Blockchain based Power Transaction Asynchronous Settlement System

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***Abstract*—The popularization and rapid development of distributed energy becomes a trend of the times. Distributed energy prosumers should be able to trade with each other to reduce losses, increase efficiency, flexibility and economy. The traditional centralized power settlement scheme is not suitable for the utilization on the situation of distributed energy transaction settlement. Energy internet as the next generation energy system integrating cutting-edge information technologies with energy system could realize peer-to-peer energy services. The distributed interactive concept of the energy trading is highly consistent with the principle of blockchain. In this paper, aiming at the problems of information disunity, trust system difficult to establish, power deviation waste and cost advance caused by power pre-sale, a power transaction asynchronous settlement system for microgrid is proposed based on blockchain technology. The experiment results illustrate that the system obtains good performance and is promising for practical application.**

***Keywords*—energy internet, micro grid, blockchain, power transaction**

I. Introduction

The popularization and rapid development of distributed energy becomes a trend of the times. Distributed energy resources refer to distributed generations and storages which are connected to distribution network to provide flexible loads at the end users [1]. The access of distributed energy to the grid facilitates the realization of multiple forms of energy complementarity, which could promote energy efficiency and expand the scale of renewable energy utilization. With the development of technologies in related fields and the support of renewable energy development policies, distributed energy has developed rapidly [2]. Encouraging distributed energy to participate in market-based transactions could further boost the reformation of the power system and change in trading models.

Energy internet is a new type of information-energy integrated network constructed by the concept of Internet [3]. Formed by the power system as the core, internet and other cutting-edge information technologies as the basis, distributed renewable energy as the primary energy, and deep integration with other systems such as natural gas networks and transportation networks, energy internet is the next generation energy system to realize peer-to-peer energy services. Its main operation mode to let end users utilize the homegrown power firstly. Then the excess power is traded and distributed in the energy internet from local grid until wide area grid.

Micro-grid is an important portion of energy internet [4]. It is a novel energy networked supply and management technology, which can not only meet the needs of local power users, but also ensure the stability of power supply under extreme conditions and improve energy efficiency. The main research subjects of the energy internet micro-grid include various distributed energy harvesting and storage devices, loads and energy routers [5]. Energy router is a type of device that can collect data from electric devices and dispatch energy. It is not only connected to electrical devices, but also interconnected with other energy routers to transmit energy and energy data to schedule and control energy within and between micro-grids effectively. The structure of a typical micro-grid is shown in Fig. 1, which is the main introduction object of this paper.

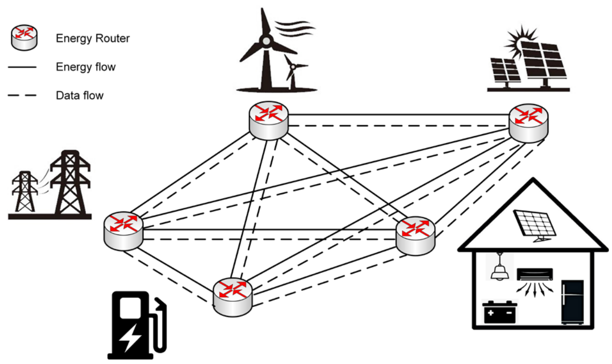


Fig. 1. The structure of a typical micro-grid.

The traditional micro-grid trading system applies centralized settlement scheme [6]. The metering and acquisition module processes the electricity collection business and the settlement module handles the electricity bill settlement business, in which there are problems such as inconsistent transaction information and difficulty in establishing a credit system [7]. Although smart meter infrastructure could accurately record user power consumption [8], planned power transactions inevitably have contract power deviations. Even though the market transactions can be settled on a monthly basis and annual

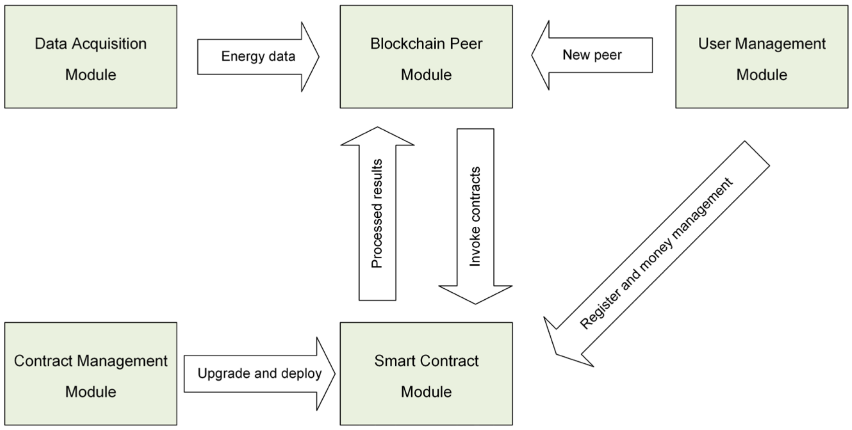


Fig. 2. System architecture.

balance to settle this kind of deviation, it still could causes in the waste of power supply resources and the loss of power user funds in some degrees.

Blockchain is a type of distributed ledger, which realizes chain storage through one-way connection of block hash values. It uses asymmetric encryption, Merkle tree and other technologies to ensure that the information in the chain cannot be tampered, which ensures data security well [9-11]. Blockchain technology has the characteristics of decentralization, transparent transactions, trustworthiness, and tamper-resistance, which is highly consistent with the concept of energy internet: the reliable data recorded in the blockchain can provide reliable records for energy transactions within an energy internet; the distributed ledger storage corresponds to the distributed energy subject, avoiding problems caused by the failure of the central organization; the information of all parties in the blockchain is open and transparent, which is conducive to flexible energy deployment.

At present, there are not many explorations of applying blockchain technology to microgrids, and most of them stay at the theoretical and experimental stages. In terms of theory, [12] proposed a model of energy-integrated blockchain, and [13] established a blockchain-based energy internet security sharing network system. It attempts to prove that blockchain can be well applied in micro-grid power trading systems, solving the problems of asymmetric centralized power grid settlement information and difficulty in establishing a credit system. [14] researched an electricity trading scheme that stored electricity transaction information in the form of smart contract and automatically performed fund transfers. [15] described the application research of the combination of smart contract technology and power auctions to solve the problem of difficult contract control.

As projects, Brooklyn microgrid developer *LO3 Energy* and blockchain technology developer *ConsenSys* jointly developed and operated a microgrid project [16], participating users can track and record the amount of electricity used and electricity transactions through smart meters connected to the blockchain. Smart energy grid transactions are more efficient than traditional top-down energy distribution systems, allowing users to conduct electricity transactions themselves, while no national power company involvement is required. The EU *Scanergy* project [17] aims to achieve direct transactions of small users' green energy based on blockchain systems. The project envisages detecting the production and consumption status of the network every 15 minutes in the trading system and providing energy suppliers with an *NRGCoin* similar to *Bitcoin* as a reward for energy production. However, the trial scales of these two projects are limited, just to prove the feasibility of small-scale micro-grid to conduct decentralized power transactions, further verifications are required on a larger-scale, and the design of energy transaction settlement for them has still tremendous room for improvement.

In this paper, we address the problems of inconsistent information in the micro-grid, the difficulty in establishing a trust system, and the waste of electricity and cost advances caused by pre-sale, in combination with the good characteristics of the blockchain, proposes an asynchronous settlement system for microgrid power transactions. The design of this system effectively avoids the loss caused by the deviating power. In Section II, the overall structure and module functions of the system is provided. The description of the specific steps of the asynchronous settlement scheme for power transactions are presented in Section III. Experiment designs and results for the system performance are illustrated in Section IV. The paper is summarized in Section V.

II. BLOCKCHAIN BASED MICRO-GRID TRANSACTION SYSTEM

A. System Framework

We design and propose a blockchain based asynchronous settlement system for micro-grid transaction. This system combines with the *Hyperledger Fabric* [18] project to implement the proposed asynchronous settlement system for transactions between energy routers in the energy internet micro-grid. The overall architecture of the system is shown in Fig. 2, it mainly includes data acquisition module, blockchain node module, user management module, smart contract module and contract management module.

B. System Modules

1) User management module: This module is used to perform identity authentication registration based on user registration information and manage other stuffs about users, such as user fund management and node status management, it also can initiate new user registration based on its number and user identity information after users get energy routers. After the smart contract verifies the registration information, it will allocate a user node to the user, and the user participates in the transaction business in the system through this node.

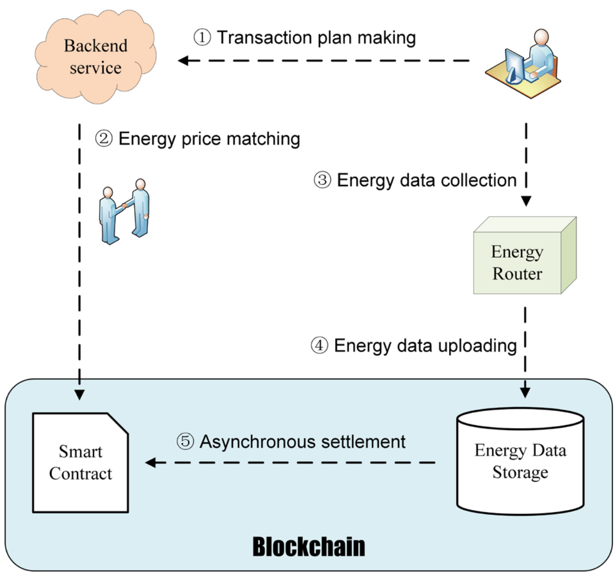


Fig. 3. Steps of the asynchronous settlement scheme.

2) Data acquisition module: This module monitors energy subjects through energy routers, collects the power supply and consumption data of these subjects, and organizes them into blockchain transactions. Finally, these blockchain transactions are sent to the blockchain network through use nodes.

3) Blockchain node module: This module is used for specific data transmission and communication between the blockchain node corresponding to the whole blockchain network. It mainly includes user nodes, system administrator nodes, ordering nodes, and endorsement nodes. Each node realizes the uploading of off-chain data and the query of on-chain data by invoking smart contract. It is a window for users to interact with the blockchain network.

4) Smart contract module: This module is used to provide all kinds of smart contract with corresponding functions for each module, and process smart contract invoking requests for each module. It mainly includes user registration contract, data uploading contract, asynchronous settlement contract, fund management contract, and violation penalty contract.

5) Contract management module: This module is used to remotely upgrade and deploy the new version of smart contracts. The system will perform the corresponding function contract research and development according to the different needs of users. After the new contract is approved by the user, the module will perform remote upgrade and deployment.

III. Transaction Asynchronous Settlement Scheme

The asynchronous settlement method we propose mainly includes five parts: transaction plan making, energy price matching, energy data collection, energy data uploading, and asynchronous settlement. This chapter mainly introduces the process and related knowledge of these five parts. Fig. 3 is an overview of all process.

A. Transaction Plan Making

Users in this system can freely set prices for the energy they produce. A user can set a reasonable price for energy supply according to his own situation and publish the price of energy supply online. All users in this system can see the energy supply plan published by this user. At the same time, users who need to use energy also can set their own energy purchase price and publish energy purchase plans.

B. Energy Price Matching

All energy sellers and buyers in this system can match freely. After negotiation and confirmation, a pair of users will record their energy transaction price in a price table, and finally save it in the blockchain with the form of price matrix. In addition, a user can set different energy transaction prices with multiple users, and the purchase priority can be set. For example, user A can negotiate transaction prices with users B and C at the same time, and A can choose to supply energy to C first. The setting of priority is also recorded in the price matrix. Table. 1 is an example of a price matrix with four users.

TABLE I. Energy Price Table

Seller \ **Buyer**	User A	User B	User C	User D	Grid
User A		(1, 0.3)	(2, 0.4)	(3, 0.5)	0.5
User B	(3, 0.5)		(1, 0.2)	(2, 0.4)	
User C	(3, 0.4)	(2, 0.3)		(1, 0.3)	
User D	(1, 0.2)	(2, 0.4)	(3, 0.4)		
Grid	0.5				

The element in the table is the purchase strategy, which is a two-dimensional vector. The first element represents the purchase priority and the second element represents the corresponding purchase price. For example, the second row represents the seller as user A, and the third column represents the buyer as user B. Then the element in the third column and second row represents the strategy of user B to buy energy from user A. This strategy is that B buy energy from A with priority of 1, i.e. the first buyer, and the purchase price is 0.2 RMB/kW·h. If A can supply 10 kW·h of electricity, while B needs 7 kW·h, and C needs 5 kW·h, A will supply B with 7 kW·h first, and then supply the remaining 3 kW·h to C. User C needs to match the next supplier for enough electricity.

The last column and row of the table is the main grid price. When users have surplus energy and do not sell it or some demands for energy cannot be satisfied, the system shall conduct transactions with the main grid and settle the remaining transactions according to the grid price.

C. Energy Data Collection

In this system, an energy upload cycle is set as $\boldsymbol{T}$. Energy router is connected to various power supply and consumption devices to accurately detect the power supply and consumption data. The data is collected once a cycle and transmitted to the corresponding user node - *Peer*. Power supply and consumption data include user's ID, electric quantity, and timestamp. Each energy router can register one user and connect to multiple access agents. In other words, one user can be used by multiple families or companies. electric quantity represents the sum of power supply and consumption of all access subjects connected to the energy router within a week. The positive value represents the power supply and the negative value represents the power

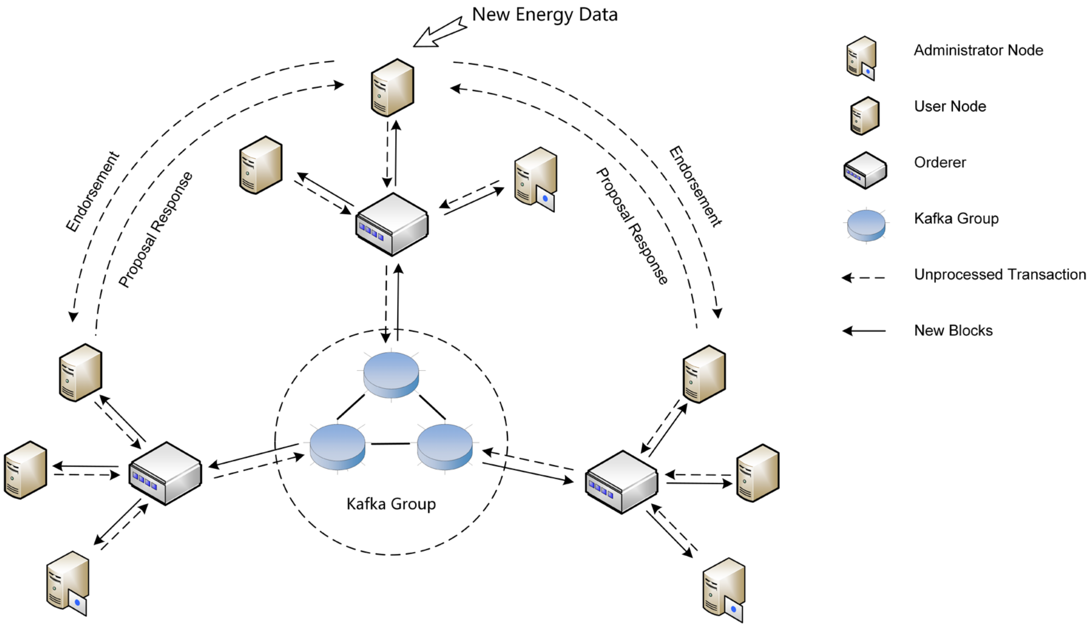


Fig. 4. Blockchain transaction consensus process.

consumption. The timestamp represents the time point when energy routers collect energy data.

D. Energy Data Uploading

When receiving the energy data, *Peer* generate a blockchain transaction according to the energy data. Then the

Algorithm 1 Asynchronous Settlement

```
Input: SL, CL, PM, systemPrice
Output: RL
For each s in SL:
  While s.value > 0:
    Choose a buyer of s by priority;
    If there is no one to choose from:
      Set amount = s.value × systemPrice;
      Generate a record r(s.value, amount, s.user, "Grid");
      Add r into RL;
      Set c.value = 0;
    Get c in CL that belong to buyer;
    If c.value != 0:
      If c.value > s.value:
        Set amount = s.value × PM[s.user][c.user];
        Generate a record r(s.value, amount, c.user, s.user);
        Add r into RL;
        Set c.value = c.value - s.value;
        Set s.value = 0;
      Else:
        Set amount = c.value × PM[s.user][c.user];
        Generate a record r(c.value, amount, c.user, s.user);
        Add r into RL;
        Set s.value = s.value - c.value;
        Set c.value = 0;
For each c in CL:
  If c.value > 0:
    Set amount = c.value × systemPrice;
    Generate a record r(c.value, amount, c.user, "Grid");
    Add r into RL;
    Set c.value = 0;
```

Fig. 5. Asynchronous settlement algorithm.

data upload contract is invoked by the transaction to upload these data to the blockchain, and the transaction containing data will be stored on the blockchain by consensus. Consensus mechanism we used in this system is Kafka in the Fabric project, the specific process as shown in Fig. 4. The *Peer* sends the transaction to the endorsement nodes (other *Peers*) for endorsement; endorsement nodes verify this transaction and return the verified transaction to the *Peer*; the *Peer* sends the verified transaction to the ordering node - *Orderer*, which collects transactions and sends them to the Kafka group. All the *Orderers* will receive a consistent transaction sequence returned by the Kafka group and generate the same block.

E. Asynchronous Settlement

Asynchronous settlement of on-chain data refers to the settlement using energy data stored on the blockchain, which is executed asynchronously with the uploading of those data. Asynchronous settlement is based on accurate energy data, which can effectively solve the problem of electric deviation waste and cost advance payment caused by pre-sale. Due to the possibility of node downtime in the blockchain network, which may cause the loss of data, settlement is divided into normal cycle settlement and abnormal cycle settlement.

Normal cycle settlement refers to the situation where all nodes upload energy data on time, and the asynchronous settlement contract is triggered after all nodes' transactions are recorded on the blockchain within the cycle. The contract finishes the settlement according to these supply and consumption energy data with price matrix. Abnormal cycle settlement refers to that transactions of some users cannot be uploaded to the blockchain on time due to node downtime or network problems, and this cycle is marked as an unsettled cycle. $\boldsymbol{n}$ is a violation of tolerance, if those missing data are uploaded in the next $\boldsymbol{i}^{th}$ ($\boldsymbol{i} < \boldsymbol{n}$) cycle, a normal settlement will be finished in this cycle; otherwise, the asynchronous settlement contract will be triggered in the $\boldsymbol{n}^{th}$ cycle to do an incomplete settlement in which the grid will process all the remaining transactions. Meanwhile, the violation penalty contract will be triggered to punish the users who don't upload data on time and even freeze their accounts.

The specific settlement algorithm is shown in Fig. 5. **SL** represents the list of all supply data in the cycle; **CL** represents a list of all consumption data for the period; **PM** represents a

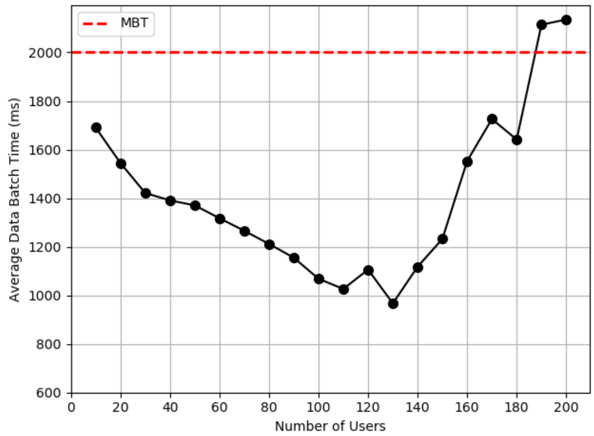


Fig. 6. The impact of user growth.

two-dimensional table that records the price and priority between every two users; *systemPrice* represents the electricity price of the main grid. **UL** represents a list of user accounts that record changes in energy and capital, whose elements are made up by transaction quantity, transaction price, buyer and seller. These records are stored in block chain to provide effective proof of energy supply and consumption.

IV. Implemention and Performance Evaluation

In this section, the implementation of this system is firstly described. Then the experiment results are illustrated to demonstrate its performance.

A. Implemention

This system is implemented based on Hyperledger Fabric v1.4.4. The experimental equipment is a Huawei 2288H V5 server with 40 cores and 64GB RAM, which allocate 30 virtual machines with 1core and 2GB. The operating system on the virtual machine is CentOS Linux release 7.7.1908. Each virtual machine deployment one or more *Peers*, which is divided into several organizations. Each *Peer* can carry one or more users.

The consensus mechanism we adopted is Kafka, which has a good performance in the actual production environment and is applicable to the blockchain network composed of multiple organizations. The management of *Peers* and users is based on the organization. In order to save the data sent by users in the blockchain network, at least one member of each organization should endorse them.

In this system, two conditions are prescribed for block generation:

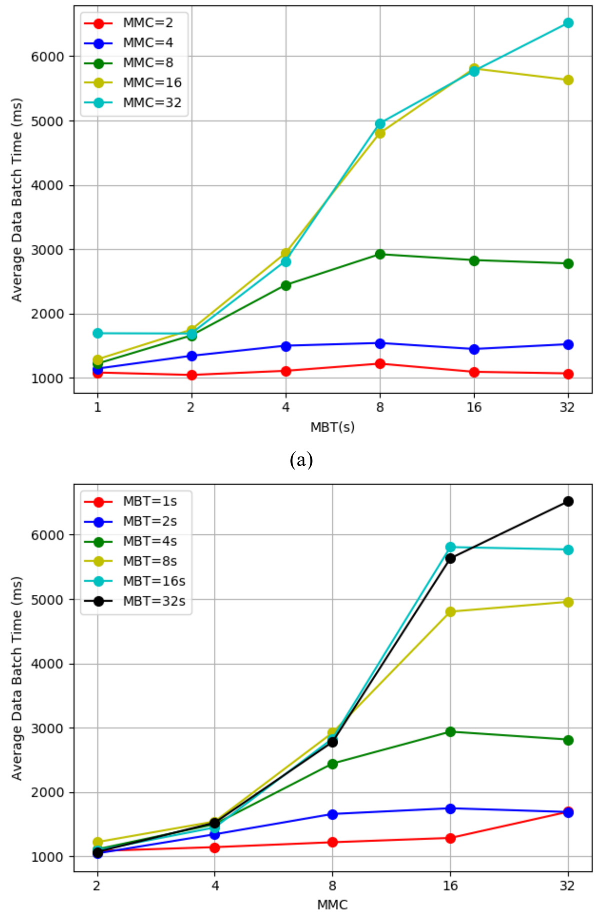
1) Timeout condition: the waiting time reaches the maximum block batch time (*MBT*);

2) Capacity condition: the number of transactions in one block reaches the maximum message capacity (*MMC*).

Parameters in both conditions can be modified when the network is running normally.

B. Performance Evaluation

A series of experiments is designed to evaluate the performance of the system. The tested dataset is obtained by a simulation of an existing micro-grid environment which includes micro-photovoltaic, distributed storage, electric vehicle pile, electrical illumination load, etc.



(a)

(b)

Fig. 7. The impact of *MBT* and *MMC* growth.

The variation trend of average data batch time is tested with the growing of user's number firstly. Each experimental parameter is set as following: organization number is set as 5, *Peer* number is set as 10, *MBT* is set as 2s, *MMC* is set as 10 transactions, data upload cycle $\boldsymbol{T}$ is set as 20s, and the user number in the system is gradually increased. The experimental results we got are shown in Fig. 6. At the beginning, with the increase of user number, the average time decreases. The reason could be the more users in the system, the easier it is for the number of transactions to reach the maximum capacity of a block and reduce the waiting time. Subsequently, the average time recovers, which is caused by the increase in the number of transactions, which results in the slow processing of some transactions and affected the average processing time.

The variation trend of average data batch time is then tested with the growing of *MBT* and *MMC*. The experimental parameters are set as following: organization number is set as 5, *Peer* and user number is set as 30, data upload cycle $\boldsymbol{T}$ is set as 20s, and *MBT* and *MMC* is increased exponentially. The experimental results we got are shown in Fig. 7. We can see that as the *MBT* and *MMC* grow, so does the average data batch time. In Fig. 7(a), when *MMC* is large, the growth trend of average time is close to that of *MBT* (exponential growth). This phenomenon could owe to there is limited number of transactions in each cycle, and it is difficult to satisfy the available capacity in a short time. When the *MBT* is large, it is more difficult to satisfy the timeout condition than the capacity condition, so a similar situation is appeared at Fig. 7(b). However, when *MBT* = 32, the data batch time almost

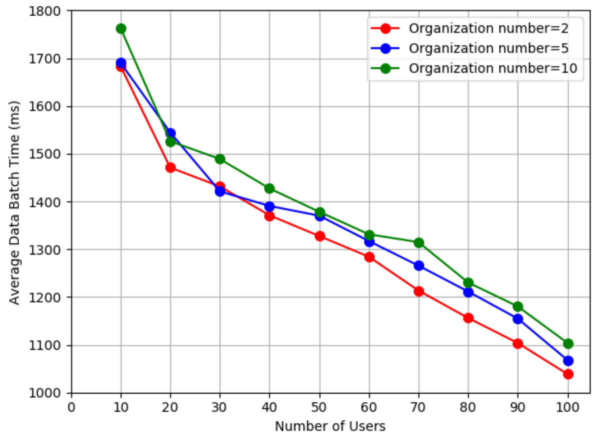


Fig. 8. The impact of organization growth.

stops growing, the reason could be that the transaction number in one cycle is not much enough to satisfy the *MMC* condition, and the size of *MMC* no longer affects the data batch time.

For average data batch time, the performance is tested respectively when organization number is 2, 5, 10. *Peer* number is set as 10, *MBT* is set as 2s, *MMC* is set as 10 transactions, data upload cycle ***T*** is set as 20s, and the user number in the system is gradually increased. The experimental results are shown in Fig. 8. It can be seen that the increase of organization number will slightly slow down the data batch time of the system. The reason could be that the increase of organization number leads to the corresponding increase of endorsements required number for each transaction. However, compared with user growth, the impact of organization growth is acceptable.

V. Conclusion

In this paper the challenges in the traditional centralized power settlement scheme are analyzed, which are not applicable for the usage of distributed energy transaction settlement. Aiming at the problems of inconsistent information in the microgrid, difficulty in establishing a trust system, and waste of electricity and cost advances due to pre-sale, a blockchain based asynchronous settlement system for energy internet micro-grid power transaction is proposed and implemented. This system combines asynchronous settlement with blockchain and smart contract. A series of experiments proved that this system can well solve the problems mentioned above, and can meet the requirements of practical applications.

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