Design of Distributed Intelligent Terminal System of Electric Distribution Network Based on Blockchain Technology

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Abstract. With the construction of the energy internet and the maturity of the electric Internet of Things technology, intelligent terminal products in the distribution network are widely used in power system. Under the existing architecture of distribution IoT network, the access of large number of intelligent terminals will bring problems such as over-centralization and data security. In response to these problems, this paper proposed a distributed intelligent terminal system of distribution network based on blockchain technology, illustrated the overall architecture of the system, and analyzed the necessity of adopting the distributed intelligent terminal system. The system's operating mechanism was showed combined with a specific case, and the technical solution was elaborated. Finally, the advantages and limitations of the system were discussed, and the integration of blockchain technology and power IoT technology was prospected.

Keywords: Blockchain technology; Electric distribution network; Intelligent terminal system; Electric IoT.

1. Introduction

Since the advent of blockchain technology, it has received extensive attention and research. Blockchain technology is essentially a distributed ledger technology that is jointly maintained by multiple nodes. It can achieve distributed storage of data, establish a trust mechanism between multiple subjects, and ensure that data cannot be tampered with. At present, the most mature application of blockchain technology is digital tokens represented by Bitcoin and Ethereum. With the development of blockchain technology in technical principles and consensus mechanisms, the applications of the blockchain technology in the fields of IoT (Internet of Things), distributed storage and energy are more in-depth and extensive [1]. In the energy field, the application exploration of blockchain technology mainly focuses on distributed energy transactions[5-9], virtual power plant scheduling[10], digital identity authentication[11], and decentralized storage of data[12-13] etc. At present, the research and exploration on the application of blockchain technology to the decentralized transaction of distributed energy is relatively rich. Distributed energy transaction itself is the participation of multiple subjects lacking mutual trust, and blockchain technology can be Trust and collaboration mechanisms have been established between multiple trading entities to achieve decentralized trading of energy. Reference [5] proposes to treat all parties of distributed energy transactions as nodes, and all transaction records are chained to ensure that the transaction records cannot be tampered, so as to achieve decentralization among multiple agents without a transaction center. Reference [6] optimizes the underlying technology of the blockchain on this basis, so that the trading system based on the blockchain technology can better meet the increasingly complex trading
scenarios of the power system. Reference [7] proposes to use heterogeneous blockchain technology to solve cross-chain communication problems, on this basis, a multi-energy trading system is constructed, which effectively integrates information resources and physical resources. Reference [8] uses a smart contract running on the blockchain to execute the power purchase strategy of the charging station to achieve the purpose of reducing the cost of power purchase. Reference [9] proposed a microgrid energy trading mechanism based on blockchain technology. Reference [10] introduced the blockchain technology into the dispatch operation of virtual power plants. Reference [11] proposes to use blockchain technology to store the user's digital identity, thereby ensuring the privacy of the user and the integrity of the transaction data. References [12-13] use blockchain technology to perform distributed storage of asset data and security data of power systems and optimize the data storage model.

The overall architecture of the current distribution IoT is shown in Figure 1. The transformer area refers to the area powered by a transformer. The current distribution network is divided into units of transformer area. Along with each transformer area, there is a terminal installed. The terminal is part of the perception layer in the architecture. It is responsible for gathering the data collected by the equipment such as smart meters, fault diagnosis devices, and switching devices and makes preliminary processing of the data and sends it to the cloud master station of the platform layer. The cloud master station stores data and provides the data to the application layer. The current overall architecture of the power distribution IoT is essentially a centralized data storage and processing mode. With the substantial increase in the type and number of equipment in the transformer area, the amount of data gathered by the terminal and sent to the master station will also increase. This increase will bring geometric pressure to the data storage and data processing of the master station, which will cause the following three problems:

Firstly, the architecture of data storage is too centralized. In the current architecture, the data of all transformer areas must be finally aggregated and stored in the cloud master station. The master station is the core of the entire system. The realization of system functions depends on the normal operation of the cloud master station. The failure of the master station will lead to paralysis of the entire system. At the same time, with the advancement of the construction of the distribution IoT, the amount and type of data collected by the terminals in the transformer area has increased significantly. The cloud master station needs to be equipped with more servers to meet the growing demand, resulting in a surge in the cost of the master station.

Secondly, the security of data can’t be guaranteed. Under the current architecture, all transformer area data is stored in the master station, and the number of data backups on the master station is limited. If the master station is subjected to a malicious attack, the data is tampered or lost, and the security of the data is difficult to guarantee.

Thirdly. The present architecture is not applicable for distributed energy trading. The birth of the concept of decentralized energy trading and the maturity of microgrid technology have made it possible to realize decentralized transactions between distributed energy in different transformer areas, which will become the main distributed energy transaction mode in the future. The transaction data only needs to be transmitted and stored between the terminals in the transformer area, and does not require the transformer area terminal to transmit the data to the cloud master station. Obviously, a centralized architecture is not suitable for decentralized transaction mode of distributed energy.
Wireless private network

Smart meter, switchgear, Fault diagnosis equipment, Other IoT devices

2. Distributed Terminal System Architecture
The distributed distribution network terminal system is mainly composed of the terminals of the distribution network, and all the terminals of the distribution network are used as nodes to form a blockchain network. The point-to-point communication between the terminals are realized through wireless private network or public network. The data collected by the terminal in the transformer area will be sent to the master station, and the important data will also be transmitted to other terminals in the network; at the same time, the data of the transformer area in the distribution network is stored in all terminals in the form of blockchain. Thus the point-to-point communication and distributed storage architecture can be established between the terminals in the distribution network. The distributed terminal system establishes a point-to-point communication channel between terminals, which no longer needs to pass through the master station. When the master station fails, important data in the transformer area can still be transmitted between the terminals. At the same time, due to the distributed storage mode of the data in the transformer area, there is a corresponding data backup in each terminal. Even if the main station is subjected to malicious attacks or artificial tampering, all terminals store complete data backups, thus ensuring that the data will not be lost or tampered with, which greatly improves the security of the data.
2.1. Distribution Network Terminal
In the distributed terminal system architecture proposed in this paper, the terminal in the transformer area is the core part and each terminal in the transformer area participates in the maintenance of the blockchain network as a complete node. As a node of the blockchain network, it is necessary to store the main chain data of the entire blockchain network, so compared with the terminal at the perception layer in the current architecture, the terminals in the distributed terminal system not only need to collect data, but also need to have stronger data storage and computing capacity.

2.2. Point-to-point Communication Mechanism
In a distributed terminal system, the communication between terminals no longer needs to go through the cloud platform. By formulating a point-to-point communication protocol and establishing a communication channel between the terminals, it can ensure that the point-to-point communication mechanism can be implemented between the terminals. Based on this mechanism, the entire system operation no longer depends on a few central nodes, realizing decentralization in the true sense. After the terminal collects the station area data of its corresponding station area, it needs to transmit the data to other terminals in the entire system. This process is called whole-network broadcasting. When a terminal receives data from other terminals, it needs to transmit the data to neighboring terminals. This process is called forwarding.

2.3. Main Chain of Distribution Network
In the distributed terminal system, the data of transformer area is stored in the form of blocks. Each block is composed of a block header and the data sheet. The block header contains the block version, the hash value of the previous block, and the timestamp of the block. The data list of the transformer area contains the data of the transformer area stored in the block. The blocks are connected by hash values to form a chained data structure which is the main chain of the distribution network. After a certain time a new block will be generated, during this time the data of the transformer area will be stored in a new block, and the new block will be connected to the main chain by recording the hash value of the previous block in the block header. When a terminal forms a new block according to the structure of the block and connects the important data of the transformer area and the hash value of the previous block to the main chain, it is called packaging.

2.4. Digital Identity Authentication System
In order to ensure that there are no malicious nodes in the distributed terminal system, it is necessary to establish a digital identity authentication system in the system, and assign a corresponding digital ID to each terminal in the system through a smart contract running on the blockchain network. It represents the digital identity of the terminal and is used to verify the identity of each other between nodes. When the terminal broadcasts the data of the transformer area on the entire network, it needs to add the digital ID of the terminal to the data. When other terminals receive the data, the digital ID of the data needs to be verified first, and the data in the transformer area will be further processed after the verification is passed. Each terminal stores the digital IDs of all the terminals of the entire system. When new terminals are added to the system or old terminals exit the blockchain network, they need to pass digital identity authentication and then broadcast on the entire network. Other terminals will correspondingly add new ID or delete old ID. Through the establishment of a digital identity authentication system, on one hand, each data can be identified to determine the location of the terminal; on the other hand, the data transmitted in the system can be trusted to maintain the system data storage safety.

2.5. Consensus Mechanism
In order to maintain the security of the system in the blockchain system, a consensus mechanism is used to encourage nodes to keep credible. A node only has the right to package transaction information over a period of time only if it wins the competition with other nodes. For example, Bitcoin uses a proof-of-work mechanism and Ethereum uses a proof-of-stake mechanism. Although the existence of the consensus mechanism restricts the node to do evil, it consumes a lot of computing
resources and reduces the operating efficiency of the system. The premise of the existence of the consensus mechanism is the lack of mutual trust between the nodes in the blockchain network, and the need to establish trust through the consensus mechanism.

In the distributed terminal system, the accounting function refers to the process that the terminal of the station packs the data of the transformer area into blocks and links the new blocks to the main chain. As all terminals in the distributed terminal system trust each other as nodes, there is no need to compete for accounting rights. The use of a digital identity authentication system can ensure that external malicious nodes cannot be accessed. Therefore, there is no need to establish complex consensus mechanisms in the distributed terminal system. The consensus mechanism can save a lot of computing resources and greatly improve the operating efficiency of the system.

The consensus mechanism of the distributed terminal system draws on the authorization consensus mechanism. During the system operation, the smart contract embedded in the terminal runs a verifiable random number generation program, and a random number generated by the program determines the new accounting node of the block. When other terminals receive the new block, they need to verify the random number. If the verification is passed, the other terminals will write the new block to the main chain. At this time, the entire distribution network main chain is updated. After finishing this program, the random number generation program is run to generate a new random number to determine the terminal to serve as the next accounting node.

3. System Operation Mechanism

In order to explain the operation mechanism of the distributed terminal system in detail, an example system is used in this section, as shown in Figure 2. The distribution network of the example system has 5 terminals installed which form a blockchain network (the number of terminals does not affect the system architecture and operating mechanism). The digital IDs of the five terminals are 101~105.

The data of the transformer area will be transported through point-to-point communication and distributed stored in the blockchain network in the example system. Each node stores the network main chain of the distribution network and the data buffer of the non-entered data. Assuming that the 105 terminal collects the data from to the corresponding transformer area, and the 105 terminal stores the data in the data buffer. Afterwards the 105 terminal forwards the data a to the 101 terminal and the 104 terminal, and the 101 terminal and the 104 terminal also store the data a to the data buffer. At the same time, the 101 terminal and the 104 terminal forward the data a to the 102 terminal and the 103 terminal respectively. The data a will be written to the data buffer of all nodes. Assuming that the 104 terminal also collects the data b, and the 104 terminal broadcasts the data b throughout the network according to the above procedure, thus the data b will also be written into the data buffer of all nodes, as shown in Fig.3.
After the data broadcasted through the whole blockchain network, the smart contract will run a verifiable random number generation program which the random number will determine the terminal that acts as the accounting node. In this example system, assume that terminal 102 is selected as the accounting node, and terminal 102 will pack the data a and data b into a new block, written into the main chain, and deleted data a and data b from the data buffer at the same time, as shown in Figure 3. Then terminal 102 broadcasts the new block to the whole network. When other terminals receive the new block, the random number is verified by other terminals. After the verification is passed, the new block is connected to the main chain of the distribution network, and the data a and data b of the data pool buffer are deleted. Up to now, the main chain of the distribution network of all terminals has been added a new block, as shown in Figure 4, so far the data a and data b of the transformer area have been stored in the blockchain.

Figure 3. Broadcast of data and new block.

Figure 4. New block stored in all terminals.
Through the example system, the operation mechanism is illustrated. After the transformer area data is generated, firstly it will be stored into the data buffer of the terminal. And when the accounting node is selected by the smart contract, the accounting node terminal will pack all the data in the data buffer to form a new block, and broadcasts this block to the entire network. And then all terminals of the entire network will connect this the new block to the main chain of the distribution network. The data of the transformer area in the new block will be stored in all terminals of the transformer area, which realizes the distributed storage of the data of the transformer area.

4. Technical Solution

Distributed terminal system lies in the terminal of the transformer area. It is necessary to transform and optimize the terminal from the two levels of hardware and software on the existing basis, so as to ensure that the terminal of the transformer area can fully perform the function of the node and the distributed terminal system can operate normally. At the hardware level, the terminals in the distributed system have more data storage functions than existing terminals, so the key to upgrade the hardware is to increase the computing power of the main control board and increase the data storage space.

At the software level, the terminal adopts a decoupling design method of hardware and software, and develops an embedded APP on the main control board to ensure the realization of terminal functions. In the distributed terminal system, it is necessary to ensure that the terminal has the point-to-point communication function, the function of storing data in the form of block, and the accounting function. Point-to-point communication APP, block data APP and smart contract APP need to be developed on the main control board. The point-to-point communication APP is responsible for managing the point-to-point communication protocol with data forwarding capabilities, which can realize the point-to-point communication function. The block data APP is responsible for writing the transformer area data into the block, and storing the distribution network main chain data. The smart contract APP runs a random number generation program and verifies the random number and the digital ID of other terminals.

5. Conclusions

This article describes the system architecture, operating mechanism and technical solution of the distributed terminal system in detail. The following main conclusions are drawn:

1) The research about the combination of blockchain technology and electric IoT technology is still blank, and the distributed terminal system proposed in this article is an active exploration and attempt to break the gaps in related fields. The system operation mechanism and technical solution of the system are firstly proposed in this paper. At the same time this paper also provides new ideas for the application of blockchain technology in the energy field.

2) The distributed terminal system establishes a collaboration mechanism between a large number of distributed terminals, so that the operation of the entire system no longer depends on the central node. Even if the cloud master station fails, the distributed terminal system can still operate normally. The shortcomings of the centralized IoT architecture also relieved the storage pressure of the cloud master station to a certain extent.

3) At present, the computing power and storage space of the terminal in the transformer area are limited, and it is impossible to achieve distributed storage of all the data in the station area. Therefore, the data content that needs to be distributed storage needs to be determined according to the specific needs of the transformer area. Generally speaking, important data such as digital energy transaction data, the length of power outages, and equipment failure information are more necessary for distributed storage;

4) The point-to-point decentralized transaction method between distributed energy will be the main component of the distributed energy trading system in the future, and its realization is based on the establishment of efficient, safe and flexible collaboration between equipment in transformer area. The mechanism of the distributed terminal system proposed in this paper can ensure the realization of the point-to-point decentralized transaction method at the device level;
5) With the large number of terminal access to the distribution network, a distributed structure of a large number of terminal terminals is gradually formed, which is very suitable for the use of blockchain technology. A collaboration mechanism can be established between distributed terminals by using the blockchain technology. At the same time, the maturity of the electric Internet of Things technology and the continuous improvement of the storage and computing capabilities of terminal equipment also make the realization of distributed terminal systems possible. The distributed terminal system will further conduct pilot verification in the actual power system transformer area, and make targeted improvements and optimizations according to the actual operating conditions.

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References
[1] Ministry of Industry and Information Technology of the PRC. White paper on the development and application of blockchain technology in China (2016)[R]. Beijing, China: Ministry of Industry and Information Technology of the PRC, 2016
[2] China State Council. The “13th five-year plan” national informatization plan (2016)[R]. Beijing, China: China State Council, 2016.
[3] Maesa D D F, Mori P. Blockchain 3.0 applications survey[J]. Journal of Parallel and Distributed Computing, 2020.
[4] Robert K. Perrons, Tonya Cosby. Applying blockchain in the geoenergy domain: The road to interoperability and standards[J]. Applied Energy, 2020, 262.
[5] DOU XiaoBo, CHANG Limin, NI Chunhua, et al. Multi-level Dispatching and Control of Active Distribution Network for Virtual Cluster of Distributed Photovoltaic[J]. Automation of Electric Power Systems, 2018, 42(03): 1-7.
[6] PING Jian, CHEN Sijie, YAN Zheng. A novel energy block chain technology for convex optimization scenarios in power system [J]. Proceedings of the CSEE, 2020, 40(01): 108-116.
[7] Bin LI, Wangzhang C, Jie Z, et al. Transaction System and Key Technologies of Multi-energy System Based on Heterogeneous Blockchain[J]. Automation of electric power systems, 2018, 42(04): 183-193.
[8] Zhong C, Yanxi C, Songyang C. Framework of Integrated Charging Station for Renewable Energy Vehicle and Energy Optimal Dispatching Method[J]. Automation of electric power systems, 2019, 43(24): 23-31.
[9] Wang Jian, Zhou Niancheng, Wang Qianggang, et al. Electricity direct transaction mode and strategy in microgrid based on blockchain and continuous double auction mechanism[J]. Proceedings of the CSEE, 2018, 38(17): 5072-5084.
[10] She Wei, Hu Yue, Yang Xiaoyu, et al. Virtual power plant operation and scheduling model based on energy blockchain network[J]. Proceedings of the CSEE, 2017, 37(13): 3729-3736 (in Chinese).
[11] Fu-Liang T, Xiu-Xia T, Xi C. Blockchain-based smart meter authentication scheme[J]. Journal of east china normal university (natural science), 2018(05): 135-143.
[12] JIANG Haitao, WANG Xiang, LI Zhi, et al. Research and application of power system security evaluation management system based on blockchain[J/OL]. Electric power information and communication technology, 2020, 18(01): 67-73.
[13] Jun Z, Fei-Yue W. Digital Asset Management System Architecture Based on Blockchain for Power Grid Big Data[J]. Electric power information and communication technology, 2018, 16(08): 1-7.