JOURNAL OF INFORMATION SCIENCE AND ENGINEERING 37, 55-66 (2021)
DOI: 10.6688/JISE.202101_37(1).0004

Distributed Energy Intelligent Transaction Model and Credit Risk Management Based on Energy Blockchain

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This paper puts forward a distributed intelligent power information (DIPI) transaction model based on energy blockchain and a credit risk management mechanism, such that distributed power generation companies (DPGCs) and users can transact directly in a smart, real-time and secure manner. Specifically, the credit evaluation index of mobile power information was designed for DIPI transaction parties, after analyzing the sources and harms of the credit risk of DIPI transactions. Under the blockchain-based DIPI transaction model, the author established a mechanism that assesses the credit of DIPI transaction parties openly and transparently and outputs tamper-resistant credit values. Based on the digital proof of credit asset, the credit value was recorded as a special label in the serial number of the transaction script, making the credit weight corresponds to credit value under the credit index blockchain (CIB). Next, the author put forward the credit management mechanism for DIPI transactions based on the proof-of-credit assessment (POCA) consensus mechanism, with which the market players are economically incented to maintain their credit. The case analysis shows that our transaction model achieved higher transaction efficiency, fewer breaches and more orderly transactions in the DIPI market than the traditional centralized transaction mode. The research findings provide a reference for further research on the application of block chain technology in distributed energy mobile power information transaction.

Keywords: energy blockchain, distributed intelligent power information (DIPI) transaction, credit risk, credit assessment, consensus mechanism

1. INTRODUCTION

With the deepening of power market reform, China now allows distributed power generation companies (DPGCs) to engage in transactions in the power market [1]. The power transactions between the DPGCs and the users are often scattered, many-to-many and small in scale. These inherent features, coupled with the fact that the transaction contract is generally concluded before the transaction, bring a certain degree of credit risk to the transactions of the distributed mobile power information (DIPI) [2]. In fact, the credit risk has always been the focus of market risk management [3, 4].

The breach of the transaction contract will destroy the trust between the DPGC and the users and dampen the market enthusiasm. To prevent the breach, it is very meaningful to assess the credits of the transaction parties under the blockchain-based DIPI tran-

Received February 3, 2020; revised March 20, 2020; accepted April 11, 2020.
Communicated by Mahmoud Abdel-Aty.

saction model [5]. The assessment results help to evade the transaction risks and promote the marketization of power transactions. The blockchain is a peer-to-peer decentralized network based on distributed databases. It is a highly secure and transparent technique, supporting smart contact, distributed decision-making, collaborative autonomy and tamper resistance. The blockchain can perfectly satisfy the operation, topology and security demand of mobile power information transactions, marking the future trend of the mobile power information market. The integration of blockchain technology and mobile information system can solve the security challenges faced by mobile information system with the help of the inherent information security technology in blockchain technology [6, 7].

Many scholars have applied the blockchain technology in mobile power information spot market. For instance, Jesse *et al.* [8] considered the blockchain as a peer-to-peer decentralized network based on distributed databases, and suggested that the network is naturally suitable for power spot transactions in terms of operation mode, topology and security. Sawa *et al.* [9] examined blockchain features like smart contract, distributed decision-making and collaborative autonomy, analyzed the key techniques for blockchain application in power spot market, and put forward a verification plan for the techniques. Sabounchi and Wei [10] designed a point-to-point blockchain for networked microgrids, and proposed a method to verify the adaptability of the integration between blockchain and grid technologies.

Considering the development needs of the existing power system, the above studies have explored how the apply blockchain techniques (*e.g.* smart contract and collaborative autonomy) in direct power purchases by large users, cross-province transaction of generation rights and automatic response of the seller to power demand. The research findings provide references to the study on the architecture and workflow of blockchain-based power market models. Nevertheless, there is no report that tackles the architecture of the DIPI market, the mechanism of transactions between DPGCs and user, or the credit risk control of DIPI transactions. To make up for the gap, this paper integrates the blockchain technology to the power market, in view of the similar topologies between the two entities, and explores the architecture and workflow of blockchain-based DIPI transaction model, which achieves secure, autonomous, peer-to-peer transactions between DPGCs and users under partial decentralization. Considering factors like credit risk, the author put forward a credit management mechanism, making the DPGC credit assessment transparent, open and tamper-resistant. Under the mechanism, market players are incented economically to maintain their credit and obey transaction rules.

The paper is organized as follows: First, we put forward the evaluation index of distributed energy mobile power credit, by analyzing the cause and harm of distributed energy power credit risk. Then, establishing the credit evaluation mechanism on the basis of the distributed energy mobile power information trading model based on block chain. Next, we add a specific mark to the serial number in the transaction script to prove the credit score, basing on the digital proof of credit assets and realize the echo of the weight of credit score and credit value under the credit index block chain. Finally, we discuss the feasibility and advantages of distributed energy power credit control mechanism based on the consensus mechanism of proof-of-credit-assessment (POCA).

2. CREDIT RISK ASSESSMENT OF DIPI TRANSACTIONS

The two parties of a typical DIPI transaction need to agree on the power volume, settlement price and transaction duration. Below is an analysis on the possible breaches by the transaction parties. Firstly, it is assumed that the buyer has a poor credit, failing to use the agreed power volume. If the buyer consumes more power than the agreed volume, the DPGC will not be negatively affected; if the buyer consumes less power than the agreed volume, the DPGC will sell the excess DIPI power to the grid at a price below the settlement price. In the latter case, the DPGC will suffer from an economic loss. Depending on the compliance performance, the credit of the buyer in the transaction can be assessed by:

$$C_i^{buyer} = \begin{cases} \dfrac{\sum_{i=1}^{n-1} C_i + \dfrac{P_i^{act\_buy}}{P_{ij}} * 100}{n}, & P_i^{act\_buy} \le P_{ij} \\ \dfrac{\sum_{i=1}^{n-1} C_i + 100}{n}, & P_i^{act\_buy} \ge P_{ij} \end{cases} \tag{1}$$

where, C_i^{buyer} is the credit value of buyer *i* in the current (*n*th) transaction; $\sum_{i=1}^{n-1} C_i$ is the total credit value of the buyer in $n-1$ transactions; $P_i^{act\_buy}$ is the actual volume consumed by the buyer; p_{ij} is the power volume agreed by buyer *i* and seller *j*.

Secondly, it is assumed that the seller has a poor credit, failing to generate the agreed power volume. If the seller generates more power than the agreed volume, the buyer will not be negatively affected; if the seller generates less power than the agreed volume, the buyer will purchase power from the grid company to make up for the shortage. In the latter case, the buyer will suffer from an economic loss. Depending on the compliance performance, the credit of the seller in the transaction can be assessed by:

$$C_j^{seller} = \begin{cases} \dfrac{\sum_{j=1}^{n-1} C_j + \dfrac{P_j^{act\_sell}}{P_{ij}} * 100}{n}, & P_j^{act\_sell} \le P_{ij} \\ \dfrac{\sum_{j=1}^{n-1} C_j + 100}{n}, & P_j^{act\_sell} \ge P_{ij} \end{cases} \tag{2}$$

where, C_j^{seller} is the credit value of seller *j* in the current (*n*th) transaction; $\sum_{j=1}^{n-1} C_j$ is the total credit value of the seller in $n-1$ transactions; $P_j^{act\_sell}$ is the actual volume generated by the seller; p_{ij} is the power volume agreed by buyer *i* and seller *j*.

3. BLOCKCHAIN-BASED DIPI TRANSACTION MODEL

The blockchain is a desirable technology to promote the utilization of DIPI in China, for its data are tamper-resistant, highly transparent and traceable [11, 12]. In this chapter, the blockchain technology is introduced to support the information transmission and settlement of DIPI transactions [13, 14], forming a blockchain-based DIPI transaction architecture. As shown in Fig. 1, the architecture contains three blockchains, namely, scheduling chain DU1, the transaction chain JY1 and the credit assessment chain LH1.

(1) DU1 is a private chain encompassing nodes of the same status. DU1 generates the power volume to be transacted in the specified duration of 2h at a fixed cycle, and then broadcasts the power volume to all nodes in JY1. After JY1 initializes the transaction plan, DU1 will check the executability of the plan. If it is executable, the power volume will be distributed to the designated user(s) within the agreed duration.
(2) JY1 is a public chain. After simultaneously receiving the power volume for the corresponding duration from the DU1, the sellers and buyers will exchange the power volumes to be sold and bought and share the bid and offer prices within the transacttion duration. During the matching process, JY1 will continuously publicize the transaction information to both sellers and buyers, including the transaction prices, the current optimal buyer and the current optimal seller. JY1 will also report the information to the DU1 for verification. LH1 is an independently formed alliance chain.

As shown in Fig. 1, the coordinated operation between DU1 and JY1 is the key to DIPI transactions. Thus, it is necessary to determine JY1's matching mechanism under the market transaction mode specified by DU1, and disclose the logic control between the two chains. The DIPI output and load are difficult to be predicted accurately. To overcome the difficulty, DU1 nodes should negotiate the power volume to be transacted in a specified period within a fixed length of time ($\Delta t = 1$h). The time length was set in light of the fixed duration (10 min) for consensus-making and block-generation mechanism in blockchain technology. Taking the period from T_i to $T_i + \Delta t$ as an example, the flow of a blockchain-based DIPI transaction was explained as follows:

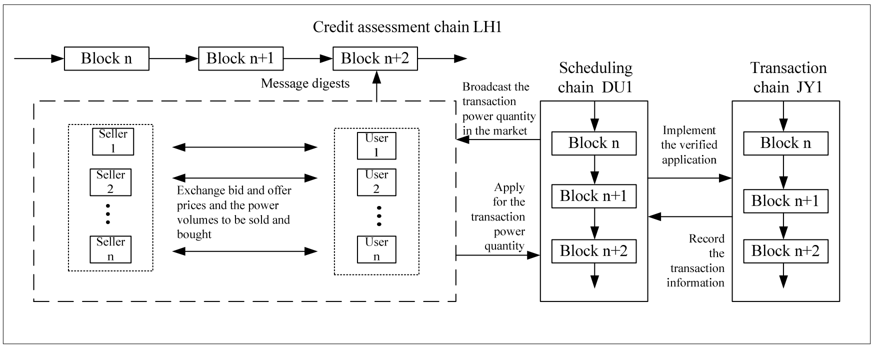

Fig. 1. Blockchain-based DIPI transaction model.

Step 1: DU1 computes the power volume according to the planned load of the lines within the target area in the target period (effective moment: $T_{te} = T_i + 3\ \Delta t$), and determines the transmission and distribution prices for the target area.
Step 2: The sellers and buyers update information at the same time.

Step 3: The sellers release the volume and price of the power to be sold, while the users release the volume and price of the power to be bought. The two parties are matched by the order of price and time. Then, DU1 checks whether the matching is successful, and records the matching result. After that, JY1 executes the transaction and records the transaction information.
Step 4: Before $T_i + 2\Delta t$, DU1 generates the power transaction block based on the negotiated results, formulates the point-to-point smart contract, and broadcasts the consensus across the network. DU1 also integrates the actual transaction information in the previous period into a block, and saves the message digest of the block into LH1.
Step 5: The expected transaction information generated at $T_i + 2\Delta t$ is reported to the DU1 for verification, facilitating the transaction in the next period.

The blockchain-based DIPI transaction model has no fully centralized node. All the nodes are of the same status, and jointly maintain the normal transaction through the consensus mechanism [15, 16].

4. CREDIT ASSESSMENT AND INCENTIVE MECHANISM FOR BLOCKCHAIN-BASED DIPI TRANSACTIONS

To reduce the credit risk in DIPI transactions, this paper puts forward a credit assessment and incentive mechanism for blockchain-based DIPI transactions. In the settlement phase, the smart contract is applied to automatically assess the credit values of both parties according to the digital proof of credit asset, and to record the assessment results on the credit index blockchain (CIB). The credit values will affect the basic weights of the parties in the CIB, which in turn determines the mining difficulty of the parties [17, 18].

4.1 DIPI Transaction Credit Assessment Based on Digital Proof of Credit Asset

After being matched, the user will exchange purchase price for power volume with the DPGC. In this paper, the bitcoin protocol is adopted for settlement. The user and the DPGC were required to transact with bitcoins, and the digital proof of credit asset was realized by the token system.

The token provides a digital proof of the credit asset in the blockchain. The bitcoins of a transaction are labelled by the serial number in the input script of the transaction, and turned into colored coins, which are essentially bitcoins. The digital proof of credit asset can be constructed with only a few bitcoins. In the input script, the serial number (*Sequence N*) is a 32-bit character. The last 6 digits specify the type of transaction *Zag_Zp*. If colored coins are transferred in the transaction, the value of *Zag_Zp* will be 11011, or 0×33 in hexadecimal value; if colored coins are generated in the transaction, the value of *Zag_Zp* will be 100101, or 0×25 in hexadecimal value. The transaction type label can be extracted as follows:

$$Zag\_Zp = Sequence\_N \& 0 \times 3F \tag{3}$$

where & is bitwise AND operation. If $Zag\_Zp = 0 \times 25$, the transaction belongs to the colored coin generation transaction; if $Zag\_Zp = 0 \times 33$, the transaction belongs to the colored coin transference transaction.

There is a lower bound for transaction volume in bitcoin transactions. As the digital proof of credit asset, the colored coins represent a very limited number of bitcoins. To reach the lower bound, a padding variable was calculated from 7^{th} to the 12^{th} digits in the serial number, like the computation method for transaction type label. The calculation of the padding variable can be divided into three steps:

Step 1: Set up the expression of the variable.

$$Value = Padding + Ve \tag{4}$$

Step 2: Extract the 7^{th} to the 12^{th} digits from the serial number:

$$Padding\_N = Sequence\_N \& 0 \times 0FC0 \tag{5}$$

Step 3: Calculate the value of the padding variable

$$Padding = 2^{Padding\_N} \tag{6}$$

where, *Value* is the bit value in the output script; *Padding* is the padding variable; *Ve* is the actual value of colored coins. Using Eqs. (4)-(6), the user can calculate the number of colored coins it receives according to the bitcoin value it receives and the serial number of the input script. In this way, a digital proof can be constructed for the credit asset.

The credit values are the most important index for assessing the parties of a blockchain-based DIPI transaction, and should be a basic attribute of blockchain nodes. The set L_h of basic attributes of node h in the blockchain for a DIPI transaction can be expressed as:

$$L_h = \{a_h, s_h, c_h\} \tag{7}$$

where a_h, s_h and c_h are the blockchain address, account balance and credit value of node h, respectively.

4.2 CIB

This paper proposes the CIB to control the credit risk in DIPI transactions:

$$M_{CIB} = (M, CMA) \tag{8}$$

where M is the main blockchain; *CMA* is the credit matching algorithm. The data structure of the CIB is presented in Fig. 2 below.

The storage of credit values plays an important role in DIPI transactions, especially in security assurance. After the CMA outputs results, the CIB forms a new block. Then, the transaction nodes will transmit relevant transaction information to the CIB, after learning from the latter about the success in matching.

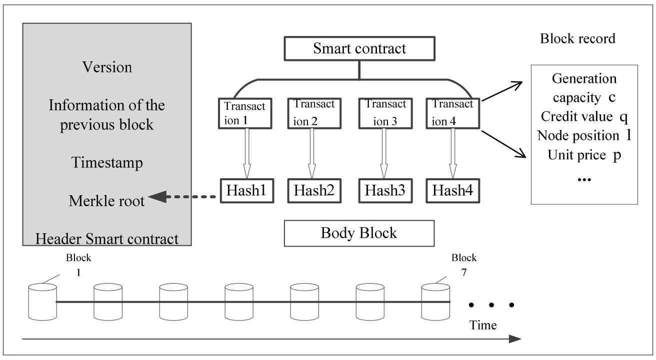

Fig. 2. Data structure of the CIB.

The CMA was designed based on the delegated proof of stake (DPOS). As a proof of rights mechanism, the DPOS randomly selects the next block uploader in the blockchain. The randomized selection considers the possessed assets. Thus, the DPOS can effectively guard against 51% attack and malicious script attack. The CMA can be implemented in the following steps:

Step 1: Each player in the DIPI market broadcasts its transaction status and other information about its identity (*e.g.* ID and credit value) across the network at an interval of Δt.
Step 2: Each node receives information and saves it to its own data storage center.
Step 3: In 0.1 Δt after the completion of information reception and storage, each node broadcasts its transaction status across the network: <TradeIntention, ID, *t*, *q*, *l*, *p*>, where *t* is the node type, *q* is the credit value, *l* is the node position and *p* is the unit price, and send the status to the CIB.
Step 4: Through the smart contract, each node computes the weights according to Table 1, ranks the results in descending order, and selects the highest value. Then, the node sends the information about successful matching to the CIB: <TradeResult, ID, *t*, *q*, *l*, *p*, *w*>, where *w* is the weight of successful matching.
Step 5: After any node receives more than *m* (depending on the total number of nodes and the system's operation ability) identical pieces of information, the consensus is reached and a new block is generated.

4.3 Credit Incentivization for DIPI Transactions Based on Proof-of-Credit Assessment (POCA) Consensus

In a fully decentralized network, the network nodes rely on the consensus mechanism to reach a consensus, and the node winning the billing right will receive a certain amount of reward [19, 20]. Under the DPOS consensus mechanism, the billing right algorithm can be expressed as:

$$SHA256(SHA256(Bprev), A, t) \leq balance(A) \tag{9}$$

where *t* is the timestamp; *Bprev* is the previous block; balance (A) is the equity of account A. Since the t value is a variable, the greater the value of balance (A), the more likely it is to find a reasonable t. The node with the highest equity will obtain the billing right and thus the greatest probability of receiving the reward. On this basis, this paper puts forward the POCA consensus mechanism. Under the mechanism, the nodes compete for the billing right by the following algorithm:

$$F(W_j, S_j) \leq N_{diff} * e^{c_j} \tag{10}$$

where $F(,)$ is the hash function; W_j is the Merkle root of node j; S_j is a random number that suits node j; N_{diff} is the basic difficulty coefficient; C_j is the credit value of node j.

By the billing right competition algorithm, node j can obtain the billing right in the following steps:

Step 1: Node j packs the transaction data into the block, and then computes the Merkle root W_j of the transaction data.
Step 2: Node j looks for a random number S_j that suits Eq. (10) in an exhaustive manner. If there exists an $S_j = S_j^*$ such that Eq. (1) is valid, node j will record S_j^* in the block and broadcasts it across the network.
Step 3: Upon receiving the S_j^* from node j, any other node in the blockchain will verify the legitimacy of S_j^*. If S_j^* passes the verification, the said node will add it to the blockchain, giving node j the billing right; otherwise, the block will be discarded.

Under the POCA consensus mechanism, if there are N network nodes with equal computing power involved in the transaction, then the probability P_k^{block} that transaction node k obtains the billing right of the next node can be calculated as:

$$P_k^{block} = \frac{P_j^{\sin gle}}{\sum_{g=1}^{N} P_g^{\sin gle}} = \frac{e^{c_k}}{\sum_{g=1}^{N} e^{c_g}} \tag{11}$$

where P_k^{single} is the probability that node x succeeds in mining through a single hash function operation; C_y is the credit value of node y.

5. CASE STUDY

5.1 DIPI Transaction Tests

To validate the proposed credit management mechanism for blockchain-based DIPI, three accounts, respectively representing the DPGC, the user and the grid company, were set up under the Ethereum smart contract, and subjected to seven tests. The grid company sells the distributed power at RMB 0.615 yuan/kWh, referring to Grade 1 of residential time-invariant electricity price in Shanghai, China, and charges the DPGC a wheeling cost of RMB 0.41 yuan/kWh. The test results are listed in Table 1.

As shown in Table 2, the results of the seven tests agree well with the expected outcomes. This verifies that the blockchain-based DIPI transaction model can record the transaction information of the players automatically and openly, and ensure that the record is tamper-resistant.

Table 1. Parameter weights.

Parameters	Weight coefficient	Basic weight
Generation capacity c	π_c	0.6
Credit value q	π_q	0.8
Renewable energy r	π_r	0.5
Node position l	π_r	0.4
Unit price p	π_p	0.5
Power volume s	π_s	0.6
Generation stability n	π_n	0.6

Table 2. Smart contract test results on distributed power transactions.

No.	Agreed unit price RMB yuan/kWh	Agreed power volume kWh	Agreed wheeling charge RMB yuan/kWh	Actual power consumption of the user kWh	Actual power output of the seller kWh	Total spending of the buyer RMB yuan	Total income of the seller RMB yuan	Total income of the grid company RMB yuan	Cumulative power volume kWh	Credit value of the buyer	Credit value of the seller
1	0.55	200	0.02	220	200	126.3	110	16.3	480	100	100
2	0.56	200	0.02	200	200	116	112	4	500	100	100
3	0.54	200	0.02	180	200	100.8	105.4	–4.6	720	90	100
4	0.54	200	0.02	250	250	140	135	5	800	100	100
5	0.56	200	0.02	180	180	104.4	100.8	3.6	700	90	90
6	0.55	200	0.02	190	190	108.3	104.5	3.8	600	95	90
7	0.54	200	0.02	240	220	135.9	118.8	17.1	900	90	85

The DPGC output is highly unpredictable, due to the great impacts from natural factors like sunshine and wind. The unstable output increases the probability of the DPGC to breach the transaction agreement, which may adversely affect the DPGC's credit value. To keep the market transactions fair, the credit assessment formula of the DPGC was updated with a natural weighting factor α:

$$C_j^{seller} = \begin{cases} \dfrac{\sum_{j=1}^{n-1} C_j + \dfrac{P_j^{act\_sell}}{P_{ij}} * 100 * (1+\alpha)}{n}, & P_j^{act\_sell} \le P_{ij} \\ \dfrac{\sum_{j=1}^{n-1} C_j + 100}{n}, & P_j^{act\_sell} \ge P_{ij} \end{cases} \tag{12}$$

where C_j^{seller} is the credit value of seller j in the current (nth) transaction; $\sum_{j=1}^{n-1} C_j$ is the total credit value of the seller in $n-1$ transactions; $P_k^{act\_sell}$ is the actual volume outputted by seller j; p_{ij} is the power volume agreed by buyer i and seller j; α is the natural weighting factor, $\alpha \in (0, 0.3)$.

The above tests were repeated using the new credit assessment method. The integrated credit value of the DPGC was thus obtained (Fig. 3). It can be seen from Fig. 3 that the addition of the natural weighting factors effectively reduced the negative effect of natural factors on the integrated credit value of the DPGC. The high integrated credit value of the DPGC demonstrates that, it is feasible to economically incentivize market players to maintain their credit.

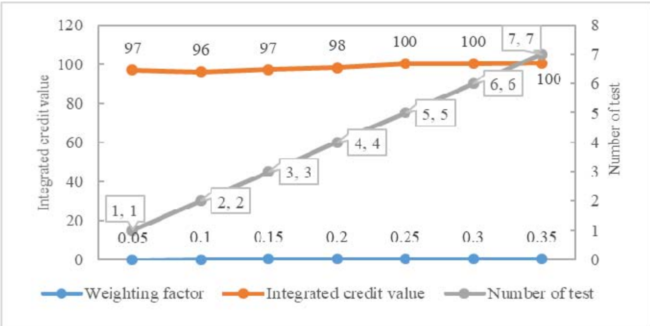

Fig. 3. The integrated credit value of the DPGC.

5.2 Tests on Credit Incentive Mechanism for DIPI Transactions

Ten market players with credit values between 90 and 100 points were investigated to verify the effect of the proposed credit incentive mechanism for DIPI transactions. The billing right ownership of each block was recorded during the mining of 50 blocks in a DIPI transaction blockchain, yielding the relationship between the probability of successful mining and credit value of each player. The results are plotted as Fig. 4 below.

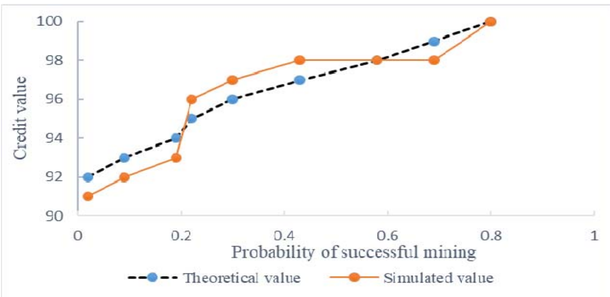

Fig. 4. The relationship between the probability of successful mining and credit value.

The test results show that, under our credit incentive mechanism, the probability of successful mining of a player is positively correlated with its credit value, that is, a player with high credit value is more likely to be successful in mining. Thus, the proposed credit incentive mechanism can effectively suppress the breach probability of market players, encourage them to actively obey transaction rules and maintain their credit.

6. CONCLUSIONS

As more and more players join the DIPI market, the credit risk soars for the massive amount of transactions information, making it harder to manage the DIPI transactions. This calls for a credit incentive mechanism that effectively controls credit risk, and a transaction model that properly simplifies the transactions. In this paper, the sources and harms of the credit risk in DIPI transactions are analyzed, and then the DIPI transactions are modelled under the architecture of blockchain. The DIPI transactions were turned into a blockchain, and integrated with the smart contract, making them reliable and intelligent. Considering the credit in DIPI transactions, the author examined the value of the blockchain in managing the credit risk of the DIPI market. In addition, a blockchain-based mechanism was established to assess the credit risk, and obtain a digitized credit value for each player; the smart contract was introduced to ensure the openness, transparency and tamper-resistance of the credit value assessment. Furthermore, a credit incentive mechanism was formulated for DIPI transactions based on the POCA consensus mechanism, which rewards the players that honor the transaction agreement and encourages the market players to obey the transaction rules and maintain their credit.

The DIPI market in China is gradually opening, the transaction policies are constantly improved, and the blockchain technology is making continuous progress. Against this backdrop, the blockchain is destined to play a greater role in the research and application of DIPI transactions. Therefore, the future research will improve transaction credit management with consensus mechanism, and perfect the blockchain-based DIPI transaction model, providing a reference for the application of blockchain technology in DIPI transactions. As a new database technology, blockchain technology can increase the mutual trust of multi-stakeholders in the energy power supply and demand network. Its decentralization, openness, and transparency are consistent with the decentralized system structure of the energy power supply and demand network. The field has wide application potential and is becoming an important new direction in the energy field today.

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