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An Exploration of the Optimization of Distributed Power Transaction Models Based on Blockchain

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Abstract. In order to solve the problem (purpose) that the current "residual power grid" mode does not adapt to the distributed network structure and is not conducive to the promotion of distributed generation, the optimization method of distributed power transaction mode based on blockchain is proposed. The distributed power trading system based on blockchain can realize efficient, safe and decentralized power trading. Firstly, the technical system of "production, sales and transportation" is constructed, and the difficulties in the system are pointed out; Secondly, the transaction mode based on smart contract and continuous bilateral auction is designed; Finally, the consensus algorithm is improved based on the proof of entrusted rights and interests. The experimental results show that the seller's income of the distributed electricity trading mode designed in this paper is significantly higher than that of the "residual electricity online" mode, with the average income increased by 16.7%, and the buyer's cost also decreased significantly, with the average cost reduced by 7.6%. In the consensus algorithm experiment, the proportion of malicious nodes in the initial DPOS algorithm is much higher than that in the improved consensus algorithm, and the proportion of malicious nodes in the subsequent transaction consensus process of DPOS continues to increase, while the proportion of malicious nodes in the improved consensus algorithm has not exceeded 50% in 24 consensus times, indicating that the security of the improved consensus algorithm has been improved. Conclusion: Compared with the "residual power online" mode, the transaction mode proposed in this paper has significantly improved the economic benefits of both buyers and sellers, and the improved consensus algorithm has effectively curbed malicious nodes from doing evil.

Keywords. Distributed electricity, blockchain, smart contracts, continuous two-way auctions

1. Introduction

As the power system gradually becomes clean and low-carbon, the proportion of clean energy supply gradually increases, and a large number of distributed energy sources such as wind energy and solar energy are connected to the grid, China's energy and economic structure will change significantly [1]. On January 28, 2022, the National Development and Reform Commission and the National Energy Administration proposed to improve the multi-level unified power market system, enhance the basic functions of the unified

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power market system, improve the trading mechanism of the unified power market system, strengthen the overall planning and scientific supervision of power, build a market mechanism suitable for the new power system, and strengthen the organization and implementation [2]. In March 2022, the National Development and Reform Commission and the National Energy Administration proposed to actively promote the market-oriented transaction of distributed generation. Support distributed generation and distribution network regional power users to trade nearby, and improve distributed generation market-based transaction price policies and market rules [3].

China's typical power market mainly has four main types, namely, medium- and long-term, auxiliary services, spot and capacity market. At present, China's power market-oriented transactions are mainly medium- and long-term transactions, with the development of the power market, a single form of transaction is no longer able to meet the demand for transactions, power transactions should be moderately expanding the development of spot transactions should be the main form of transactions, so that the market can be carried out in an orderly manner, and to ensure the security of the market transactions is the key to the spot market can be a safe and stable development [4]. The current distributed power supply is small, scattered and close to the distributed load, very suitable for the realization of distributed power trading in a retail manner [5]. However, the current transaction is still in the centralized power transactions, if the distributed point-to-point transactions, the transaction user information and transaction data cannot be safely stored to ensure that there are certain problems with data sharing [6].

2. Literature review

In recent years, the research on the micro grid energy trading mechanism is mostly based on the community micro grid and micro grid cluster. Goldstein, B. and others proposed a game theory based electric energy trading mechanism based on the maximization of trading interests and the minimization of electricity costs of the internal members of the community microgrid, and achieved the above goals by optimizing the output mode of energy components and the dispatching mode of trading electric energy [7]. Also based on game theory optimization, Wang, H. and others considered the satisfaction of load and power cost and established an "iterative resource load load" optimization model [8]. These literatures have established mathematical models and proposed relevant trading mechanisms for the power trading market of community micro grid, which have certain reference value. However, the trading roles of the internal members of the community microgrid are not equal, so more scholars study the power trading mechanism of the microgrid cluster. Huang, H. et al. studied the operation problem of multi component microgrids and derived the optimal solution of equipment operation in microgrids. When equipment operates according to the proposed operation strategy, it can make each microgrid obtain greater benefits [9]. Xu, Y. et al. proposed a distributed optimal dispatching strategy for micro grid groups in combination with ADMM algorithm and model predictive control method to realize energy complementation between micro grids, improve renewable energy absorption capacity and system operation reliability [10]. Lin, Y. J. and others proposed a distributed trading strategy for multi microgrid systems, and determined the best market price by improving Gossip algorithm [11]. Hamouda, M. R. and others put forward the bidding strategy between microgrids based on game theory, and combined with the optimization method of equal incremental rate to achieve the goal of maximizing the internal benefits of microgrids [12].

The existing research ignores the fact that the electric energy transaction is a closely related whole of "production, sale and transmission", and does not consider the preparation before the distributed electric energy transaction and the transmission after the transaction. Therefore, this paper takes the distributed new energy power transaction as the background, builds a distributed power transaction system integrating the "production, sale and transmission" function of electric energy, and designs the transaction process in detail.

3. The research methodology

3.1 Distributed Electricity Trading System Framework Design

The main body of the distribution network side is generally various types of users, these users are smart meters as power transmission, metering equipment. Therefore, a distributed electricity trading system can be designed based on smart meters, and various software environments and hardware facilities required for the trading system can be constructed with smart meters as the carrier. In this section, the smart meter is used as the carrier terminal to design a trading system framework that takes into account the whole process of distributed electricity "production-sale-transmission", as shown in Figure 1.

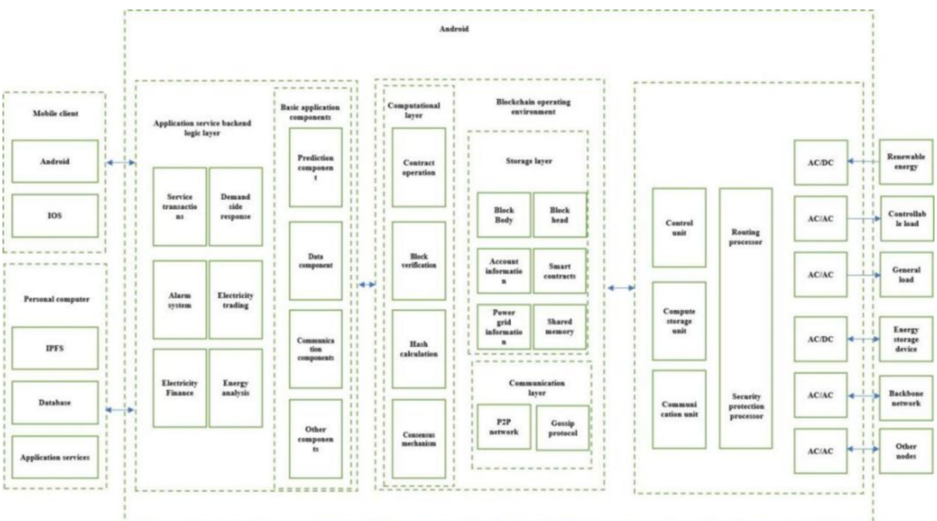

Figure 1. Architecture diagram of the distributed electricity trading system

In Figure 1, the smart meter mainly carries three parts, namely, the back-end module, the blockchain module, and the power routing module, which correspond to the three links of "production, sale, and transmission" of distributed power.

The back-end module consists of two parts: the basic application component and the application service layer. The application service layer provides external services such as energy consumption analysis and power finance, while the basic application component provides internal components required for power trading, such as power forecasting and data access. The module is directly related to the trading of power generation forecast and load forecast, corresponding to the "production" of distributed electricity, which directly provides trading information for the trading of electricity.

3.2 Blockchain-based distributed electricity trading mechanism

3.2.1 The current method of trading electricity

Existing power trading methods are the following: ① bilateral power transactions, power transactions between the two sides of the independent negotiation of power, tariffs, trading time and other information, not through a third-party platform, suitable for long-term contracts, large-scale direct supply scenarios; ② listing transactions, trading centers on the buyer and seller information to publicize the two parties to query the match for the long term, short-term power transactions, real-time, time before the transaction is not applicable; ③ centralized matching The center accepts the offer to form a supply and demand curve, the intersection of supply and demand curves become clearing prices for buyers and sellers to clear, suitable for long-term and short-term, real-time, time before the transaction scenario.

3.2.2 Distributed Electricity Trading Mechanism Process

Using blockchain technology to build a distributed power trading platform on the distribution network side, relying on the consensus mechanism to realize the record trust and relying on smart contracts to realize the execution trust.

The general CDA needs multiple rounds of auctions, and the resource consumption is large, which is not suitable for individual scenarios on the distribution network side. Therefore, this mechanism uses two-stage two-way auctions to achieve a compromise between public fairness and efficiency. Here, a distributed power trading mechanism based on two-stage two-way auction is designed, and the mechanism is realized by using the smart contract of the blockchain, so that the distributed power can be automatically matched, traded, and settled. The flow of this mechanism is shown in Figure 2.

1) Submission of transaction information stage. In the prescribedT_1 time for buyers and sellers to submit transaction information to form a buyer's queueQ_b with the seller queueQ_s。

2) Transaction stage. Qs in ascending order, Qb in descending order. The selling price of the seller at the head of the Qs queue is Ps, and the selling electricity is Vs; the purchasing electricity price of the buyer at the head of the Qb queue is Pb, and the purchasing electricity is Vb. Judging Ps ≤ Pb, if it is less than, both parties will conclude the transaction, and the transaction price is $(P_s + P_b)/2$, the trading volume is the minimum value Vmin between Vs and Vb, the transaction price is stored in the transaction price queue Qa, and the information of both parties who have reached a transaction is formed into a transaction pair Pair<s, b>, and is put into the set S. Clear the satisfied party out of the queue, and continue trading after subtracting Vmin from the unsatisfied party's trading volume. If Qs and Qb are still not empty when Ps>Pb is matched, the average value Pa of all transaction prices in Qa will be calculated, and then broadcast to the network. Then the remaining buyers and sellers refer to Pa to start the second stage auction.

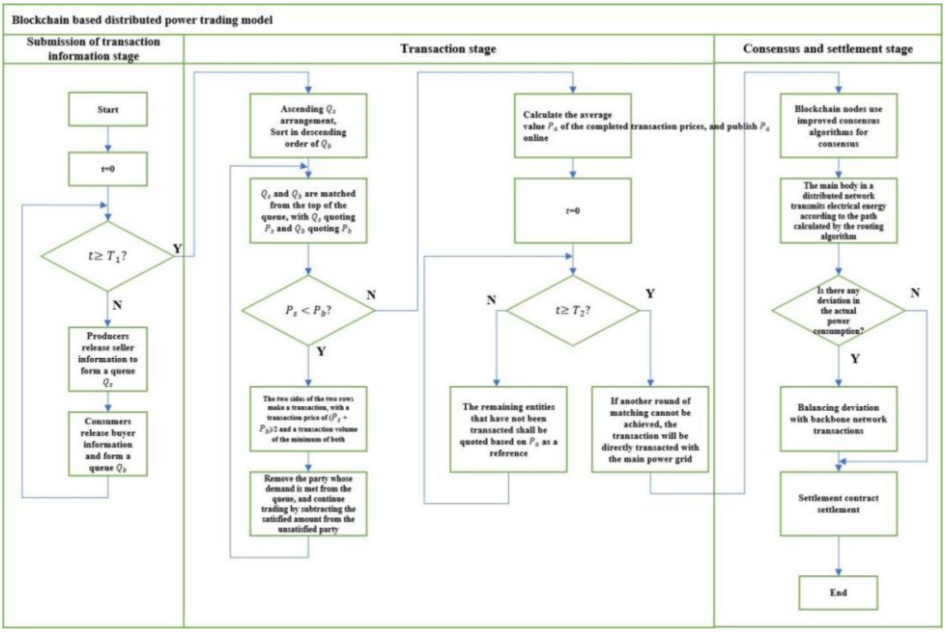

Figure 2. Blockchain-based distributed electricity transaction process

3) Consensus settlement stage. Use consensus algorithm to reach consensus on the transactions reached in the set S, clear the outstanding transactions, and conduct power transmission and settlement for the transactions reached.

3.3 Consensus algorithm based on node composite score

This paper designs a consensus algorithm based on the comprehensive score of nodes with reference to DPOS, which can effectively guarantee the security of distributed energy transactions.

3.3.1 Node composite scoring mechanism

Referring to the concept of "shares" in DPOS share authorization, this paper designs a node comprehensive scoring mechanism. This mechanism can give each node in the network a comprehensive score, which can be used as the basis for election proxy nodes, and the expression is as follows: (1) (2) (3) (4) (5) (6):

$$S_{com} = \alpha S_{reputation} + \beta S_{amount} \tag{1}$$

$$S_{reputation} = 1 - \frac{|E_{pre} - E_{real}|}{E_{pre}} \tag{2}$$

$$S_{amount} = \frac{|E - E_{min}|}{|E_{max} - E_{min}|} \quad (3)$$

$$\alpha \in [0,1] \quad (4)$$

$$\beta \in [0,1] \quad (5)$$

$$\alpha + \beta = 1 \quad (6)$$

Where: S com is the comprehensive score of the node; S reputation is the credit score; S amount is the importance score; Γ and β respectively correspond to the weight of the two scores. For the credit score S reputation , it is mainly evaluated by the difference between the power value of the transaction contract and the actual transmission power value. Epre is the predicted value at the time of the transaction, which is also the value in the transaction contract, while Ereal is the actual delivery value after the power transmission. The larger the difference represented by Epre Real, the greater the impact on the stability of the network. Therefore, the smaller the difference, the better.

S amount is mainly used to evaluate the relative size of electricity produced or consumed by nodes,E refers to the current node's electrical energy capacity (production or consumption), theE_{min}means the minimum electrical capacity in the current set of transactions, theE_{max}It refers to the maximum electric energy capacity. The closer the S amount value is to 1, the greater the electric energy capacity of the node. To sum up, S com is a tradeoff between economic benefits and security of distributed energy trading. S reputation represents the security of the network, and S amount represents the economic benefits of the network. Using S com as the basis for proxy node election can promote nodes to maintain integrity and avoid evil.

3.3.2 Improved Consensus Algorithms

This section proposes an improved consensus algorithm based on DPOS and comprehensive scoring, which is mainly divided into three parts.

1) Proxy node selection. According to S com of the current node, N nodes are selected from the network as proxy nodes to form a block sequence Q block , which acts as block nodes N block in order. If the node does not actively participate in the voting, the system will by default allocate the comprehensive score of the node as the number of votes to the N nodes with the highest comprehensive score in the current network.

2) Consensus stage. All nodes collect the transaction information of this transaction period, and N agent nodes calculate the transmission path of the transaction in this period according to the routing algorithm to form a path queue L, and hash L to form their own Hash value h. Broadcast h to other N-1 agents. At the same time, count the number k of each received h that is the same as its own h. If more than half of k is recorded as Hveri, and the Hash value of the current outgoing node N block broadcast is recorded as H block .

The remaining N-1 agents vote for H block , and count the number of affirmative votes m, if H block =H veri =h andm $\geq N/2$, then vote for it, otherwise vote against it. If N block currently obtains no less than N/2 of the affirmative votes, it can execute the block out operation. The other nodes reach a consensus on the block and will deprive the current N block of the right to block out, and punish them for failing to participate in the proxy election for K cycles. At the same time, the next agent in Q block will assume the role of N block , and repeat the above steps again.

3) Information update stage. Update the node's comprehensive score according to the current round of transaction information. Q block removes the current outgoing node. If Q block is not empty, continue with the next round of transaction. If it is empty, conduct proxy election again.

4. Analysis of results

4.1 Electricity trading experiments

On the basis of Ethereum, build an EVM operating environment on CentOS7 system and deploy the private chain, and use Solidity to build a smart contract for the electric energy transaction process. Create eight nodes, one for the administrator, the administrator node deployment contract, and the rest for four sellers and three buyers. Initialize 200 ETHs for each node, and simulate the transaction and settlement process of distributed electric energy (regardless of line constraints and routing paths) .

Taking the current "surplus power grid" method as the control group, the purchase price of the "surplus power grid" method after removing the national subsidies is between 0.4 and 0.5 yuan. This paper takes 0.45 yuan. The current market price of household users is generally between 0.6 and 0.8 yuan, and this paper takes 0.67 yuan. To facilitate the experiment with Ethereum, replace "meta" with "eth". Three loads are selected from the Electricity LoadDiagrams dataset, and four photovoltaic producers are selected from the NREL photovoltaic dataset. The 24-hour data of a day are intercepted respectively as the transaction data of three buyers and four sellers for experiments.

Three buyers and four sellers on Ethereum's private chain submit the above seven groups of data to the smart contract at 1h intervals to participate in the transaction. Using the distributed electric energy trading mode designed in this paper, the seller's income is significantly higher than that of using the "residual electricity online" mode, with the average income increased by 16.7%, and the buyer's cost also decreased significantly, with the average cost reduced by 7.6%. Therefore, this mode can effectively improve the economic benefits of both parties to the transaction, and there is no central organization to maintain the whole transaction process, reducing the cost, which is conducive to the promotion of distributed new energy in the distribution network side.

4.2 Experiments with consensus algorithms

Select 50 agents from these 150 nodes, and then these 50 nodes simulate the consensus process of 24 transactions in 24 hours. In order to verify that the improved consensus algorithm can inhibit malicious nodes and maintain transaction security in the transaction process, the experiment set that each normal node has a 10% chance of becoming a malicious node in each round of transactions. Set DPOS as the control group, and take the proportion of malicious nodes in the total nodes in the consensus process as the evaluation standard to evaluate the effectiveness of the improved consensus algorithm. The simulation results are shown in Figure 3.

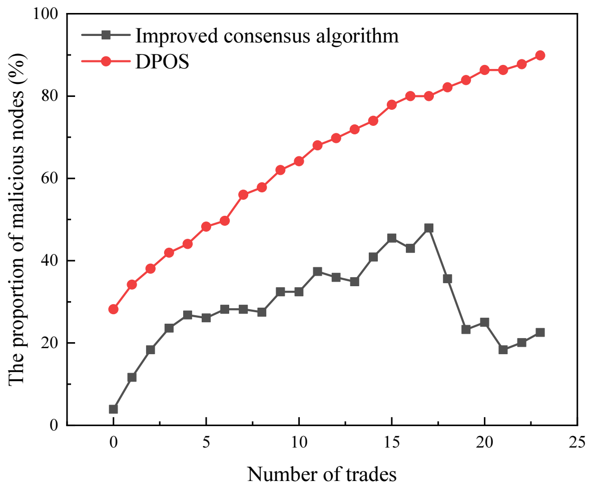

Figure 3. Comparison between DPOS and improved consensus algorithm

As can be seen from Figure 3, the initial proportion of malicious nodes in the DPOS algorithm is much higher than that in the improved consensus algorithm, and the proportion of malicious nodes in the DPOS consensus process of subsequent transactions is constantly increasing, while the proportion of malicious nodes in the improved consensus algorithm has not exceeded 50% in 24 consensus times, indicating that the security of the improved consensus algorithm has been improved.

5. Conclusion

The architecture of distributed electric energy trading system based on blockchain proposed in this paper covers the whole process of "production, sale and transmission" of distributed electric energy, points out the problems that need attention, and provides a new idea for the construction of distributed electric energy trading system. The paper also designs a distributed electric energy trading mode based on smart contract and CDA, and the experiment shows that the mode can effectively improve the economic benefits of both parties. Finally, an improved consensus algorithm based on DPOS is proposed, and its security is improved compared with DPOS through experiments. However, the system system designed in this paper is still immature, and the internal details and internal links of each module are still worthy of follow-up research. In addition, the routing computer mechanism in the consensus algorithm improved in this paper still needs further research and experiment.

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