P2P Energy Trading based on Blockchain and Customer Risk Preference

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***Abstract*—In this paper, we study a local P2P energy trading with help of Blockchain technologies and consideration for customers' risk preference. The local energy transactions are based on double-side auction mechanism, meanwhile enabling immediate seller-buyer pairing process via iterative price adjustment. Additionally, the quantitative description of risk preference guarantees the optimal decision-making according to customers' subjective gain reference. The Blockchain platform is also used to support the proposed P2P energy trading mechanism, strengthening the decentralized implementation and smart contract deployment. The demonstration is provided using Ethereum and Remix development environment.**

***Index Terms*—Electricity market, P2P energy trading, Risk Preference, Blockchain.**

I. Introduction

With the penetration of distributed energy resources (DERs) and the development of new information and communication technology (ICT), customers that consume or produce energy will have more "energy choice," or freedom to choose different types of energy services. However, most prosumers, who are able to produce electricity with help of DERs and have energy surplus at their disposal, can only accept the fact to trade with grid companies directly, if without any proper local energy trading mechanism or business model designed [1]. They are doomed to suffer price or revenue gap no matter purchasing prosumer-to-grid energy or directly selling energy surplus back to the grid. It is believed that the key to overcome this problem and open market of energy services is to provide some proper mechanism design for Peer-to-peer (P2P) energy trading, which encourages customers to trade with each other directly within their local communities or group. Especially, with the support of new ICT technologies, such as Blockchain [2], Internet-of-Things (IoT) [3], 5G [4] and other tools, the energy trading and management at end-user side will definitely become much more efficient. Thus, following this IT-like energy industry paradigm, the generalized energy exchange will be a level playing field, where all customers have an equal opportunity to actively participate directly.

In order to push such P2P energy trading ideas, an eBay-like market platform is often discussed in different research works [5][6][7]. Some kinds of gamification are also carefully designed to encourage diverse energy activities at demand side [8]. For example, the concept of a facebook-like prosumer community is proposed in [9] to guide local energy sharing and internal community energy trading. In [10], a consensus-based approach is proposed to allow for multi-bilateral trading within prosumer groups, in which the product differentiation is also considered. A practical laboratory-scale implementation of solar energy exchange based on Blockchain is demonstrated in [11]. The work [12] also provides an up-to-date view of much recent research for P2P energy trading, which is a quite good summary for those who are interested in this topic.

This work is supported by "Research on Value-added Service Scenarios and Modes of Power Trading" with funding No.2019FD01 and "the Fundamental Research Funds for the Central Universities".

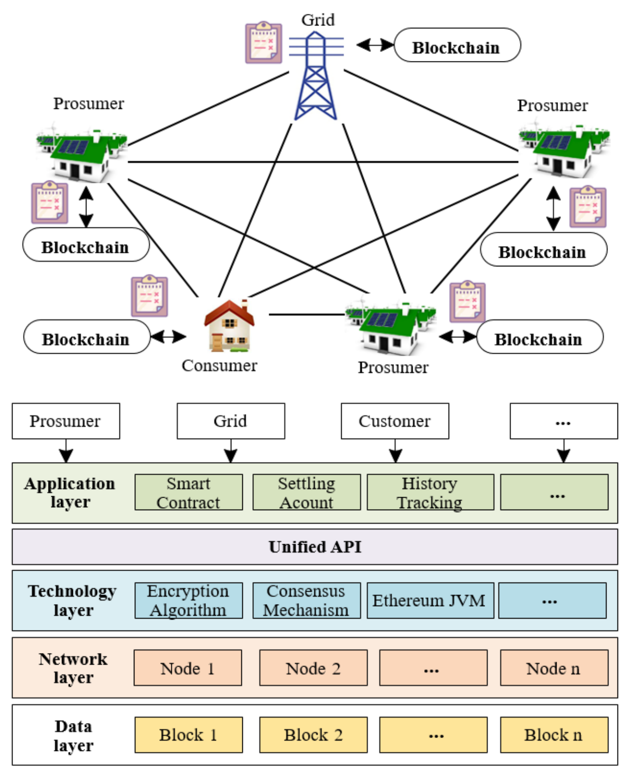

Fig. 1. P2P energy trading based on Blockchain

However, most works assume the customers, especially small residential customers participating in P2P energy trad-

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ing, have the same rationality and risk-neural attitude similar to participants in the bulk energy trading, and ignore the Blockchain demonstration in practical software development environment. As shown in Figure 1, this paper proposes a novel P2P energy trading mechanism based on customer risk preference with practical Blockchain demonstration in Ethereum Remix platform and smart contracts coded in Solidity language [13].

In this paper, our contribution is to: (1) propose a new P2P energy trading mechanism based on customers' risk preference; (2) utilize Blockchain technology, specifically Ethereum platform and smart contract, to strengthen the decentralized energy trading business model; and (3) provide some interesting observations for the proposed P2P energy trading mechanism based on various simulation results in Blockchain development environment.

II. Blockchain and Smart Contract

Either for application of virtual money transactions, like bitcoin, or the proposed P2P energy trading, Blockchain should consist of several components, such as a decentralized P2P network, a public/private transaction ledger, a set of rules for independent trading validation (consensus rules) and a mechanism for global decentralized consensus validation (Proof-of-Work algorithm, PoW) [14]. However, different types of Blockchain have different characteristics suitable for different trading scenarios, as summarized in Table I.

TABLE I
Comparison of different Blockchain types

Blockchain Type	Public	Consortium	Private
Example	Ethereum	Hyperledger	Coin Science
Writing/ Accounting Permission	Any nodes	Nodes in consortium	Nodes with authorization
Major function	Smart contract	Business handling	Computing platform
Consensus algorithm	PoW, PoS	PBFT, Raft	PBFT, Raft
Trading speed	Slow	Fast	Ultra-fast
Degree of decentralization	Full decentralization	Partial decentralization	Partial centralization
Application scenarios	Virtual currency, Internet finance for B2C, C2C, C2B	Different coalition trading, settling account scenario for B2B	Institutional internal data management and audit

Specifically for the proposed P2P energy trading, we choose *Ethereum* platform because it is easy to deploy smart contract functionality, which can help a lot in the facilitating overall P2P energy trading process. Some advantages of using

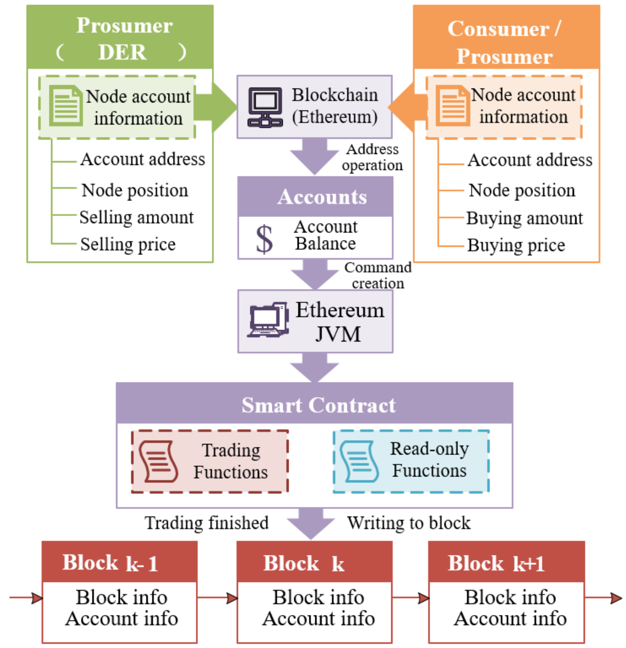

Fig. 2. Smart contract deployment on Ethereum

Ethereum Blockchain, as well as smart contract development environment *Remix*, will be discussed in Section III-C and Section IV.

III. Problem Formulation

A. Bidding strategy

The motivation is straightforward for P2P energy trading, in which the prosumers or customers [1] can enjoy a lower price for energy consumption and a higher price for selling energy surplus back to grid. Thus, in P2P energy trading, the assumed lowest selling price c_i is bounded by the selling-back-to-grid price $p_{b,grid}$ [2] and its energy generation cost C_i, while the assumed buying price l_j is bounded by the regular energy supply price $p_{s,grid}$. This fundamental price relationship is as shown in (1) and (2).

$$c_i = \max\{p_{b,grid}, C_i\} \tag{1}$$

$$l_j = p_{s,grid} \tag{2}$$

At the beginning of bidding process, each customer does not have any knowledge about others and can only provide an initial bidding price according to his own subjective risk preference included in the well-defined target price τ. In the following rounds of iterative bidding process, customers will also consider the current maximum or minimum biding price from others as reference. This iterative bidding updating process can be detailed in (3) and (4). Due to page limit,

[1]Strictly, each prosumer could be a seller or buyer, and each customer could be a buyer. For sake of simplicity and concise description, the terms "prosumer" and "customer" will be used interchangeable, except specific use, in the following discussion.

[2]The selling-back-to-grid price from customer's perspective is equivalent to buying price from grid perspective. That's why subscript of $p_{b,grid}$ is denoted in such way.

$$bid_{p,i}(k) = \begin{cases} bid_{p,max}(k) - \Big(bid_{p,max}(k) - \max\{c_i, bid_{c,min}(k)\}\Big)/\eta_i, & k = 1 \\ bid_{p,max}(k) - \Big(bid_{p,max}(k) - \tau_i(k)\Big)/\eta_i, & k \geq 2 \end{cases} \tag{3}$$

$$bid_{c,j}(k) = \begin{cases} bid_{c,min}(k) - \Big(bid_{c,min}(k) - \min\{l_j, bid_{c,min}(k)\}\Big)/\eta_j, & k = 1 \\ bid_{c,min}(k) - \Big(\tau_j(k) - bid_{c,min}(k)\Big)/\eta_j, & k \geq 2 \end{cases} \tag{4}$$

we only take seller/prosumer's biding, $bid_{p,i}$, as example. The description applies similarly to buyer's bidding $bid_{c,j}$. In (3), $bid_{p,max}$ indicate for the maximum selling price at kth round, $bid_{c,min}$ for the minimum buying price at kth round, $\tau_i(k)$ for target price of ith seller at kth round, η for accepted revenue decrease rate, which implies that the more aggressive the seller would like to decrease its bidding price, the more likely it will be chosen with his revenue locked earlier. The target price $\tau_i(k)$ also reflects customer risk preference that will be further discussed in the following Section III-B.

B. Bidding adjustment with risk preference

In order to guarantee each customer's economic benefit and reflect different customers' risk attitude towards their revenue gain or loss, a risk factor r is defined in (5)-(7) and used to build target prices τ in (9)-(12).

$$r(k+1) = r(k) + \gamma\big[\delta(k) - r(k)\big] \tag{5}$$

$$\delta(k) = \big(1 + \lambda(k)\big) r_{shout} \tag{6}$$

$$\lambda(k) = \{-0.05, 0.05\} \tag{7}$$

where, $r(k)$ is the adjusted risk factor at kth round; $\gamma \in (0, 1)$ is learning rate; $\delta(k)$ is the expected risk factor; $\lambda(k)$ is the fine-tuning margin for the last round risk factor r_{shout}.

Since P2P energy trading involves many small customers that are different from bulk energy trading, which usually lead to quite dramatic price change, the equivalent price p_e can only be roughly estimated by weighting historical market-clearance price p_i in (8).

$$p_e = \sum_{i=1}^{k} (a_i \times p_i) \tag{8}$$

By considering the updated risk factor information, which contains customer risk preference, and equivalent price information, the target prices for internal trading within prosumers and external trading with grid are indicated in (9)-(10) and (11)-(12), respectively. They will be further used to help forming bidding strategies introduced in Section III-A.

$$\tau_{i,intra}(k) = \begin{cases} p_e + (p_e - c_i) r(k), & r(k) \in (-1, 0] \\ p_e + (MAX - p_e) r(k), & r(k) \in (0, 1) \end{cases} \tag{9}$$

$$\tau_{j,intra}(k) = \begin{cases} p_e + (p_e - l_j) r(k), & r(k) \in (-1, 0] \\ p_e\big(1 - r(k)\big), & r(k) \in (0, 1) \end{cases} \tag{10}$$

where, $\tau_{i,intra}(k)$ stands for internal target price of customer i at kth round, and MAX stands for the maximum bidding price limit in internal trading within prosumer groups. $\tau_{j,intra}(k)$ holds the similar explanation.

$$\tau_{i,extra}(k) = \begin{cases} c_i, & r(k) \in (-1, 0] \\ c_i + (MAX' - c_i) r(k), & r(k) \in (0, 1) \end{cases} \tag{11}$$

$$\tau_{j,extra}(k) = \begin{cases} l_j, & r(k) \in (-1, 0] \\ l_j\big(1 - r(k)\big), & r(k) \in (0, 1) \end{cases} \tag{12}$$

where, $\tau_{i,extra}(k)$ stands for external target price of customer i at kth round, and MAX' stands for the maximum bidding price limit in external trading with grid. $\tau_{j,extra}(k)$ holds the similar explanation.

C. Overall trading process with smart contract deployment

The market-clearance is based on classic demand-supply matching mechanism [7]. In order to automate the overall P2P energy trading process, as shown in Figure 3, smart contracts could be deployed on Blockchain and used to provide highly efficient trading functionality with preventing from malicious manipulation.

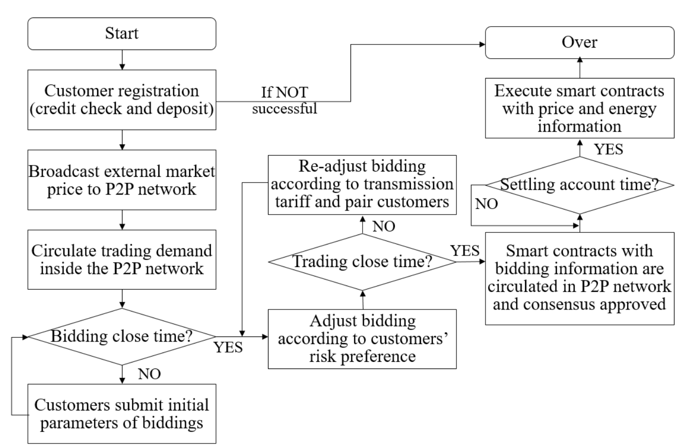

Fig. 3. The flowchart of P2P energy trading with smart contracts

Some specific smart contract functions or API examples are also defined and presented as follows:

- *RiskBasedBiddingStrategy()*: customers, as buyers or sellers, could call this function to activate the smart contract with bidding parameter submitted;

- *ReservePrice()*: this function allows customers to calculate the bottom line price according to their rational expectation;
- *RiskFactor()*: this function is called to calculate all the risk factors in each round of bidding;
- *MarketClearing()*: this function handles the market-clearance with pairing different sellers and buyers for actual transactions according to their bidding information;
- *CongestionManagement()*: this function execute the congestion management after all the bidding information is submitted, congestion elimination begins from revoking the last transaction until the capacity is satisfied;
- *Settlement()*: this function would allow the smart contract to record all the customers' account or cash flow information with settlement time stamp and tracking address in P2P network;

Due to page limit, these functions are just six out of thirty-four smart contract functions coded in *Solidity* language and deployed in *Ethereum* Blockchain platform and *Remix* environment [13]. It will be introduced further more in details in Section IV with demonstration of actual P2P energy trading results.

IV. Case Studies

All the case studies are performed on a desktop PC with an Intel i7 CPU and 16.0 GB RAM. The smart contract is deployed in a browser integrated IDE based on Ethereum JVM and Remix 4.5 version.

A. System setup

The numerical result is based on the IEEE 33-buses test distribution system with modification to incorporate sellers on node [6,12,15,19] and buyers on node [9,18,22,24,30,33]. Their node index information, price parameters, and risk preference parameters, are presented in Table II and Table III.

TABLE II
Parameters of Sellers' Price and Risk Preference

Node	c_i	τ_i	$bid_{p,max}$	$Q_{p,i}$	r_i	η_i
6	0.3	0.4	0.4	100	0.1	5
12	0.3	0.3	0.3	75	-0.1	4
15	0.35	0.5	0.5	75	0.1	3
19	0.35	0.4	0.4	100	0	3

The input parameters will be coded into *Solidity* variables and pre-defined data structure and facilitate available smart contract function execution, as introduced in Section III-C. The layout of smart contract development environment is as shown in Figure 4.

B. Results

In the trading process, we can observe the sellers and the buyers keep adjusting their bidding strategy in different rounds (Figure 5 and Figure 6) with consideration of risk preference to optimize their economic benefit and secure the existing trading opportunity (i.e. available revenue or utility) as early as possible.

TABLE III
Parameters of Buyers' Price and Risk Preference

Node	l_j	τ_j	$bid_{c,min}$	$Q_{c,j}$	r_j	η_j
9	0.62	0.5	0.5	100	0.5	3
18	0.62	0.45	0.45	45	-0.5	4
22	0.62	0.45	0.45	45	-0.5	4
24	0.62	0.6	0.6	30	0.5	5
30	0.62	0.6	0.6	100	0	6
33	0.62	0.6	0.6	30	0	6

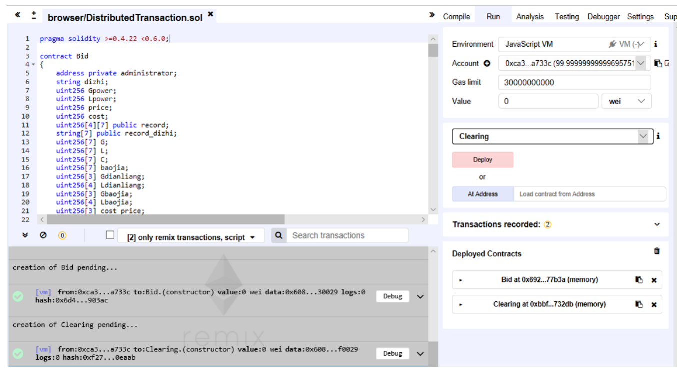

Fig. 4. Layout of Remix-Ethereum smart contract development environment

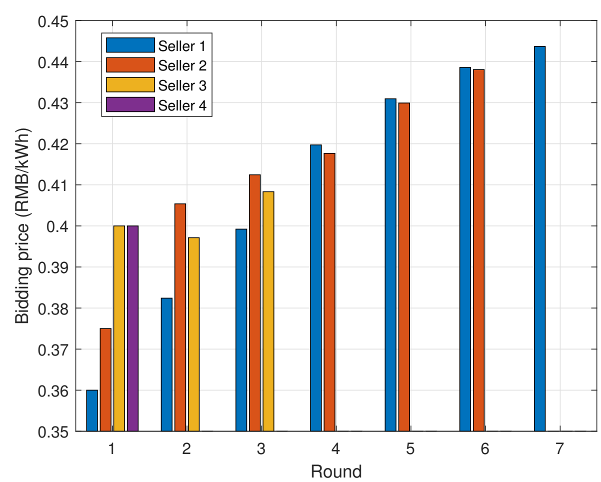

Fig. 5. Bidding price of sellers in each round

It is also observed that some sellers or buyers quit the bidding process with 0 price indicated, since they have satisfied their trading goal in previous rounds and already secured the available revenue. This phenomenon can even be more clearly observed in Figure 7, which present the energy amount information in each round. The equivalent-size energy block (e.g. top left and bottom fight in the first round) will counteract each other, and leave the unsatisfied trading amount for the

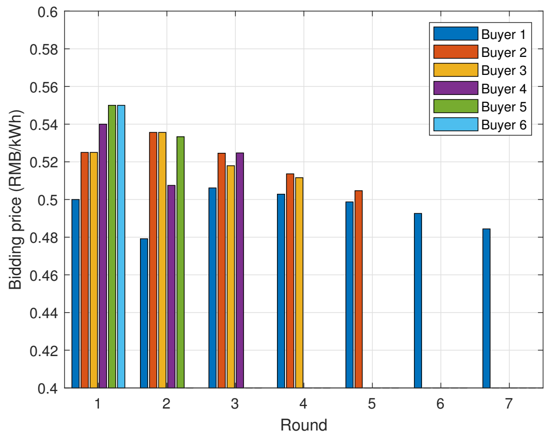

Fig. 6. Bidding price of buyers in each round

next round.

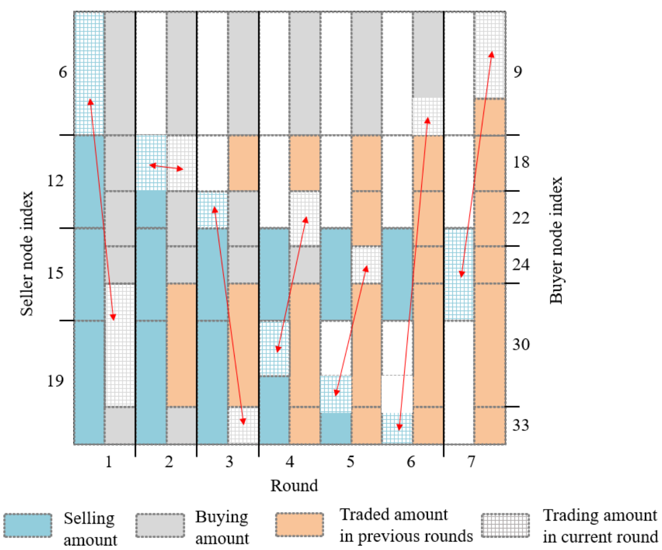

Fig. 7. Trading amount in each round

Last but not least, the bidding information and trading results from smart contract execution is saved into the customer address-specified account with receipts as shown in Figure 8. In the future work, some more advanced *Payable* functions available via using Solidity language will be tested to separate the energy transaction with account settlement for security purpose.

V. Conclusion

In this paper, we proposed a new P2P energy trading mechanism based on customers' risk preference, while using Blockchain technology to strengthen the decentralized trading business model. The overall trading process and operation principles are also introduced to support practical P2P energy trading implementation. We also demonstrated the Blockchain enabled P2P energy trading in Ethereum platform with smart

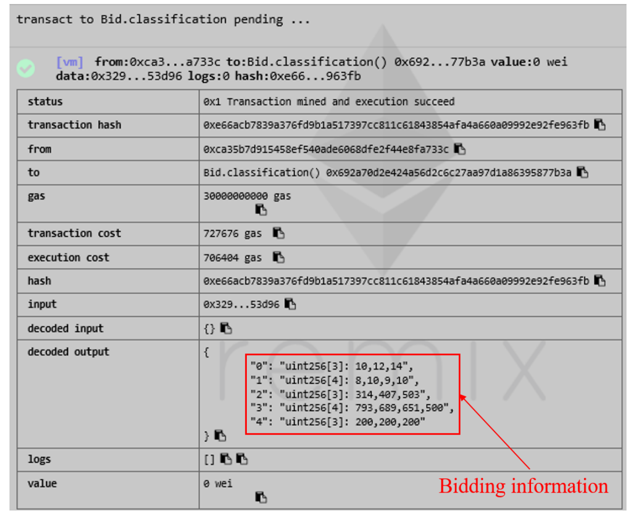

Fig. 8. Bidding information in the receipts

contract deployment. It is believed that more and more new energy business models, like P2P energy trading, under incubation will come into practice and revolutionize the future energy ecosystem.

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