# Research on new energy trading system based on blockchain


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## ABSTRACT

With the rapid development of new energy industry, the new energy structure is gradually shifting from centralized system to distributed system. The problems of trust and fair trade have become increasingly prominent in traditional centralized energy trading systems. The decentralized blockchain technology can provide a trusted, safe and transparent technical solution for energy transactions. This paper proposes a blockchain-based new energy trading platform in multi-seller-multi-buyer distributed new energy power platform. It establishes multi-party trust relationship through blockchain technology and optimizes transaction strategy by multi-party game algorithm to improves multi-party revenue. Simulation results prove that the proposed solution can reduce energy consumption and optimize energy structure, which provides a reference for theory and technology of new energy trading platform.



## CCS CONCEPTS

• **Security and privacy**; • **Trust frameworks**; • **Applied computing**;

## KEYWORDS

blockchain, game theory, new energy, trading system

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## 1 INTRODUCTION

With the vigorous development of new energy sources, green energy technologies such as solar and wind power have ushered in a technological boom and are being used in a wide range of applications. For example, the use of photovoltaic industry in the community: the community or households use photovoltaic panels to generate electricity, and as producers of electricity, they can exchange their excess electricity with other groups to maximize energy use, thus changing the market from consumer-oriented to producer-consumer-oriented [1-[2] [3] 4]. This kind of large-scale, multi-user distributed capacity approach has launched a huge challenge to the traditional power management [5], various high-tech such as big data, Internet of Things, AI technology and blockchain technology have been fully penetrated into all aspects of the energy system, using various high-tech solutions to grid architecture and energy trading is the fundamental way to promote the development of electricity [6, 7].

Blockchain technology provides a secure platform for storing transaction records between distributed peer-to-peer networks, and it ensures that the data on the chain is authentic, traceable and tamper-proof. In recent years, blockchain technology has been widely used in the financial sector and has produced good effects. Meanwhile, the application of blockchain in energy trading has also been extensively researched, and the literature [8] provides an in-depth analysis of the application value of blockchain in energy trading. Literature [9] used blockchain technology to optimize the existing electricity spot market transactions.

On the other hand, how to maximize the benefits to multiple parties and save energy in a distributed generation-consumption framework is another focus of research. The literature [10] uses the transaction price as an entry point to build the microgrid into an ordinal potential game model maximizing the revenue through optimization and improving the energy utilization. However, in the game process, literature [10] considers only the power sales strategy to maximize the revenue while it may lead to high cost of power purchase, in addition to the sale price to the main grid is constant in a certain time and should not be used as a game element. Therefore, in this paper, the number of new energy power transactions within the community grid and between the community grid and the main grid is used as the game point instead of the selling price when conducting the game. This way the maximum benefit is obtained without increasing the cost of electricity purchase for the households.

In this paper, we combine the application value of blockchain technology in new energy trading and establish a new energy trading model based on blockchain and game theory. In the scenario of new energy power network, the model is used to conduct a multi-party non-cooperative game with the main purpose of promoting regional power balance, increasing community grid transactions and reducing transactions with the main network, defining a set of reward mechanisms, and finally finding the optimal strategy to reach the Nash equilibrium point, and guaranteeing the strategy execution with smart contracts. Finally, the effectiveness of the blockchain-based new energy trading model proposed in this paper is demonstrated by simulation.


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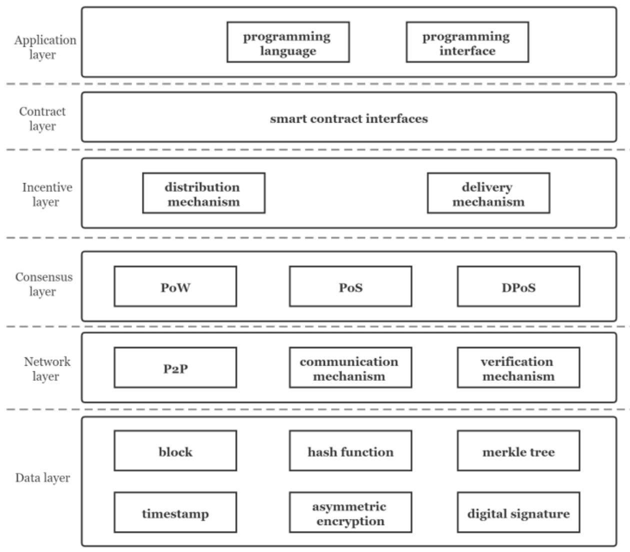


**Figure 1: Blockchain-based new energy trading platform**

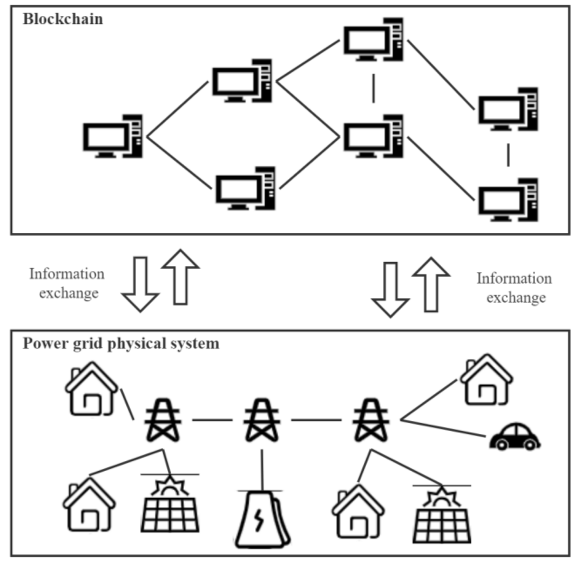


**Figure 2: Blockchain-based new energy trading platform**

# 2 BLOCKCHAIN-BASED NEW ENERGY TRADING MODE

## 2.1 Blockchain

Blockchain [11] technology is an open, transparent and decentralized database. Transparency is reflected in the fact that the database is shared by all network nodes, updated by the database operator, and supervised by all nodes; decentralization is reflected in the fact that the database can be regarded as a huge interactive database, which can be accessed and updated by all participants, and the data in it can be confirmed to be true and reliable. Blockchain is a data structure formed by blocks linked together in an orderly manner, where blocks are collections of data, and relevant information and records are included in them, which are the basic units forming the blockchain. The blockchain network is a P2P network with no centralized hardware or governing body for the entire network. In the blockchain system, each node keeps all the data information in the whole blockchain, therefore, there are multiple backups of data in the whole network. The more nodes involved in the network, the more backups of data there are.

Figure 1 represents the architecture of the blockchain. The data layer is the physical form of the blockchain technology and describes the data structure of the blockchain. The data layer stores all the transaction data and information records in the form of blockchain in full volume. The network layer is mainly to realize information exchange between nodes in the blockchain network and decentralization of bookkeeping nodes. The network layer is typically a P2P network with communication and verification mechanisms. The consensus layer is responsible for orchestrating the task load of bookkeeping nodes and enables highly decentralized nodes to reach consensus on the validity of block data efficiently in a decentralized system. Commonly used consensus mechanisms include PoW and PoS. The incentive layer proposes issuance mechanisms and incentives, such as in the PoW consensus protocol, which rewards miners who calculate the hash value first. The contract layer and the application layer work together to complete the application function. Smart contracts [12] are programs that run on the blockchain and have the characteristics of being tamper-proof and automatically executed. Developers write smart contracts to form distributed applications (Dapp) [13] based on business requirements, thus fulfilling various functional requirements.

## 2.2 Trading model

New energy sources include light and wind energy, etc. This paper examines new energy trading models using light energy and devices that can harness it as the main entry point. Within a community grid, households may have installed photovoltaic power generation equipment that can produce electricity. The households consume electricity by using the electricity-using equipment. Excess electricity or lack of electricity can be traded among each other through the community grid, and also with the main grid, which is mainly an electricity network consisting of thermal power generation. If users can trade new energy power with each other and as little as possible with the main grid, this will make full use of new energy power. However, unlike the main thermal network, PV power is a distributed power structure and the power status cannot be guaranteed. In addition, the self-interest of households makes it difficult to establish trust and ensure that new energy transactions are carried out. If centralized transactions are used, there are security issues such as privacy leakage. Therefore, blockchain technology needs to be used to establish a trust channel for households without a third party to guarantee smooth transactions [14].

In view of the distributed nature of PV power generation and the trust problem among users, this paper proposes a new energy trading platform based on blockchain as shown in Figure 2. At the physical level both households and occupants can interact with

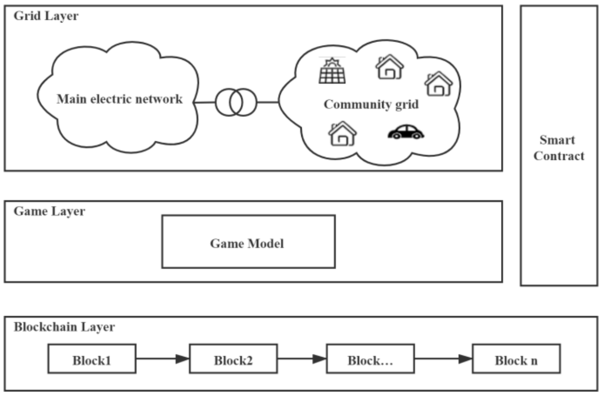


**Figure 3: Blockchain-based energy trading model**

electricity through the community grid, while the community grid has to be connected to the main grid. The households installing PV are both producers and consumers called producers and consumers. The blockchain interacts with the community grid to trade electricity. When the households generate electricity consumption information, it is broadcasted across the blockchain, recorded on the blockchain, and then traded in the physical grid for electricity [4]. The security of the data is ensured because the blockchain data is tamper-proof and each node has a backup of the data. And based on the consensus protocol to ensure that the information on the blockchain is authentic and valid, a transaction channel can be established for trustless users. The occupants do not need to know the specific information of the transaction object when they conduct electricity transactions through the blockchain platform, which guarantees privacy, and in addition, because the transaction data is always kept on the blockchain, it has traceability for the regulators.

Compared with the centralized system, the distributed deployment based on blockchain can make the community, community and other units as the nodes of the blockchain, which can perceive the change of electricity faster and trade electricity through the open mechanism, so that the new energy electricity can be used more rationally and consume less computing resources than the centralization. In the blockchain-based new energy trading system, a distributed architecture is used to actively maintain the stable state of the blockchain through consensus protocols, and the more nodes there are, the higher the failure resistance of the whole system, which is the opposite of the centralized system, which is often prone to single point of failure [6]. For the centralized power trading system, once the center fails, all the power dispatching and trading in the whole region will fail, while the blockchain system as a decentralized deployment can guarantee the operation of power trading and dispatching with high reliability even if some blockchain nodes fail, which is especially important in the power trading system.

The energy trading model proposed in this paper is shown in Figure 3. The blockchain ensures that the data is tamper-proof, and smart contracts are used to guarantee smooth transactions between individual households. Smart contracts are tamper-evident programs built on the blockchain that can be executed automatically and need to be executed on the blockchain nodes [15]. Each user can send a transaction to the blockchain's and the system automatically executes the smart contract. All occupant users iteratively calculate the optimal strategy based on the game model, and to guarantee that the strategy can be executed, the optimal strategy is formed into a smart contract and broadcasted across the network. Each blockchain node executes the smart contract and performs the power dispatching of the community grid. The process of creating smart contracts and executing smart contracts are packaged as transaction data and stored as new blocks on the blockchain according to the consensus protocol [16].

The variation in the power of the PV-produced electricity for each household is small and the curves do not vary much. However, the consumption of power by households is complex and varies greatly, and the respective load curves differ greatly. When the peak load is reached, the community grid is heavily loaded and needs to trade power with the main network, which does not maximize the use of PV power and causes waste of resources.

To address this situation, this paper proposes a non-cooperative game model to encourage households to trade within the community grid. It allows households to trade reasonably without a coordinated plan to maximize the use of PV energy and promote the power balance of the community grid. The game model provides support for the entire trading system, so that trading is no longer unstructured, but that both the overall and the individual are moving toward a good trend.

In practice, the trading period is first divided into half-hour intervals. In this interval, all the households get the optimal strategy through gaming, and create smart contracts on the blockchain according to the optimal strategy and broadcast them across the network. Then each household acts as a blockchain node to execute the smart contract automatically to ensure the smooth execution of the strategy. The transaction data is recorded on the blockchain using the PoW consensus mechanism. Then the next transaction block is carried out and the cycle repeats.

## 3 GAME MODEL

In a blockchain-based transaction system, the transaction data is visible to users because it is stored on the blockchain. Each user can be informed about the payments of other users. Users can be considered to have complete information. However, in a transaction period, the user cannot get access to the actions of other users, cannot be informed whether other users are inputting or acquiring power to the community grid, and cannot be informed about the actions of other participants as a static game. In such a case, the blockchain-based community grid system can be considered as a static game with complete information [17].

Households can produce power through PV or consume it, and are players in the game theory model. Define $N = \{1, 2, 3, \ldots, i, \ldots, n\}$, where n denotes the number of participants and i denotes the i-th participant. The set of strategies for participant i is $S = \{S_1^i, S_2^i, \ldots, S_{m_i}^i\}$, and $m_i$ denotes the number of strategies that can be adopted by the i-th participant.

There are n participants in this game model, and if each participant chooses a strategy, it will form an n-dimensional vector named s, $s = \{s_1, s_2, s_3, \ldots, s_n\}$. For all participants, participant i can choose any strategy from among them. Therefore, $s \parallel t_i = \{s_1, s_2, \ldots, s_{i-1}, t_i, s_{i+1}, \ldots, s_n\}$ is introduced to indicate that participant i chooses strategy $t_i$ and others' strategies are not specified, where $t_i \in S_i$. There are five main strategies for participants as follows. i participant sells electricity to other participants in the community grid; ii participant buys electricity from other participants in the community grid; iii participant neither buys nor sells electricity; iv participant buys electricity from the main grid through the community grid; and v participant sells electricity from the main grid through the community grid.

Each participant, i.e., household, has its own payoff function [18], which represents the reward received when the participant chooses a strategy, which will motivate the participant to adopt certain strategies to maximize their gains. Thus the payment function is the key to this game system. The payoff function of participant i is represented by $\mu_i(s)$, and s denotes the set of strategies when participant igains. That is, when all participants choose a set of strategies s, the payoff obtained by participant i is $\mu_i(s)$. The formula is shown below.

$$\mu_i(s) = \begin{cases} \frac{\lambda^{\mathrm{Ein}(s)}}{|\mathrm{Emain}(s)|} C_{i(s)}, Emain(s) \neq 0 \\ \omega \lambda^{\mathrm{Ein}(s)}, Emain(s) = 0 \end{cases}$$
$$\text{s.t. } \lambda > 1 \tag{1}$$

Emain(s) denotes the electricity traded by participant i with the main grid through the community grid under policy set s. $\omega$ is a constant taken as the reciprocal of the minimum accuracy of the meter count, which ensures that the payment function $\mu_i(s)$ yields the maximum benefit when Emain(s) equals 0. Ein(s) denotes the electricity traded by participant i under policy set s, and with other participants through community grid to interact with the electricity energy. Ein(s) takes a positive value if energy is sold to other participants through the community grid, and a negative value if energy is obtained from other participants. $\lambda$ is related to the actual grid situation, and $\lambda^{\mathrm{Ein}(s)}$ is a monotonically increasing function and is always greater than 0. This ensures that participants who sell electricity have higher returns than those who buy electricity. This ensures that participants who sell power have higher returns than those who buy power, and that those who buy less power have higher returns than those who buy more power from the grid. In order to avoid the situation where the participant obtains a greater gain in order to obtain a gain while affecting his or her standard of living. For example, in very high temperatures, participants do not use air conditioning in order to sell electricity, etc. The system is designed for better dispatch of power resources rather than degrading the living experience of residents. Based on this situation, the concept of comfort $C_i(s)$ is introduced to ensure that the residents can satisfy the comfort level while gaining revenue.

The comfort formula is shown in equation (2). $T_{max}$ is the maximum temperature that humans find appropriate, and t_min is the minimum temperature that can be tolerated by users. This varies from person to person, so the range of this definition has to be combined with statistics and has to be relaxed a bit. If the participant's strategy during the trading session makes the temperature inside the household greater than the maximum temperature or lower than the minimum temperature, causing great discomfort to the human body. In this case $C_i(s) = 0$ and the participant does not receive any benefit. If the strategy used by the participant makes the temperature inside the household between $T_{min}$ and $T_{max}$, which is comfortable, then$C_i(s) = -a(T - T_{min})(T - T_{max})$. And the closer the indoor temperature is to the upper bound or the lower bound of comfort, the smaller $C_i(s)$ is. When participant i chooses a strategy that results in the occupant's temperature being greater than the maximum temperature or less than the minimum temperature, participant i's payment function $\mu_i(s)$ will be equal to 0 and no benefit will be gained. The scenario of comfort eliminates participants who gain higher benefits by reducing the quality of life.

$$C_i(s) = \begin{cases} 0, T \leq T_{min} \\ -a(T - T_{min})(T - T_{max}), T_{min} < T < T_{max} \\ 0, T \geq T_{max} \end{cases}$$
$$\text{s.t. } -a(T - T_{min})(T - T_{max}) \leq 1 \tag{2}$$

In equation (1), participants who want to gain more revenue in the case of guaranteed comfort can be divided into three directions.

One is the need to increase the volume of transactions within the community grid to make the value of $\lambda^{\mathrm{Ein}(s)}$ larger. $\lambda^{\mathrm{Ein}(s)}$ is in the denominator, and the larger $\lambda^{\mathrm{Ein}(s)}$ is, the larger the gain $\mu_i(s)$ of participant i under the set s of strategies. Therefore, participants are encouraged to trade with other participants in the community grid, which will lead to higher gains for participants.

The second is to reduce the transaction with the main grid, Emain(s) in the denominator, the smaller Emain(s), the larger the result of $\mu_i(s)$, the greater the gain for the participants. If the participants do not trade with each other within the community grid but trade electricity with the main network Emain(s) will become larger, and at this time the participants' gain $\mu_i(s)$ will be smaller.

Third, to reduce its own power consumption, the smaller the value of $\lambda^{\mathrm{Ein}(s)}$ of the participant with more power consumption, the smaller the gain $\mu_i(s)$ when trading with other participants in the community grid. The gain $\mu_i(s)$ is meaningful only if it satisfies the comfort level of the participants. If the chosen strategy does not satisfy the participant's comfort level, the participant will not receive any gain.

Driven by the goal of maximum gain, all participants after the game will try to trade with other participants in the community grid as much as possible, reduce trading with the main grid, and at the same time reduce their own energy consumption as much as possible without affecting their comfort, so that they can promote the local new energy balance.

In the game model, it is assumed that all participants will not cooperate with each other to achieve higher returns, forming a non-cooperative game with n (n is the total number of participants) people. According to the game theory the following equation is obtained [19].

$$\mu_i(s^* \parallel t_i) \leq \mu_i(s^*), i \in N \tag{3}$$

The strategy $s^* = \{s_1^*, s_2^*, s_3^*, \ldots, s_n^*\}$ is a Nash equilibrium point, then for any participant i,for any strategy $t_i \in S_i$, there is a combination of strategies $s^*$ such that each participant approaches the maximum payoff, i.e., such that the payoff function of each participant converges to the maximum.

**Table 1: Household photovoltaic power generation energy**

| Time (Hour) | electricity consumption(kW•h) | | | |
|---|---|---|---|---|
| | household 1 | household 2 | household 3 | household 4 |
| 7:00 | 0 | 0 | 0 | 0 |
| 9:00 | 0.8 | 1 | 0.8 | 0.5 |
| 11:00 | 3.3 | 3.7 | 3.4 | 3.1 |
| 13:00 | 5.3 | 5.4 | 5.7 | 5.2 |
| 15:00 | 3.6 | 3.8 | 3.3 | 4 |
| 17:00 | 0.8 | 1 | 0.6 | 1.3 |
| 19:00 | 0.1 | 0.1 | 0.1 | 0.1 |

## 4 SIMULATION EXPERIMENT

In a community grid consisting of four households that install PV generation equipment. Households can trade electricity between them and the community grid, and households can also trade electricity between them and the main grid through the community grid. After a period of statistical observation and combined with the actual situation, $\omega = 100$, $\lambda = 4$, $T_{min} = 15°C$, $T_{max} = 27°C$, and $a = 1/36$ in Equation (1) and Equation (2). participants select strategies in a half-hour interval, and the strategies selected by each participant when Nash equilibrium is reached are calculated in this time interval, and blockchain smart contracts are used to guarantee strategy execution. Photovoltaic power generation only plays a role from 7:00 to 19:00, so the simulation experiment is set in the interval of 7:00 to 19:00 during the daytime [11].

The electricity generation of the households is shown in Table 1. Figure 4 shows the generation curves of the households. All households have similar generation curves. The power generation tends to increase gradually from 7:00 onwards to a maximum at noon, and then the power generation decreases.

The energy consumed by the households is shown in Figure 5. The consumption curve of grid power varies from household to household and is not evenly distributed. And the maximum consumption of each household also varies, resulting in uneven load on the community grid, and households need to purchase power from the main grid at peak times to avoid oversupply of the community grid. And most of the participants are self-interested and will buy power far beyond their own maximum losses, which will further increase the peak grid load and make greater power transactions with the main grid.

In the case of household 1, for example, the energy consumption is significantly lower after the power trading after gaming. As shown in Figure 6, the peak consumption of the household is 7 kW·h, and the peak consumption after gaming through the new energy trading system is 6 kW·h reducing the consumption by 14%. Table 1 lists the electricity consumption of household 1. It is clear that after gaming, the peak consumption is advanced and reduced. The households' electricity consumption strategies are gamed to reach the Nash equilibrium point to obtain a near-optimal strategy, which is created as a smart contract and guaranteed to be executed by the smart contract. Each household is rewarded with a near-maximum value [20]. Reducing electricity consumption increases the reward without affecting comfort, so the final blockchain-based energy trading reduces resource consumption compared to the usual situation.

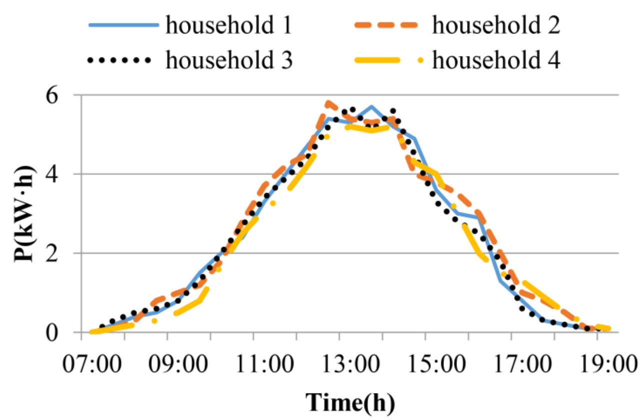


**Figure 4: Household photovoltaic power generation energy**

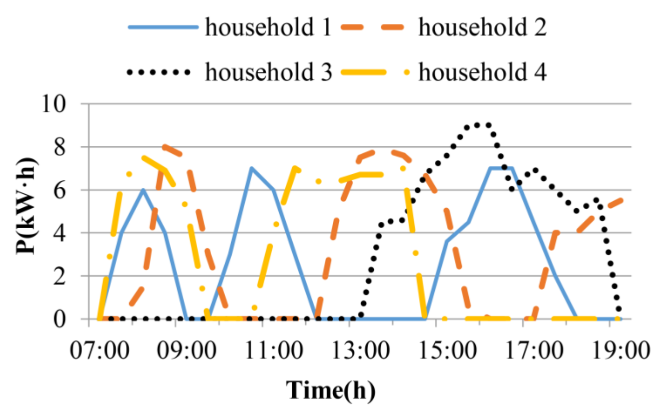


**Figure 5: Household electricity consumption**

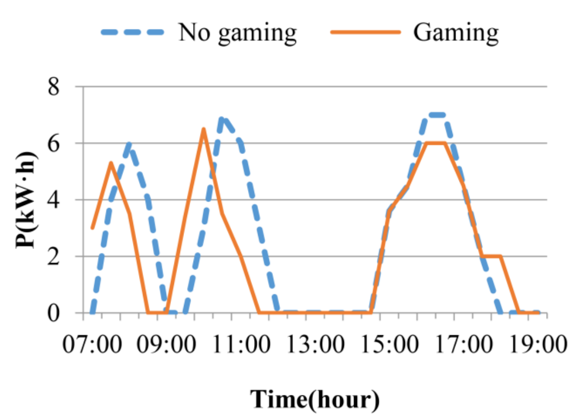


**Figure 6: Electricity consumption of household 1**

**Table 2: Comparison of Household1 Electricity Consumption Data**

| Time (Hour) | electricity consumption(kW•h) | |
|---|---|---|
| | Before the game | After the game |
| 7:00 | 0 | 3 |
| 7:30 | 4 | 5.3 |
| 8:00 | 6 | 3.5 |
| 8:30 | 4 | 0 |
| 9:30 | 0 | 3.4 |
| 10:00 | 3 | 6.5 |
| 10:30 | 7 | 3.5 |

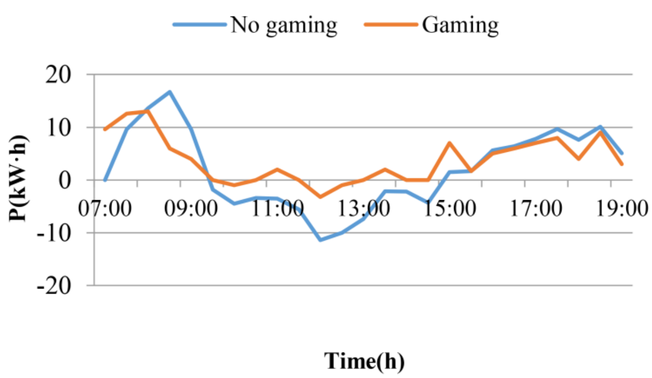


**Figure 7: Grid load**

Figure 7 represents the grid load, and a positive power level indicates that the power generated by PV in the community is being consumed, and a negative power level indicates that the households in the community are trading power with the main grid. From Figure 4, it can be seen that the peak is reduced by 10% after adopting blockchain-based energy trading, which has a significant peak shaving effect. Before the game from 10:00 to 15:00 the households traded a lot of electricity with the main grid through the community grid. After the new energy trading system, the trading between households and the main grid is greatly reduced, which contributes to the regional balance. Although the individual households reduce their energy consumption, the total PV generation is slightly less than the total consumption. Therefore, transactions with the main grid are inevitable. If the energy consumption of households is further reduced, the comfort level will be reduced, and although it can further promote the balance of supply and demand of the new energy grid but at the expense of the happiness index of the residents.

## 5 CONCLUSION

In this paper, we construct a blockchain-based model for new energy trading, with the main participants being a community grid composed of households. The blockchain ensures the security of data, guarantees the execution of strategies, and is the basis for households in the community to trade electricity with each other. The rules of new energy trading are developed by combining blockchain and practical situations through game theory. Simulation results show that blockchain-based new energy trading will reduce resource consumption, lower transactions with the main grid, cut peaks, and promote the power balance of the community grid. It provides a reference for further exploration of new energy trading model based on blockchain. Subsequent research will build on the current foundation and propose a new energy trading model among complex power networks that include more participants and multiple community grids.

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