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Smart contract for electricity transactions and charge settlements using blockchain

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Abstract

In this article, aimed at the future "let go" electricity market, smart contracts for grid enterprises doing electricity transactions and charge settlements based on blockchain technology, as well as the trading model using the smart contracts, are proposed. Then the key technological difficulties are analyzed, and the solutions are given. The main goal of our research is to help developing the infrastructure for electricity market members, and match their bilateral trading. By running a smart contract instance in a peer-to-peer network composed by 4000 nodes, experiments show that the success rate is 99.38% and the average time consumption for each transaction is 16 seconds. If our method is applied, we can reduce the trust cost of the electric electricity market, and improve the efficiency of the electricity transaction and charge settlement.

KEYWORDS

blockchain, charge settlement, electricity transaction, smart contract, smart grid

1 | INTRODUCTION

According to the Article 4 and Article 8 of the State Electricity Structural Reform Document "Implementation Opinions on Promoting the Reform of the Electricity-Sale Side"[1], the grid enterprises have the responsibility for the electricity charge settlement, and should ensure the security of the funds. In order to adapt to the electricity structural reform and the electricity market, the grid company needs to build an efficient, convenient, and secure information system, establish suitable settlement rules and work processes, to provide better electricity transaction and charge settlement services for the electricity market members.

However, compared with the traditional electricity charge settlement, the market-based settlement after the electric structural reform is much more complicated.[2] The market members have increased, the variety of transactions has been diversified, and the rules of the trading contracts have become more flexible. At the same time, both of the electricity purchase and sale sides are allowed to negotiate and bid independently, resulting in different final market prices.[3] Therefore, the settlement system should be flexibly expanded and settled according to the market price.

Blockchain[4] is a revolutionary technology that is currently receiving strategic attention from various countries, which has been hailed by the *Economist* magazine as a "trust machine."[5] It combines distributed storage, consistency verification, and cryptography to provide a new solution for peer-to-peer network. This blockchain-based distributed management architecture creates trust between different peers, which can effectively solve problems of data tampering, historical traceability, effective supervision, and financial data security.

Blockchain has been applied to the field of transaction and charge settlement. In 2015, Nasdaq officially announced the Linq blockchain ledger technology for global stock exchange.[6] Based on blockchain technology, Linq reduced the standard settlement time from 3 days to 10 minutes, while reducing the settlement risk by 99%. In 2016, Overstock started trading equity on its T0 Blockchain Platform,[7] enabling settlements and transactions to complete almost at the same time. In the meanwhile, Goldman Sachs developed a system called SETLcoin,[8] ensuring almost instantaneous settlement. Ripple focuses in the cross-border payment, and its blockchain InterLedger Protocol[9] has established a global distributed clearing and settlement system based on linking different accounting systems for financial institutions such as banks. R3CEV has been leading the consortium of more than 70 global financial companies in the sphere of blockchain technologies development in a financial system, and taking Corda as a settlement option available to banks.[10]

Some academic institutions have also participated in the blockchain-based clearing and settlement research. Chiu and Koeppl[11] proposed a blockchain-based settlement method for asset trading. Williams[12] analyzed some open, permissioned, and centralized models for blockchain engagement by financial institutions and pointed out the challenges and drawbacks. Mori[13] suggested that only 20% of the barriers to blockchain adoption are technology based, the other 80% being attributable to current business processes and business models. Lewis et al[14] pointed out that blockchain technology is likely to be a key source of future financial market innovation. Spain's Santander Bank believes that by 2022, blockchain technology will help the financial industry reduce its billing costs by $20 billion.

Solar energy is one of the most used types of renewable energy sources, and blockchain technology is widely used in this sector.[15] One of the blockchain project in smart grid is provided by Belgian Enervalis company and Dutch Eemnes Energie company.[16] Also, there are some projects in UK and USA which use blockchain technology[17-19] For example, LO3 Energy, a young New York company, is working in the Brooklyn Microgrid project.[20] In UK, Centrica company aims to make a local energy market using blockchain technology.[21] There are also some projects using this technology for the energy storage optimization of photovoltaic systems.[22] These projects use blockchain to build trust between energy providers and consumers, and help them trade solar energy in real time, mostly in energy transactions and settlements.

This article focuses on the future "let go" electricity market, and carries out research on distributed ledger, consensus mechanism, and smart contracts based on blockchain technology. The main goal of our research is to help developing the infrastructure for electricity market members, and match their bilateral trading. We use the distributed ledger to store the accounting data from the electricity trading, the settlement data provided by the transaction center, and the user electricity data provided by the marketing department, then link various business process from payment planning, billing, payment, clearing, settlement, to accounting, analysis, and financial forecasting, thus enable efficient and secure electricity charge settlement for the grid enterprises, and improve the transparency and auditability of financial data. By the use of blockchain, data are shared automatically, and nontamperable records are kept, which help avoid errors caused by human operation. Also, the smart contracts running on the blockchain can automatically reduce liquidation process and improve the efficiency of clearing and settlement.

2 | TRADING MODEL OF ELECTRICITY MARKET BASED ON SMART CONTRACTS

The future electricity market includes trading entities such as power plants, electricity sales companies, power grids, users, and a trading center. On a blockchain platform, these trading entities can freely customize trading smart contracts, write clearing and settlement rules of the electricity sales transactions in the contracts. By using the membership management system,[23] the market identity of the two parties are determined and the corresponding smart contracts[24] are matched. The users can customize the smart contract through the blockchain platform to achieve efficient electricity clearing and settlement.

As shown in Figure 1, the settlement model for power purchase and sale is represented as a smart contract by computer codes and written into the distributed network of the blockchain in advance. When a certain item in the contract occurs, the smart contract will be activated and automatically executed. Membership services are responsible for managing identity, privacy, and confidentiality on the network.[25] Before the contract occurs, the membership management first identifies the market identity of both parties and matches the corresponding smart contract. At the same time, the membership mechanism also ensures that unauthorized third parties cannot obtain confidential information about the identities, transaction mode, transaction content, and so on.

We can take the retail smart contract of power companies for example. Under the new mode of electricity distribution, the electricity transactions will be more flexible and freer by placing the power company as the main body of the electricity settlement.[26] The power company makes a sales plan by forecasting the customer load, and sign a three-party purchase contract with the power plant and the Power Grid Corp. In many cases, it is difficult to sign contracts in paper form so

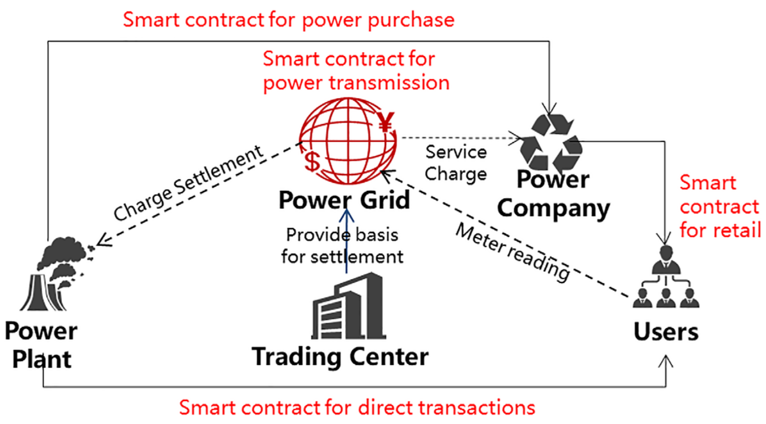

FIGURE 1 Trading model of electricity market based on smart contracts [Colour figure can be viewed at wileyonlinelibrary.com]

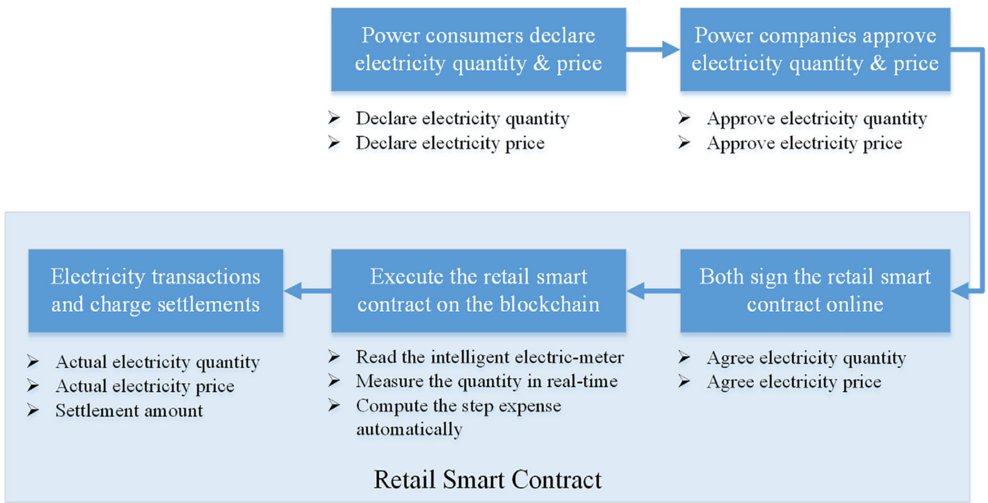

FIGURE 2 Retail smart contract for power companies [Colour figure can be viewed at wileyonlinelibrary.com]

that mostly they use electronic contracts. However, electronic contracts are lack of legal effect and credibility, which can easily lead to mistakes. Smart contracts on blockchains are written and executed in code, so once the contract is fulfilled, the traceability and nontampering of the blockchain can avoid contract disputes. So it is a good solution for the power companies to do power retail.

As shown in Figure 2, on the retail side, a power company releases a retail smart contract on the sales platform, and sign it with a power consumer on the blockchain. The elements of the deal, such as electricity quantity, agreed price, liability for breach of contract, and so on, are defined in the smart contract. Then the intelligent electric meter directly records the electricity quantity on the distributed account ledger based on blockchain. The whole process can be done automatically, including reading the meter, measuring the quantity, executing the smart contract, and computing the expense. Blockchain can make the retail contract transparent and trustless, help the power companies enhance the credibility of the power sales platform and the intelligent electric meter. In the meanwhile, since the electricity sales platform is built and managed by the power company itself, it is very likely and easy for them to apply the smart contract.

3 | KEY TECHNICAL DIFFICULTIES AND IMPLEMENTATION

The smart contract was proposed by Nick Sabo in 1994, but it was not applied due to the lack of a credible execution environment.[27] Until the birth of Bitcoin[4] in 2009, people realized that the basic blockchain technology of Bitcoin could provide a credible execution environment for smart contracts. However, Bitcoin's blockchain architecture focuses on decentralized digital currencies, and the support for smart contracts is still very limited. For example, Bitcoin's blockchain platform uses Proof of Work (PoW), which requires each node to calculate random numbers to compete for the rights to

TABLE 1 Technical improvements

	Bitcoin system	The smart contract system of this article
Consensus mechanism	PoW	PoW+PoS
Scripting engine	Nonturing complete	Turing complete
Storage strategy	Full node	Full node+cloud storage
Hash algorithm	SHA256+RIPEMD160	SHA3
Length of transaction	60 bytes	30 bytes
Payment verification method	Merkle tree	Merkle Patricia tree
Average transaction confirmation time	10 min	16 s
Security strategy	UTXO	Membership account

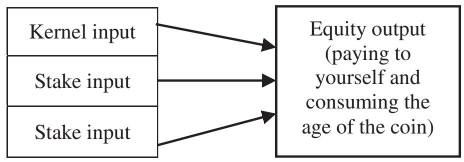

FIGURE 3 Transaction structure of PoS

write in the ledger.[28] This requires a lot of computing power and it will take at least 10 minutes to confirm a transaction, thus does not meet the commercial requirements.

In recent years, the rapid technology development of blockchain 2.0 such as Ethereum[29] and Hyperledger[30] has ensured the efficiency of smart contracts. The smart contract for electricity settlement proposed in this article is developed based on the Ethereum open source platform. Compared with the Bitcoin blockchain, there are many differences in the access mechanism, transmission protocol, hash algorithm, encryption algorithm, and consensus mechanism of the nodes. The main technical improvements are given in Table 1.

3.1 | Proof of Stake (PoS)

Bitcoin uses PoW, which not only consumes a lot of computing power, but also proceeds only seven transactions per second, which is inefficient. The smart contract system adopts the consensus mechanism of Proof of Work and Proof of Stake (PoW+PoS), and divides the block into two types: the PoW block and the PoS block. A stake is the ownership of a specific amount of currency by a blockchain node, which is called the Coin Age. In the PoS block, the nodes obtain block writing rights by paying a certain amount of token to himself. The whole process is shown in Figure 3. The first input on the left is called the Kernel. It is essentially a protocol that achieves a hash target, requiring that the Coin Age should overcome the hash target, where the hash target is determined by the average block right, the Unspent Transaction Output (UTXO) and the present time. Let a be the coin age, q be the coin quantity, and t be the time of the last transaction, then

$$a = q * t. \tag{1}$$

It can be seen that the more coins are consumed in the process of generating the kernel, the easier it is to satisfy the hash target. The PoS consensus relies on internal Coin Age without the need to consume external computing power and resources, which fundamentally solves the problem of PoW, and can shorten the consensus time to a certain extent.

3.2 | Turing-completed computing environment

From the security point of view, the Bitcoin system is not turing-completed, so there are not many Bitcoin script instructions that can be used at present. Its application scenario is limited to digital currency. The smart contract system of

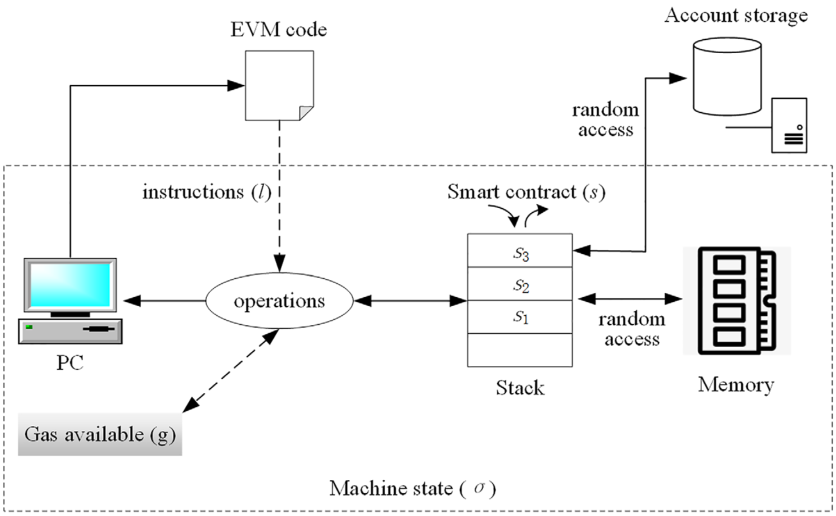

FIGURE 4 Network state of EVM [Colour figure can be viewed at wileyonlinelibrary.com]

this article is based on a 256-bit turing-completed computing environment. The Ethereum virtual machine (EVM) can perform any kinds of calculations to support the operation of smart contracts.

Running a smart contract in the EVM requires a consumption of Gas. Gas refers to the fee, or pricing value, required to successfully conduct a transaction or execute a contract on the Ethereum blockchain platform. It is defined as the fundamental unit of computation, usually, a computational step costs 1 gas, but some operations cost higher amounts of gas because they are more computationally expensive, or increase the amount of data that must be stored as part of the state.[29] Gas is used to allocate resources of the Ethereum virtual machine (EVM) so that decentralized applications such as smart contracts can self-execute in a secured fashion. That is, the executed EVM code is strictly limited by the parameter of Gas, which stipulates the upper limit of the runnable calculation instruction, thereby avoiding an infinite loop. Assuming that the entire network state is σ (as shown in Figure 4), the remaining Gas of the contract operation is g, and the important information in the blockchain running environment is stored in the vector I (current contract address, contract sender address, Gas price of the transaction, input data of the transaction, account address of the contract execution, the contract account balance, the header of the current block, the current CALL operation, and the CREATE operand). Let ψ be the state transition function, σ' be the state after the system is running, g' be the remaining Gas after running, s be the list of contracts to perform the termination operation, l be the record sequence, r be the Gas returned after running, o be the output of the contract, then the whole state transition can be expressed as:

$$(\sigma', g', s, 1, r, o) = \psi(\sigma, g, 1). \tag{2}$$

In most instances, ψ is defined as the process of iterating the system temporary state and the virtual machine temporary state, the termination of the iteration is determined by the following two conditions:

(1) An abnormality in the system state causes the EVM to stop working, such as insufficient Gas, invalid instruction, insufficient virtual machine stack, and so on.

(2) The EVM executes all instructions, returns the result, and stops normally.

As can be seen in Figure 4, during each iteration, the instructions of the smart contract are pushed onto the stack, and the EVM executes the instructions as a stack index. Each time an instruction is executed, the corresponding Gas is paid until the execution of all the instructions is completed, and the stack is cleared. If an exception is encountered, the EVM stops working and goes back layer by layer.

3.3 | Whisper protocol in the P2P networks

Smart contracts run on a peer-to-peer (P2P) network, so the distributed applications (DApps) using the smart contracts need a protocol to do P2P communications. It is called Whisper.[24] Whisper is not a typical communication system, because it was not designed to provide a connection-oriented system, nor for simply delivering data between a pair of

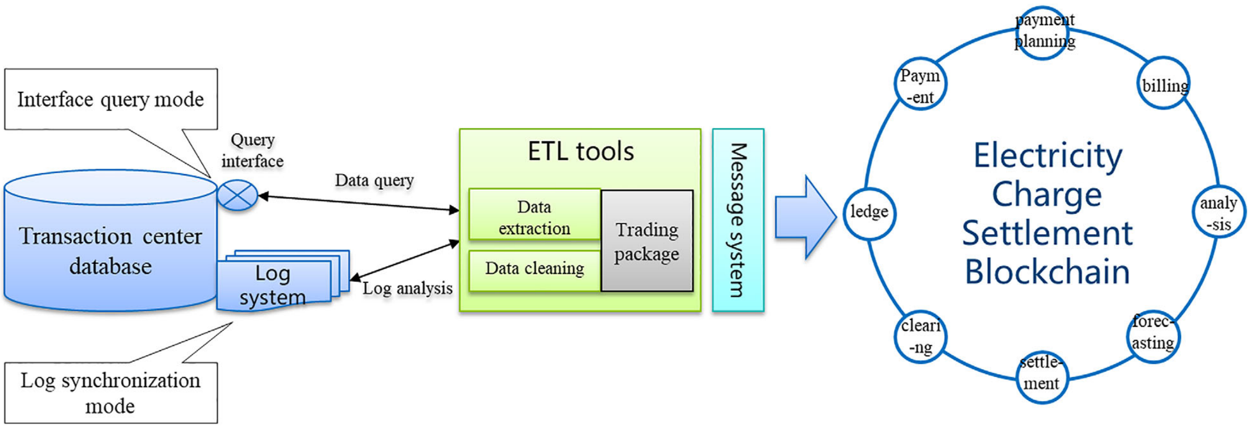

FIGURE 5 Data writing and synchronization method [Colour figure can be viewed at wileyonlinelibrary.com]

particular network endpoints. Whisper is a building block in next generation of DApps. It was designed for easy and efficient broadcasting, and also for low-level asynchronous communications.

Whisper network uses the underlying DevP2P Wire Protocol,[29] and combines distributed hash table and packet messaging systems as a purely signed messaging system. It provides low-level yet easy-to-use APIs that do not require to memorize the underlying hardware attributes.[31] In addition, it also provides resilience and privacy at considerable expense, and allows the users to configure the level of privacy (how much information it leaks concerning the DApp content and ultimately, user activities) as a trade-off for performance. Basically, all Whisper messages are supposed to be sent to every Whisper node. The operating mechanism of Whisper is as follows:

(1) A DApp publishes the contract content and broadcasts it to the P2P network;

(2) The DApp sends signals to other DApps, hoping that they participate in the coordination of a transaction (such as signing a smart contract);

(3) The DApp provides a non-real-time communication content;

(4) Except for the hash address of both parties of the transaction, the Whisper protocol hides other transaction information.

3.4 | Data synchronization process using ETL

The design idea of the smart contract for electricity market transaction and settlement is to parallel a blockchain account without changing the original business structure. Therefore, it is necessary to solve the data synchronization problem from the database to the blockchain. There are two kinds of data synchronization from the transaction center database to the electricity transaction and settlement blockchain. One is to use the Extract-Transform-Load (ETL) method to connect the transaction center database and the blockchain, and implement the transaction data collection script on the ETL tool. The ETL tool periodically extracts the electricity charge settlement data from the transaction center database to complete the data extraction. After that, the data are extracted and cleaned, and submitted to the blockchain in real time through the blockchain Remote Procedure Call (RPC) interface. The other way is to use the ETL tool to connect the log system of the transaction center database to real-time log analysis. According to the preset collection rule on ETL, the data to be collected are extracted in real time, and the extracted data are cleaned, assembled into a blockchain transaction order, placed in the blockchain front-end message queue, and submitted to the blockchain by the RPC interface.

The data synchronization process based on the ETL tool is shown in Figure 5:

4 | EXPERIMENTS AND DISCUSSION

This section analyzes the accuracy, stability, and efficiency of the blockchain system by executing a smart contract for purchasing and selling electricity on the blockchain. The following agreements are made in the smart contract based on the relationship between the annual promissory electricity and the actual electricity quantity. Let I be the annual

TABLE 2 Executing data of the smart contracts (part of)

TxID	PrdID	CsmID	Qty	Price	Amt
0016c2b3a243479cb200caab188931f2	003429b07f4a4f54be37	2f8b6c4006ec67fe93a6	6675	0.367698876	2454.39
0031714c6ffe450982339d0e2fb2a667	004472151c96473bb4cf	15889f21e9dd9ebd83ed	252 024	0.367699187	92 669.02
004a6e5f2a5c47fcb830c6b17373ff0b	00978300f41e4770bda1	53eaad517e9e4c6bd8c9	23 272	0.37168142	8649.77
00795888eb83435db9dd0048ad391aae	00badc1766024a8fac11	720971bb80d7940d023a	98 584	0.371681409	36 641.84
00837dd4f8ce4db7a243683682d36062	01411e0ca3aa477c8c6b	f003ea1a1c9b573bc8a9	210	0.367714286	77.22
00924d9d4cc6417b9343ed1328c4587f	01683098260f465790e0	583b87270c0a0482fa9e	268	0.367686567	98.54
00ae233507fd430081c2abca5e078b39	015ecf1160e14e3db2c0	7d8cbe89bacd5038bca2	15	0.367333333	5.51
00bf607e2d5040cda1d86e327ae2f804	98d97b5c4ae764a9b87c	150f394a7d62c9b82ad7	1820	0.367697802	669.21
0123767f1b7841329f00f5d39eb3751a	124f5c7d2ba76023eba8	7462c8d9be23ad63b0cc	156 072	0.371681403	58 009.06
0177311c7abd48899d3f4758eeb22540	29a48eca099eafa693b7	692fe9ad06fab9ac72b8	7382	0.367698456	2714.35

promissory electricity, J be the annual actual purchased electricity, i be the monthly promissory electricity, and j be the monthly actual purchased electricity, then

- Agreement 1: If Party A's $J > I \times 105\%$, then the settlement of the direct transaction $= I \times 105\%$, and the settlement of the excess part $= 110\% \times$ the electricity price of the large industrial catalogue corresponding to its voltage level.
- Agreement 2: If Party A's $J < I \times 95\%$, then the settlement of the direct transaction $= J$. In the meanwhile, Party A should pay Party B the liquidated damages by multiplying the difference between the electricity consumption by 2 cents/kWh (including tax, the same below). Let l be the liquidated damage, then $l = (i - j) \times 2$ cents/kWh.
- Agreement 3: If Party B suffers from equipment failure or other reasons, the total quantity of on-grid electricity in the current month is lower than 95% of the monthly promissory electricity, Party B should pay Party A some compensation according to Party A's catalogue electricity price and the direct transaction electricity price. Let b be the compensation payment, c be Party A's catalogue electricity price, and d be the direct transaction electricity price, then $b = (i - j) * (c - d)$.

Below is an example of the smart contract written in solidity language, where (a) is the smart contract for Agreement 1 and Agreement 2 and (b) is the smart contract for Agreement 3. It can be seen from below that no matter for the situations of sufficient electricity generation, insufficient electricity generation, or the unstable purchasing electricity quantity, and so on, we can always use the computer code to write the rules and store them in the blockchain. Once the purchase and sale parties sign the smart contract, it will be automatically executed according to the reading of the electricity meter.

(a) smart contract for Agreement 1 and Agreement 2

```
contract PurchasingElectricity
{
    //data structure of the saler
    struct Saler
    {
        address sale;
        unit plan_quantity;
    }
uint public value_1;
uint public value_2;
address public purchase;
address public transport;
mapping(address -> Saler) public salers;
function PurchasingElectricity(address _sale, uint _plan_value, uint _plan_quantity, address _transport, uint
_value1, uint _value2)
```

```
    {
        purchase = msg.sender;
        salers[_sale].sale = _sale;
        salers[_sale].plan_quantity = _ plan_quantity;
        transport = _tansport;
        value_1 = _value1;
        value_2 = _value2;
    }
}
//when the saler has generated enough electricity
function payment_a(address sale, uint actual)
{
if(actual>salers[sale].plan_quantity*1.05)
    //if Party A's J > I × 105%
    {
        value = (actual – salers[sale].plan_quantity*1.05)*(value_1*1.10);
        Send(purchase, sale, value);
    }
if(actual<salers[sale].plan_quantity*0.95)
    //if Party A's J < I × 95%
    {
        value = (salers[sale].plan_quantity*0.95-actual)*2;
        Send(purchase, sale, value);
    }
}
```

(b) smart contract for Agreement 3

```
//when the saler has not generated enough electricity
function payment_b(address sale, uint actual)
{
if(actual<salers[sale].plan_quantity*0.95)
    //if the total quantity of on-grid electricity is lower than 95% of the monthly promissory electricity
    {
        value = (salers[sale].plan_quantity*0.95-actual)*(value_1-value_2);
        Send(purchase, sale, value);
    }
}
```

We set up a P2P network with about 4000 nodes for distributed solar energy purchasing and selling. We basically used the blockchain to do two things. The first one was to run the above smart contracts for solar energy transactions and charge settlements. The second one was to permanently save the invoices on the blockchain. In the meanwhile, taxes were computed and deducted automatically. Table 2 shows part of the executing data of the smart contracts, where "TxID" is the hash address of the transactions, "PrdID" is the hash address of the solar energy producers, "CsmID" is the hash address of the solar energy consumers, "Qty" is the actual electricity quantity, "Price" is the agreed electricity price, and "Amt" is the settlement amount. Table 3 is the invoice information saved on the blockchain, where "InvID" is the hash address of the invoice, "InvDate" is the date of the invoice, "InvNo" is the invoice number (in China there is also a code for each invoice), "TaxAmt" is the tax amount for each transaction (with a tax rate of 13%), and "TotalAmt" is the total amount (ie, Amt+Taxamt) for each transaction.

Table 4 is the result of running the smart contract. In a week, a total of 7129 smart contracts were signed, of which 7085 were successfully executed and 44 were ineffective, with a success rate of approximately 99.38%. The reason for the execution failure is mainly because that the purchaser's deposit is insufficient or the Gas for running the

TABLE 3 Invoice information save on the blockchain (part of)

InvID	InvDate	InvNo	Amt	Tax amt	Total amt
0902edb6d5f370bd5ca7	2019.3.1	16709923	2454.39	319.07	2773.46
5432e7b0efb73404d65d	2019.3.1	16 783 287	92 669.02	12 046.97	104 715.99
a1d25be736bc4bc92634	2019.3.2	17 071 909	8649.77	1124.47	9774.24
2e8b604fc7b89749dd7c	2019.3.3	20 178 792	36 641.84	4763.44	41 405.28
37973a5b98c3345e0c1d	2019.3.4	24 079 931	77.22	10.04	87.26
1f57b4b7aa9197e4df02	2019.3.5	35133125	98.54	12.81	111.35
483a17f2c625993d17c1	2019.3.5	35133144	5.51	0.72	6.23
38a8891c02d56dce4173	2019.3.6	39093199	669.21	87.00	756.21
6992dcbeddfc33e273bf	2019.3.6	41895451	58009.06	7541.18	65 550.24
c5c928f9913e7f342402	2019.3.7	45963480	2714.35	352.87	3067.22

TABLE 4 Result of running the smart contracts

Date	Contract number	Success number	Failure number
2019.3.1	1339	1334	5
2019.3.2	2113	2097	16
2019.3.3	1337	1326	11
2019.3.4	727	725	2
2019.3.5	308	308	0
2019.3.6	1215	1206	9
2019.3.7	90	89	1
Total	7129	7085	44

smart contract is exhausted. At the same time, the average confirmation time for each smart contract is approximately 16 seconds.

Since the success rate and the performance efficiency of the smart contracts are determined by the blockchain platform on which they run, we compared some typical blockchain platforms (shown in Table 5). According to whether a permission is needed to join the blockchain network, the platforms can be divided into two types. This determines the application range of the platforms. Everybody can join in a permissionless blockchain freely, while permissioned blockchains only link specific groups or organizations (usually for a higher safety). As for our application requirements, a permissioned blockchain is more appropriate. The blockchain platforms in Table 5 are based on different kinds of consensus mechanisms and data models, which together determine the processing speed, resource consumption, safety and scalability of the platforms. As we can see in Table 5, compared with other platforms, Ethereum has a relatively high speed, low cost, good safety, and scalability. We can easily deploy an Ethereum network, and freely add or remove an Ethereum node. Therefore, we believe Ethereum is the best choice to run our smart contracts for electricity transactions and charge settlements.

Compared with the original bilateral contract, the electricity retail market managed by distributed ledger has broadened the choices for both electricity companies and electricity users. The excess electricity in the contract can be stored not only in the battery but also returned to the grid. It can be sold to the highest bidder on the network, or even redeemed offsite (such as charging an electric car on the road). By the smart contract established on the blockchain, the switching of the sales company can be completed digitally and intelligently. The power users can easily replace their supplier by simply clicking on the computer or mobile phone for several times. It can be seen that blockchain technology can promote the intelligence of the electricity retail market, making citizens play a greater role in the electricity retail market. Using blockchain technology, electricity cost and demand data can be timely reflected in the integrated electricity market, helping citizens make correct decisions, encouraging citizens to actively participate in the electricity market, and simplifying the switching of electricity supply contracts. Blockchain technology helps electricity producers and consumers jointly

TABLE 5 Comparison of different blockchain platforms (on which the smart contracts run)

	Bitcoin[4]	Ethereum[29] (our choice)	Hyperledger Fabric[30]	Bitshares[32]	RippleNet[33]	Cosmos[34]
Blockchain type	Permissionless	Both	Permissioned	Permissionless	Permissionless	Permissionless
Consensus mechanism	PoW	PoS	PBFT	DPoS	Ripple	Tendermint
Data model	Transaction-based, account-based	Account-based	Key-value	Transaction-based, account-based	Account-based	Account-based
Processing speed	Slow	Fast	Fast	Fast (faster than PoS)	Fast	Fast
Resource consumption	High CPU	Low	High bandwidth	Low	Medium	Low
Energy cost	Large	Less	Negligible	Less	Negligible	Negligible
Safety (fault tolerance)	50%	50%	33%	50%	20%	33%
Scalability	Good	Good	Bad	Good	Good	Bad
Token required	Yes	Yes	No	Yes	Yes	Yes

determine electricity prices that are dynamically changing due to demand, ensuring interconnection in different markets, and enabling electricity users in the grid to truly benefit. Through distributed electricity generation, smart grid and electricity storage technologies, residents can participate in electricity production and sales by the blockchain, reducing their electricity expenses.

5 | CONCLUSION

This article studies the application of blockchain technology in energy internet, especially the electricity industry. We proposed smart contracts for grid enterprises doing electricity transactions and charge settlements based on blockchain technology, as well as the trading model using the smart contracts. The main goal of our research is to help developing the infrastructure for electricity market members, and match their bilateral trading. By running an example of smart contracts for purchasing and selling electricity in a P2P network composed of 4000 nodes, the success rate of this method is proved to be about 99.38%, and the average confirmation time of each transaction is about 16 seconds. By the use of the smart contract running on the blockchain, we can reduce the trust cost of electricity market transactions, improve the settlement efficiency, and promote the intelligentization of the electricity retail market. If this method is applied, it will help the electricity transaction parties jointly determine electricity prices that are dynamically changing due to demand, ensure the interconnection of different energy markets.

In this work, by analyzing and comparing with some typical blockchain platforms, we choose Ethereum as our smart contract platform. Ethereum is easy to apply, and has a relatively high speed, low cost, good safety, and scalability. But it also has some limitations. First, it is not so decentralized because consensus is controlled by the highest paid. Second, it requires token to run the smart contracts, and when the users' deposit is insufficient or the Gas is exhausted, the smart contracts will fail to execute. Third, its consensus mechanism (PoS) is vulnerable to some attacks such as P+ Epsilon attack and balance attack, when DPoS can defend against such attacks.

Future work should focus on how to improve the efficiency of consensus algorithms, how to establish a smart contract with rigorous logic and customizable rules, so that it can adapt to the complex business rules of the grid, and the various types of settlement contracts. How to quickly and effectively pause the smart contract when some abnormal behaviors occur and protect the interests of users from being violated. Blockchain technology can be widely applied only after solving the problem of resource utilization, consensus efficiency, and time consumption.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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