Blockchain-enabled power distribution side management: model and method

Jianlin Yang¹, Fei Fei¹, Haiqun Wang¹, Mingxing Guo¹, Ran Lü¹, Kevin Jia²

¹ State Grid Shanghai Economic Research Institution, Shanghai, 200000 China
² School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai, 200240 China

1342127947@qq.com

Abstract. With the development of the “ubiquitous power internet of things”, the shortcomings of the traditional centralized power trading mechanism in power distribution side have gradually become apparent, e.g., low flexibility in power usage. And blockchain technology gains some insight to deal with these problems due to its distributed nature. To this end, the paper implements a blockchain-based multi-channel energy management model on the Hyperledger Fabric blockchain platform to carry out a transaction-driven power management method in the power distribution side. Simulation results show its operability and effectiveness.

1. Introduction
Electricity transactions are the foundation of electricity retailers and power users. The electricity owned by users or electricity retailers can be regarded as digital assets monitored by smart meters, which can be traded like stock certificates [1].
But due to the characteristics of “small transaction amount, high frequency, and complicated market structure” in the power distribution side, the traditional centralized management model faces three major problems: a large amount of power distribution equipments lead to high operating cost, low transaction efficiency and poor flexibility [2]; information asymmetry between producers and consumers; the centralized storage of information presents risks of transaction security and consumer privacy. Therefore, it is necessary to build a distributed power trading platform to achieve decentralized operation.
Blockchain provides us with a good perspective. In recent years, blockchain technology has been regarded as one of the most promising technologies in digital asset trading areas, e.g. carbon emission certification. At present, a few companies have tried to apply blockchain technology to the power system [3]. [4] analyzed the security and privacy risks of blockchain-based energy transactions from an information security perspective. [5] discussed the research framework and feasible application of blockchain technology in energy internet. [6] proposed a distributed power grid security verification method and established a weakly centralized power trading model. These researches provide the basis for this article.
The power distribution side energy management based on the blockchain is as follows. Individuals can use smart contracts [7] to settle the agreement with electricity retailers. In the power blockchain community, all users need to reach a consensus before the new rules are packaged into the block, which avoids unilateral decisions.
More specifically, a multi-channel energy management model on the Hyperledger Fabric blockchain platform and a transaction-driven, decentralized power management method are proposed in this paper. This multi-channel model provides a meaningful experience for the integration of distribution network operation and the blockchain. Besides, the multi-channel design separates large blocks from each other, which improves the flexibility and stability of the system. Meanwhile, the transaction-driven, decentralized power management method provides users with more possibilities to participate in the power market and encourages small, high-frequency power transactions.

2. Multi-channel transaction model based on blockchain

Hyperledger Fabric is chosen in this paper to support the implementation of multiple channels. A channel refers to a private "subnet" established among members for private transactions.

2.1. Blockchain network members
The members in this model are mainly composed of government departments, banks, electricity retailers and users.

2.1.1. Government departments. The role of government departments in the blockchain network is to provide access for electricity retailers participating in blockchain power transactions.

2.1.2. Bank. The bank interacts with all electricity retailers and users to provide a monetary intermediary between legal currency and the cryptocurrencies in power transactions. Users and electricity retailers use the legal currency to purchase cryptocurrencies "energy coin".

2.1.3. Electricity retailers and users. Electricity retailers and users, as the mainstays of energy transactions in the power distribution side, play an equal role in electricity transactions based on smart contracts in a single channel. The difference is that electricity retailers provide an access agreement to users who enter the channel by issuing an intermediate certificate CA.

2.2. Multi-channel design
In the multi-channel transaction model, we design \( N + 2 \) channels, including government departments, banks, \( N \) electricity retailers, and \( M \) users. In Hyperledger, each node can participate in multiple channels, but the transactions within the channel are independent of each other.

2.2.1. Channels 1 to \( N \). The \( N \) channels are composed of \( N \) electricity retailers and all users. The access managers of these channels are electricity retailers, who issue an intermediate certificate Fabric-ICA. Each member of these channels has equal rights. In addition to the long-term contract signed by the users and the electricity retailers, each member including the electricity retailer can participate in the double auction.

2.2.2. Channel \( N + 1 \). The channel is composed of \( N \) electricity retailers and government departments. The access manager of the channel is the government department, and the government department issues the root certificate Fabric-RCA. The government department only plays the role to give permission to electricity retailers.

2.2.3. Channel \( N + 2 \). The channel is composed of \( N \) electricity retailers, all users and the bank. The access manager is the bank, who issues the root certificate Fabric-RCA. The smart contract in the channel stipulates that the transaction can only exist among the bank, electricity retailers and users through "energy coins".
Figure 1. Schematic diagram of a blockchain-based multi-channel transaction model.

The proposed model is shown in figure 1 if \( N=3 \). It is worth noting that the orderer node refers to a collective name of the sorting service rather than a single node. The certificate CA trust chain that supports the multi-channel transaction model is shown in figure 2. A certificate chain starts from the root certificate RCA (Root CA) issued by the government department, and each intermediate certificate ICA needs the signature of the higher-level certificate CA. If the RCA is not trusted, the subordinate ICA cannot be authenticated.

Figure 2. CA trust chain.

3. The trading method
This model includes a double auction market [8] and a P2P trading [9] market in a single channel to promote the autonomy and efficiency of power trading. The blockchain is used as a coordinator to solve the problems of trust, supervision, security, and transparency of the trading process. The blockchain-based electricity transaction process in a single channel is described as follows:

- Users draw up their electricity consumption and generation plans and sign the contracts with the electricity retailers, and the miners [10] write the information into the blocks.
- When a user's actual power consumption or generation deviates from the established plan, the user will initiate a transaction through a smart contract. If the power generation is excessive, the user will request to sell power; if the power consumption is excessive, the user will request to buy power.
- Blockchain miners collect the quotations of all producers and consumers and sort the set of quotations, and conduct double auctions. The quotations of sellers are sorted from low to high while the quotations of buyers are sorted from high to low, then the queue is matched according to the double auction rules.
After the double auction, all producers and consumers can carry out P2P trading. All producers and consumers can view the bidding information announced on the blockchain. They can choose to modify the quotation and quantity and wait for a response in the market.

All users adjust their power consumption and generation according to the transaction results. Each user installs a smart meter to detect the power generation and consumption and interact with smart contracts on the blockchain. This process is autonomously completed by smart meters without centralized organizations.

This method introduces double auction and a P2P market into the electricity trading market based on the blockchain. It maximizes the optimal allocation of power resources in the power distribution side.

4. Testing based on Hyperledger Fabric

Hyperledger Fabric is the testing platform for the smart contracts. An electricity retailer and 5 distributed users in a channel are defined as A-F. Then A, D and F are sellers, and B, C and E are buyers. The bidding prices of A-F are 36, 22, 28, 20 and 16 token/kWh, and the bidding quantities are 76, 125, 159, 131, 72 and 145 kWh respectively. The matching results of the double auction are shown in table 1. C, D and F are cleared in the double auction while B fails to purchase 8 kWh. A’s bidding price is too high while E’s bidding price is too low, they are not able to be matched in the double auction.

| Users | Final price (token/kWh) | Successful bidder | Quantities (kWh) | Revenue (token) | Balance (kWh) |
|-------|-------------------------|------------------|-----------------|----------------|--------------|
| A     | —                       | —                | —               | —              | 76           |
| B     | 21                      | D                | 117             | -2457          | 8            |
| C     | 22                      | F                | 145             | -3190          | 0            |
|       | 24                      | D                | 14              | -336           |              |
| D     | 24                      | C                | 14              | 336            | 0            |
|       | 21                      | B                | 117             | 2457           |              |
| E     | —                       | —                | —               | —              | 72           |
| F     | 22                      | C                | 145             | 3190           | 0            |

After the double auction, it will enter the P2P phase. The trading behaviors and final transaction results are shown in table 2.

| Users | Trading behavior in P2P | Successful bidder in P2P | Deal amount in P2P (kWh) | Revenue in P2P (token) | Final purchased quantity (kWh) | Final sold quantity (kWh) | Final revenue (token/kWh) |
|-------|-------------------------|--------------------------|--------------------------|------------------------|-------------------------------|----------------------------|--------------------------|
| A     | 20 token / kWh for sale 76 kWh | E                        | 72                       | 1440                   | —                             | 72                         | 1440                     |
| B     | Withdraw 8 kWh          | —                        | 0                        | 0                      | 117                           | —                          | -2457                    |
| C     | —                       | —                        | 0                        | 0                      | 159                           | —                          | -3526                    |
| D     | —                       | —                        | 0                        | 0                      | 131                           | 2793                       |                          |
| E     | Buy 76 kWh under market price | A                       | 72                       | -1440                  | 72                            | —                          | -1440                   |
| F     | —                       | —                        | 0                        | 0                      | —                             | 145                        | 3190                     |

The results show that the blockchain can be used to conduct transaction settlement of digital assets. The economic incentives can promote the decentralized and autonomous in the channel. Members in blockchain can participate in small transaction settlement through the execution of smart contracts to
maximize benefits. For example, A, D, and F decided to lower the power demand and yielded 1440 tokens, 2793 tokens, and 3190 tokens respectively. B, C, and E choose to increase the power consumption and buy electricity, which achieved Pareto improvement.

5. Conclusion
To author’s best knowledge, the Hyperledger Fabric platform is used to build a blockchain network in the power distribution side for the first time. A multi-channel model, as well as a trading method was proposed to ensure transaction security. It also improves the flexibility of power usage and encourages small-amount and high-frequency power transactions. The burden of users and electricity retailers on the assessment of deviation power is reduced greatly.

6. References
[1] S Chen and C C Liu 2017 From demand response to transactive energy: state of the art J. Mod. Power Syst. Clean Energy 5 10–19
[2] Shaoyong G 2020 Blockchain Meets Edge Computing: A Distributed and Trusted Authentication System IEEE Trans. Ind. Informat. 16 1972–83
[3] Kim M, Song S and Jun M 2016 A Study of Block Chain-Based Peer-to-Peer Energy Loan Service in Smart Grid Environments Adv. Sci. Lett. 22 2543–46
[4] Zhumabekuly Aitzhan N and Svetinovic D 2016 Security and Privacy in Decentralized Energy Trading through Multi-signatures, Blockchain and Anonymous Messaging Streams IEEE Trans. Dependable Secur. Comput. 15 840–852
[5] Ning Z 2016 Blockchain Technique in the Energy Internet: Preliminary Research Framework and Typical Applications Proceedings of the CSEE 36 4011-4023
[6] Xue T, Hongbin S and Qinglai G 2016 Electricity Transactions and Congestion Management Based on Blockchain in Energy Internet Power System Technology 40 3630–3638
[7] Hye Yong P 2019 Analysis of Data Management in Blockchain-Based Systems: From Architecture to Governance IEEE Access 7 186091–6170
[8] Jian W, Niancheng Z and Qianggang W 2018 Electricity Direct Transaction Mode and Strategy in Microgrid Based on Blockchain and Continuous Double Auction Mechanism Proceedings of the CSEE 38 5072–5084
[9] Jaysson Guerrero 2018 Decentralized P2P Energy Trading Under Network Constraints in a Low-Voltage Network IEEE Trans. Smart Grid 10 5163–73
[10] Jian P, Sijie C and Ning Z 2017 Decentralized Transactive Mechanism in Distribution Network Based on Smart Contract Proceedings of the CSEE 37 3682–3690

Acknowledgments
This work is supported by State Grid Shanghai Economic Research Institution Program (blockchain-based distributed autonomous operation scheme and enabling technology for energy internet, No. 52090R19000D).