participants to choose their own matches based on only individual preferences. Therefore, achieving equality may require some trade-off.

Since there is a possibility of obtaining equal summation of scores and not being able to decide which market participants should be matched, in the future work, other indicators may be included to making decisions in such cases. Additionally, the mechanism may need to consider the impact of peer-to-peer energy trading on low-voltage three-phase distribution systems which can affect the matching process and the amount of electricity that can be traded in the market.

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