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Microgrid Energy Trading Method Based on Blockchain and Improved Auction Algorithm

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Abstract- With the continuous demands for electric energy, the government continues to advance the reform of electricity market, and then a large number of electric energy prosumers can enter the electricity market. Traditional third-party trust agencies have such problems as high cost of maintaining trust, vulnerability to defense attacks, difficulties in retrieving data and privacy disclosure in transactions. This paper proposes a microgrid energy trading method based on blockchain technology and improved auction algorithm. Firstly, it proposes the double-chain mode for power security trading. The double-chain, viz. the information chain and the transaction chain, can be used together to complete the authentication of both parties and the signature of smart contracts. The transaction rights of both parties can be guaranteed and the transaction will be settled smoothly. An improved auction algorithm is proposed to match the energy consumption orders with the prosumers and consumers, and the energy consumption orders are matched in a multi-faceted and multi-angle manner to improve the internal consumption of the micro-grid. Experiments show that the microgrid energy trading method based on blockchain and improved auction algorithm can conduct point-to-point transactions, effectively achieve the matching between orders and prosumers, and complete the safe and reliable trading of microgrid power.

Keywords- *Blockchain, Microgrid, Smart Contract, Auction Algorithm*

I. INTRODUCTION

As global energy demand continues to rise, some countries have also reformed the electricity market. More and more countries are issuing policies that allow companies or individuals to install distributed generation devices into the electricity market. With the innovation and application of photovoltaic power generation and wind power generation technology, users can not only act as consumers, but also install power generation devices as prosumers to enter the power market competition [1]. Under the condition of continuous penetration of distributed energy, the participation of a large number of prosumers and consumers will bring new opportunities and challenges to the power market in the future. Focusing on microgrid energy trading, more and more entities can join the microgrid energy trading. The traditional centralized trading model may be of such shortages as slow transaction speed, user privacy leakage, opaque transaction information, and data information being falsified and lost. A large number of electric energy prosumers and electric energy consumers have formed a small microgrid. However, at current stage, there is no safe and reliable power and token trading platform between the prosumers and consumers, and it is impossible to complete safe and reliable peer-to-peer transactions. Therefore, it is necessary to establish a microgrid energy trading platform to ensure that the transaction information is symmetric and transparent, the data is safe and reliable, and the power supply is reasonably configured and the transaction is settled smoothly [2].

Introducing blockchain technology into microgrid energy trading is the most promising application direction today. The narrow blockchain is a distributed data book. Each node in the whole network will save a data backup. Each node in the network can organize and store the transaction data [3]. A blockchain is a chained data structure in which transaction information is organized by nodes within the network to create new blocks that are linked to the longest backbone. The longest chain is called the main chain, and the information stored in the main chain is considered to be safe and untamed. Each node of the network keeps all the information of the blockchain database, preventing data loss [4].

The decentralized nature of blockchain technology perfectly fits the decentralization of prosumers and consumers in the microgrid. Blockchain technology has the following advantages in the field of microgrid energy trading [5-9]. 1) Decentralization. Each node in the network has the same status in the blockchain technology. All nodes can organize, store, and verify data. Even if the data of a node in the network is maliciously deleted, data can be recovered by copying data of other nodes. This mechanism guarantees data security and data integrity and credibility in microgrid energy trading. 2) Security. Blockchain uses asymmetric encryption and iterative hashing to ensure that the transaction data is not modified. If the attacker wants to tamper with one of the block information in the blockchain, it needs to change the information of the current block and all subsequent blocks, and tamper with more than 50% of the node information of the entire network. It is almost impossible to achieve the equivalent of the attacker's ability to challenge the computing power of the entire network. This mechanism guarantees that the transaction data cannot be falsified and unforgeable. 3) Intelligence. Blockchain uses smart contracts to complete the settlement of tokens and transactions. Avoiding the participation of third-party trust institutions can reduce the cost of labor and maintaining trust in third-party trust organizations. Both parties of the transaction sign the smart contract in advance of the transaction. Once the smart contract is successfully signed, it can't be interposed by anyone, and the code is used to enforce the command written when the smart contract is signed. Smart contracts can ensure the smooth implementation of various terms signed between prosumers and consumers, ensuring smooth settlement of transactions and avoiding bad debts.

The research on blockchain technology in the field of microgrid energy trading has achieved preliminary results at this stage. Mihaylov M proposed the energy token NRGcoin for the settlement of electrical energy in the grid [10]. Aitzhan designed multiple signatures in energy transactions and used multiple signatures to protect the interests of both parties. But this method does not design the power matching algorithm of both sides of the transaction, lacking a reliable market mechanism to ensure efficient operation of transactions [11]. TIAN et al. specifically designed an energy Internet platform based on blockchain technology, proposed a double-chain structure of identity chain and transaction chain, and explored the specific process of electric energy in blockchain trading [12]. WANG et al. designed a continuous two-way auction mechanism to achieve power matching between prosumers and consumers, and use blockchain for energy transaction settlement [13]. PING et al. used the VCG auction mechanism to stimulate consumers' rational quotations, and designed intelligent contract guarantee transactions for point-to-point transactions [14].

Aiming at the large quantity, small scale and decentralization of microgrid energy trading orders, this paper proposes a peer-to-peer trading method based on blockchain application in microgrid [15-17]. The double-chain structure is used to ensure transaction security. The information chain can verify user access, save user and power generation device information. And the transaction chain and smart contract can complete the power transaction and settlement of both parties. Furthermore, an improved auction algorithm is put forward to exchange energy consumption orders and prosumers, and the final auction results are affected by economic, distance and time factors.

II. SYSTEM STRUCTURE

Based on blockchain technology, a micro-grid power peer-to-peer transaction method is designed. The user completes the generation of electric energy by installing a distributed power generation device. The user's identity is transformed into a prosumer and the consumer, and the prosumers use the distributed generation device to generate electricity. Therefore, the cost of electricity for the consumer is reduced. The user who does not install the power generation device is called the consumer, and the consumer can trade the electricity between the prosumer and the consumer within the micro-grid. Because the internal electricity price of the micro-grid is generally lower than the grid electricity price, the consumer usually trades inside the micro-grid. It can also reduce the cost of electricity. According to their own electricity production and electricity consumption, prosumers and consumers can conduct fair and reliable energy trading on this microgrid trading platform.

The microgrid trading method based on blockchain technology mainly consists of information chain and transaction chain. The information chain is mainly used for the preservation of non-private information and the preservation of registration information. The trading chain mainly deals with energy and token transactions between prosumers and consumers.

A. Information Chain

When users want to use the microgrid energy trading platform, they must first register their identity information. The information chain generates a pair of keys P_a and P_b based on the identity information of the user. When the user is a prosumer, the user needs to provide distributed power generation device information, and the information chain generates the public and private keys of the distributed power generation device. The public key can be known by other users, can be used to send messages anonymously with other users, and can also be digitally signed. The private key is only kept by the user (generally stored locally). Then the information chain uses the user's public key and user information to generate a digital certificate. The active nodes in the network collect and record the generated digital certificate information in the blockchain to generate new blocks and broadcast them. When more than 50% of the nodes in the whole network update the block information, the digital certificate of the user cannot be tampered with.

The introduction of digital certificates is to better manage users. After the digital certificate is recorded in the blockchain database, the user can sign a smart contract with the information chain. The purpose of this smart contract is to protect the rights of each user. When some users make some malicious transactions, the smart contract will initiate measures to deal with malicious transactions, and the user's digital certificate status will be deducted. When the digital certificate is deducted too much, the smart contract releases the contract between the user and the information chain according to the contract content. At the same time, the digital certificate of the user in the information chain is abolished, and the user is unable to conduct the energy transaction.

B. Administrator Node

There are many nodes with various functions in the blockchain. The function of some nodes is to gain benefits for mining. Some node-functions are used to collect or store transaction data in order to obtain benefits. The microgrid energy trading platform based on blockchain technology sets up an administrator node to handle disputes in transactions. When a consumer trades with a prosumer, there may be a consumer paying the token, but the prosumer does not pay the consumer the corresponding amount of electricity. It is also possible that the prosumer has paid the corresponding electric energy, but the use right of the token is not obtained.

In order to cope with the above situation, an administrator node can be set in the blockchain. When the smart contract is signed, a multi-signed smart contract can be signed. For example, the characteristic of a 2-of-3 multi-signature contract is when two of the three users agree on the contract status and sign, the contract can be executed smoothly. When the above situation occurs, the administrator node can retrieve running status of the smart contract in the blockchain database to adjust the dispute and ensure the smart contract goes smoothly. When a malicious transaction order occurs, the administrator node can also judge the malicious user and impose corresponding punishment on the digital certificate of the malicious user.

C. *Trading chain*

The general function of the transaction chain is to accept consumer demand orders and prosumers' bidding information, and to match the power consumption orders with the prosumers. Then, the matching power consumption order and the prosumer information are sent, and the settlement of the transaction is completed by using the smart contract. After the smart contract is generated, it is saved in the block. Each node in the whole network stores the execution status and record of the smart contract. Only users who have been verified by digital proof can use the transaction chain to complete the energy transaction.

D. *Transaction process*

In order to meet their own interests, prosumers and consumers will conduct electricity trading on the microgrid energy trading platform based on blockchain technology. If Consumer A and Prosumer B complete the registration on the information chain, they need to complete the transaction on the transaction chain. The transaction process is shown in Fig 1.

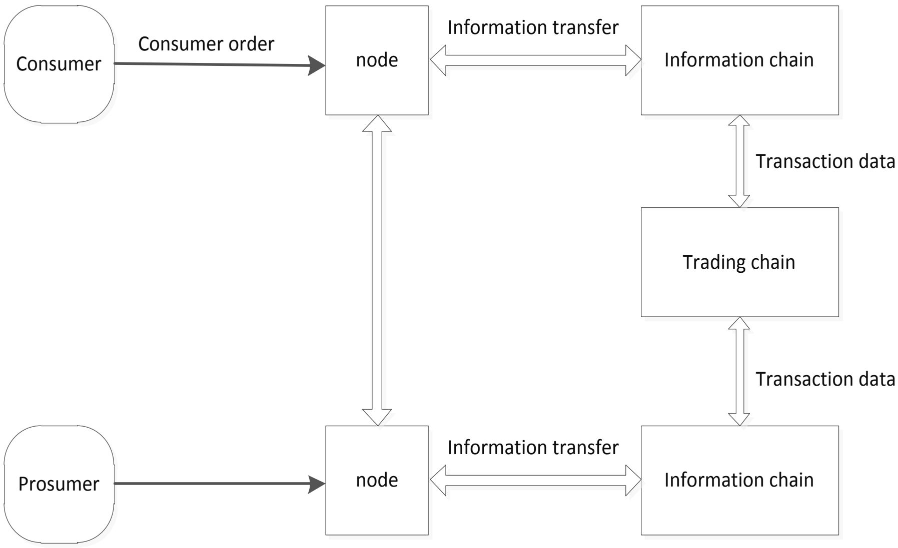

Figure 1. Transaction process

In the transaction process, there are three main stages as follows.

1) Transaction initiationConsumer:
A generates a power consumption order based on the required power and sends it to the trading platform, and simultaneously sends a digital certificate. The information chain needs to verify the digital certificate of the consumer A, firstly determine whether the consumer A is a legitimate user and whether the digital certificate is valid, and then submit the energy consumption order of the consumer A to the transaction chain.

2) Trading match
After the transaction link receives the power consumption order, it is broadcast to each node, and the intended prosumers will bid for the power consumption order. The trading chain uses a modified auction algorithm to match the power consumption order with the prosumer. The auction algorithm will be described in the next section. Assuming that the power consumption order is matched with the prosumer B, the transaction chain queries the address information of the prosumer B in the blockchain database and the information about the distributed generation device.

3) Smart contract signing:
The transaction chain generates a smart contract between Consumer A and Prosumer B, and Consumer A transfers the corresponding token to the Smart Contract. Prosumer B receives relevant transaction information and confirms the transaction. At the same time, the smart contract is running, and the prosumer B transmits the power to the consumer A. After the delivery is completed, Prosumer B obtains the right to use the smart contract assets. After the execution of the smart contract, it needs to be sorted by the active node, and then to generate a new block link to the blockchain, and finally to broadcast the new block information to the whole network. When more than 50% of the nodes in the whole network

update the block information, the smart contract transaction information is determined to be unchangeable. This method guarantees the unchangeable modification of the transaction content, and the transaction content is encrypted and stored, and the privacy of both parties of the transaction is also guaranteed.

III. GRAPH-BASED IMPROVED AUCTION ALGORITHM

In the graph-based constrained improved auction algorithm, the consumer acts as the auctioneer and issues a power consumption order. The prosumers act as bidders and bid for power consumption orders. The general flow of the auction algorithm is as follows. First, the address information of the prosumer and the consumer are divided into different maps according to different regions and stored in the blockchain database. When a consumer needs to use electrical energy, the consumer needs to submit a power consumption order to the system. The platform assigns a power consumption order set to obtain a matching set of power consumption orders, and then finds the optimal matching producer of each power consumption order to perform electric energy matching.

A. Auction algorithm flow

1) Power consumption order set preprocessing:
After the blockchain system collects the power consumption orders of the auction, the power consumption order set is divided into m sets according to different addresses. The order set is O_k, $k=1,...,m$. The graph G_k in the blockchain database is retrieved, and the divided power consumption order set is corresponding to the graph G_k. At the same time, according to the graph G_k, the vertices of the power consumption order set are traversed once, and the set of prosumers $S_j = \{v_i \mid i \in V_k\}$ closest to these vertices is generated.

2) Calculate the matching value stage:
After the power consumption order is pre-processed, the power consumption order in the set O_k needs to be traversed once, and then the power consumption order is assigned. At the same time of the assignment, the time matching value corresponding to the power consumption order and the prosumer who does not match the distance matching value are removed. All orders in the power consumption order set will generate a corresponding set of assignments. Then, based on the set S_j, a prosumer-matching value in the graph G_k that can match the power consumption order is calculated. The specific assignment and matching value calculation process will be detailed below.

3) Power consumption order matching stage:
After all the prosumers corresponding to the energy consumption order are calculated, the system will match the output of the energy consumption order according to the value of the set S_j in order to complete the matching between the prosumer and the consumer. The prosumer with the highest matching value will successfully bid for the power consumption order. Since at this stage, a prosumer can complete the auction of a power consumption order at most, the following can occur. When there is a case where the matching values of the two prosumers of the same electric energy consumption order are equal, the provision is made according to the principle that the order of the prosumers in the collection S_j is prioritized. When the optimal match of two or more power consumption orders occurs at the same time is the same prosumer, the prosumers with high matching values are preferentially matched.

4) New energy consumption order set generation stage:
After the power consumption order matching phase is completed, the matching power consumption order in the set O_k needs to be removed, and new power consumption order set O_k is generated. Because there is a power consumption order for the new energy consumption order set that has not been allocated to the prosumer, a new round of iterative matching of the power consumption order is required. Repeat steps 2) and 3) until all power consumption order matches are completed.

B. Assignment matching method

In the blockchain database, all prosumer information in the microgrid is stored, including the address information of the prosumer. Depending on the region of the prosumer, the prosumers in different regions can be composed of multiple maps. In the figure *G(V, E)*, the prosumer $v_i \in E$. If two of the consumers v_n and v_m are adjacent, then $\{v_n, v_m\} \in E$ represents an edge.

Considering the loss of electrical energy during transmission, it is necessary to consider the power transmission distance in the auction algorithm. When consumers need to use electricity, they can generate electricity consumption order j according to their own needs. For the energy consumption order j submitted by the consumer, the system needs to calculate the distance matching value D_i of the closest prosumer to the consumer. The general process is to obtain the address information of the consumer and retrieve the map G_k composed of the prosumers in the vicinity of the consumer. Calculate the distance between each prosumer v_i and the consumer who issued the electricity consumption order j, and derive the nearest prosumer v_i from the consumer. After the vertex v_i is obtained, it is necessary to start looking up the vertex adjacent thereto and store it in the set P_1, then traverse P_1, traverse the vertices adjacent to the vertices in P_1 and store them in the set P_2, and loop until the set P_n is generated. n is a manually set value. Then, the distance matching value $D_{(i,j)},...,D_{(n_i,j)}$ of all the prosumers $v_1,...,v_{n_i}$ in $P_1,...,P_n$ and the consumer electric energy consumption order J is calculated. Hypothesis:

$$D_{(n_i,j)} = (1/2)^{\alpha} \tag{1}$$

The value setting of α can be seen as the maximum distance that the consumer can tolerate. When the value of α is too large, it proves that the distance between the prosumer and the consumer is too far and the qualification for the auction is cancelled.

In the assignment process, the matching value between the power consumption order and the prosumer and the consumer includes the distance matching value $D_{(n_i,j)}$ and the time matching value $T_{(i,j)}$. $T_{(i,j)}$ represents the matching value of the time that the power consumption order *j* needs to wait from submission to completion. Assume that the time match value is:

$$T_{(i,j)} = (q_i + t_j) / st_j \quad (2)$$

Where q_i represents the time required for the prosumer to complete the current coordinator task queue, and t_j represents the time required for the current energy consumption order *j*. st_j indicates the latest limit time, which is the maximum tolerance time. it_j represents the time required to switch between two adjacent power consumption orders in the prosumer's task stack. The queue time for consumer *i* to execute order *j* is:

$$q_{(i,j)} = \sum_{1}^{q_{i_n}} st_j + it_i * q_{i_n} \quad (3)$$

Therefore, the matching value of the power consumption order and the prosumer and the consumer $MV_{(i,j)}$ is expressed as:

$$MV_{(i,j)} = T_{(i,j)} + D_{(n_i,j)} * \gamma \quad (4)$$

Where γ is an empirically set value to control the proportion of the time matching value and the distance matching value to the matching value between the energy consumption order and the consumer.

In the graph-based improved auction algorithm with constraints, the auction algorithm will match multiple power consumption orders with multiple prosumers. The prosumer will bid $pr_{(i,j)}$ for each order. According to different bids, the matching value between the energy consumption order and the prosumer will also change. Assume that in this iteration, the match value after the bidder's bid is:

$$value_{(i,j)} = MV_{(i,j)} - pr_{(i,j)} \quad (5)$$

The above description completes the first assignment calculation in the auction algorithm. At this time, if there is an unallocated power consumption order in the power consumption order set O_k, the next round of assignment is needed until there is no power consumption order in the performance consumption order set O_k. The second round of assignment is as follows, and it is necessary to check whether the time for the prosumer to complete the task queue exceeds the maximum tolerance time of the order. If the maximum tolerance time is exceeded, the consumer order is removed. Because the first round of assignment, the prosumers have obtained the power consumption order, so in the second round of assignment, the waiting time of the power consumption order will be lengthened, and consumers can purchase electricity from the grid during the waiting period. Since the waiting time is lengthened, the matching value of the prosumer and the consumer is required to be attenuated, that is:

$$value_{(i,j)}^{l} = value_{(i,j)}^{l-1} * \lambda \quad (6)$$

Where λ can be expressed as:

$$\lambda = (st_j - t_j * l) / st_j \quad (7)$$

IV. CASE ANALYSIS

Supposing there is a microgrid, as shown in Fig 2. The microgrid consists of prosumers A and B and consumers 1-6. Assume that the consumer power consumption order is 20min/order. The maximum tolerance time for consumers 1, 2, 3, and 6 is 60 minutes. The maximum tolerance time for consumers 4 and 5 is 40 minutes. When the prosumers bid to the power consumption order, the auction price is 0.3T, where T is the token unit. When the power consumption order does not complete the auction due to exceeding the maximum tolerance time, the consumer may choose to purchase electricity from the grid, or participate in other microgrid power auctions.

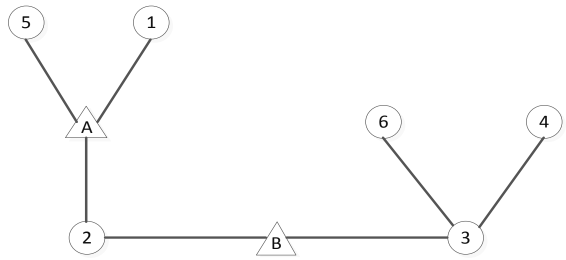

Figure 2. Microgrid instance

According to the improved auction algorithm, the distance matching value and the time matching value can be calculated, as shown in Table 1, where in *(A,I)* indicates that the prosumer has bid for the electric energy consumption order 1.

TABLE I. ORDER MATCH VALUE

	Distance matching value	Time Matching Value
(A,1)	0.5	0.333
(B,1)	0.125	0.333
(A,2)	0.5	0.333
(B,2)	0.5	0.333
(A,3)	0.125	0.333
(B,3)	0.5	0.333
(A,4)	0.063	0.5
(B,4)	0.25	0.5
(A,5)	0.5	0.5
(B,5)	0.125	0.5
(A,6)	0.063	0.333
(B,6)	0.25	0.333

According to the improved auction algorithm, the specific iteration results are shown in Table 2. In the first round of matching, prosumer A won the order of consumer 5, and prosumer B won the order of consumer 2. In the second round of matching, Prosumer A won the order of consumer 1, and prosumer B won the order of consumer 3. In the third round of matching, the consumer 4 gave up the auction for exceeding the maximum tolerance time, and the prosumer B won the order of the consumer 6.

TABLE II. ALGORITHM ITERATION

	First round	Second round	Third round
(A,1)	0.533	0.356	
(B,1)	0.158	0.105	
(A,2)	0.533		
(B,2)	0.533		
(A,3)	0.158	0.105	
(B,3)	0.533	0.356	
(A,4)	0.263	0.132	
(B,4)	0.45	0.225	
(A,5)	0.7		
(B,5)	0.325		
(A,6)	0.096	0.064	0.021
(B,6)	0.283	0.189	0.062

At this time, the task queue of the prosumer A is the power consumption order 5, 1, and the task queue of the prosumer B is the power consumption order 2, 3, 6.

The example shows that the microgrid energy trading method based on blockchain and improved auction algorithm can carry out peer-to-peer trading of microgrid energy. In this method, the prosumer is the bidder and the consumer is the auctioneer, completing the production and elimination. The expansion of the task queue enables internal transactions of microgrid power. Maximize the use of electricity generated by the prosumers, reducing the loss of electrical energy in the line.

V. CONCLUSION

The micro-grid energy peer-to-peer transaction method based on blockchain and improved auction algorithm can be used to realize peer-to-peer transaction of electric energy and secure and reliable transaction settlement. The use of blockchain distributed database and asymmetric encryption technology guarantees the security and privacy of transaction data. The smart contract guarantees that the transaction can be smoothly carried out and settled without third-party trust institutions. Improved auction algorithm completes a reasonable match between power consumption orders and prosumer .The example shows that this method can realize the point-to-point transaction of microgrid power. The auction mechanism is used to adjust the market behavior, and the prosumers' task queue can be expanded to a certain extent. The method can carry out point-to-point transaction of small-scale, large-volume, low-cost electric energy, and guarantees the efficiency and economic benefit of the transaction.

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REFERENCES

[1] M. Welisch, "Multi-unit renewables auctions for small markets - Designing the Danish multi-technology auction scheme, " Renewable Energy, 131 (2019) 372-380.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[2] E. Mengelkamp, B. Notheisen, C. Beer, D. Dauer, C. Weinhardt, "A blockchain-based smart grid: towards sustainable local energy markets, " Computer Science - Research and Development, 33 (2018) 207-214.

[3] M. T. Alam, H. Li, A. Patidar, "Bitcoin for smart trading in smart grid" 2015.

[4] E. Mengelkamp, J. Gärttner, rttner, C. Weinhardt, "Intelligent Agent Strategies for Residential Customers in Local Electricity Markets, " Proceedings of the Ninth International Conference on Future Energy Systems, ACM, Karlsruhe, Germany, 2018, pp. 97-107.

[5] Tai Xue,Sun Hongbin,Guo Qinglai, "Electricity transactions and congestion management based on blockchain in energy internet, " Power System Technology, 40 (2016) 3630-3638(in Chinese).

[6] E. Mengelkamp, P. Staudt, J. Gärttner, C. Weinhardt, "Trading on local energy markets : A comparison of market designs and bidding strategies, " Proceedings of the 14th International Conference on the European Energy Market (EEM), Dresden, Germany, 6th - 9th June 2017, IEEE, Piscataway (NJ), 2017.

[7] Zhang Ning, Wang Yi, Kang Chongqing,Cheng Jiangnan,He Dawei, " Blockchain technique in the energy internet : preliminary research framework and typical applications, " Proceedings of the CSEE, 36 (2016) 4011-4023(in Chinese).

[8] LU Jing, SONG Bin, XIANG Wan-Hong, ZHOU Zhi-Ming, "Smart Contract for Electricity Transaction and Charge Settlement Based on Blockchain," Computer Systems & Applications, 2017,26(12):43–50(in Chinese).

[9] E. Mengelkamp, J. Gärttner, K. Rock, S. Kessler, L. Orsini, C. Weinhardt, "Designing microgrid energy markets: A case study: The Brooklyn Microgrid, "Applied Energy, 210 (2018) 870-880.

[10] M. Mihaylov, S. Jurado, N. Avellana, K.V. Moffaert, I.M.d. Abril, A. Nowé, "NRGcoin: Virtual currency for trading of renewable energy in smart grids, " 11th International Conference on the European Energy Market (EEM14), 2014, pp. 1-6.

[11] N.Z. Aitzhan, D. Svetinovic, "Security and privacy in decentralized energy trading through multi-Signatures, blockchain and anonymous messaging streams, " IEEE Transactions on Dependable and Secure Computing, 15 (2018) 840-852.

[12] TIAN Xiuxia, CHEN Xi, TIAN Fuliang. Community Distributed Power Security Transaction Scheme Based on Blockchain[J]. Netinfo Security, 2019, 19(1): 51-58.

[13] WANG Jian, ZHOU Niancheng, WANG Qianggang, WANG Peng , " Electricity Direct Transaction Mode and Strategy in Microgrid Based on Blockchain and Continuous Double Auction Mechanism," Proceedings of the CSEE,2018,38 (17):5072－5084+5304.

[14] PING Jian, CHEN Sijie, ZHANG Ning, YAN Zheng, YAO Liangzhong, "Decentralized transactive mechanism in distribution network based on smart contract, " Proceedings of the CSEE, 37 (2017) 3682-3690(in Chinese).

[15] Y. Guo, M. Pan, Y. Fang, P.P. Khargonekar, "Decentralized coordination of energy utilization for residential households in the smart grid, IEEE Transactions on Smart Grid, 4 (2013) 1341-1350.

[16] S. Chen, C.-C. Liu, "From demand response to transactive energy: state of the art, " Journal of Modern Power Systems and Clean Energy, 5 (2017) 10-19.

[17] M. Kim, S. Song, M.-S. Jun, " A study of block Chain-Based peer-to-peer energy loan service in smart grid environments, " 2016.

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