This is the first half of my planning model, which contains important concepts and backgrounds.

Blockchain-based EVs Charging Right Trading Modal

Abstract—**The traditional charging transaction model between electric vehicles (EVs) and the grid has low transparency and difficult settlement. To address this problem, this paper designs a demand-side response charging right transaction mechanism based on blockchain technology. First, a trinity of blockchain transaction system of power distribution network (PDN)-charging station (CS)-EVs is constructed. Second, a charging reservation mechanism and a creditworthiness evaluation mechanism is established to schedule the power quota of CS. Finally, the test results on the Ethereum blockchain show the fairness and efficiency of the proposed charging right trading modal.**

Keywords—Electric vehicles (EVs); Blockchain; Charging right

I. INTRODUCTION

With the intensification of environmental problems such as global warming and greenhouse effect, energy saving and emission reduction have attracted attention. Countries have successively formulated relevant policies to reduce carbon emissions. The Paris Agreement, signed by 178 parties worldwide on December 12, 2015, aims to limit the increase in global average temperature to 2 degrees Celsius compared to the pre-industrial period, and aims to limit the temperature increase to 1.5 degrees Celsius [1]. The use of EVs has a significant effect on the reduction of greenhouse gas emissions [2]. It has become a trend to vigorously support the development of EV industry [3]. Under the background of " carbon peaking and carbon neutrality" [4], the production of EVs continues to grow. By 2030, the global production of EVs is expected to account for one-third of the new car market [5].

Large-scale EVs connected to the grid have brought many challenges to the safe operation of the power system [6], especially the large-scale load growth of the power grid, which has increased the difficulty of the operation control of the PDN [7]. Designing charging mechanism to guide EVs for orderly charging is an important means to achieve orderly regulation of EV charging, and is one of the key research problems in the field of EVs. Numerous scholars have launched studies on the EV charging scheduling problem. Reference [8] adopts the method of time-of-use electricity pricing to adjust the charging behavior of EVs, and guides users to discharge during peak periods of electricity consumption and charge during low-peak periods, effectively achieving the effect of peak-shaving and valley-filling. Reference [9] incorporates the randomness of charging behavior into the charging cost, aims at minimizing the long-term average cost, and solves the optimal scheduling strategy through dynamic programming. Reference [10] formulated the charging problem of EVs as an optimal control problem and proposed a distributed algorithm to solve this problem for optimal charging scheduling of EVs. As the number of EVs surges, the randomness and uncertainty of charging behavior become more and more serious. The centralized coordination scheme of the above research [8-10] has problems such as low fairness and transparency of charging transaction settlement, as well as security issues.

As a decentralized and trusted emerging Internet technology, blockchain technology has basic characteristics such as traceability and non-tampering, and has played an extremely important role in the field of energy transactions [11]. Reference [12] introduces the energy block chain in the EV charging problem in the smart community. This scheme does not require the intervention of a third party, and provides safe charging services for EVs by executing smart contracts. Reference [13] proposes an energy trading strategy for private charging piles based on blockchain technology to promote energy sharing services for EVs and private charging piles. Reference [14] introduces the blockchain into the Vehicular energy network, and provides energy delivery services for EVs and energy nodes in the form of distributed ledgers. Reference [15] uses the blockchain network to realize the dynamic electricity price decision agreement between EVs and CS. The combination of lightning network proposed in [16] and energy scheduling mechanism enhances the security of transactions between EVs and charging piles. The above studies [12-16] have well solved the trust and security problem of electric energy trading, but ignored the will of the EV user and did not consider the user-side demand into the energy scheduling.

In this paper, to address the aforementioned problems, we proposed an EV charging transaction scheme based on demand-side response. First, this paper introduces the concept of charging rights for CS. Charging rights represent the charging power quota of CS within a certain period of time[17]. In order to flexibly decentralize charging rights to each CS according to demand-side response, this paper designs a charging reservation scheme as the basis for CS power quota, which realizes the optimization of power resource allocation. Afterward, considering that there are a large number of random and uncertain factors in EVs charging behavior, this paper establishes a user creditworthiness evaluation mechanism. The charging demand of CS with high creditworthiness will be guaranteed with priority, so as to achieve reasonable scheduling of charging power quota. Furthermore, blockchain technology is introduced into the charging right transaction process. Blockchain technology is used to record transaction information, deposit the creditworthiness of users, and realize transaction settlement based on smart contracts.

The rest of this paper is organized as follows. The blockchain-based demand-side response charging right trading mechanism is introduced in Section II. The simulation results are shown in Section III. The conclusion is given in Section IV.

II. The Method

The charging behavior of EVs is characterized by randomness and decentralization. Large-scale EV loads connected to the grid bring great challenges to the scheduling of energy. It is one of the effective ways to optimize the allocation of charging resources for PDN operators to decentralized charging margin according to the charging demand of CS. This paper applies blockchain technology to charging rights plan management and market allocation, uses blockchain to record transaction information, and deposits the user's creditworthiness. On this basis, a demand-side response-based transaction mechanism for EVs charging rights is established. The transaction framework is shown in Fig. 1.

A. Distribution-Sale-Purchase blockchain system

In this paper, we first construct a trinity blockchain system of allocation-sale-purchase. The PDN operator is responsible for the distribution, the CS are responsible for the sale of electricity, and the purchasers are EVs owners. Therefore, transaction subjects in the blockchain network include PDN operators and CS, as well as EV users, who are connected to the blockchain network as nodes through smart meters. Each node needs to perform the following transactions:

- PDN Operator: As power distributor, perform the function of distributing charging power to CS, provide auxiliary services for the electric energy transaction between EVs and CS, cover the unbalanced electric energy after the transaction, supervise the electric energy trading market and verify trading results.
- CS: As power seller, it provides charging services for EVs, predicts the charging load of the station in the future, and asks for the required charging power to the grid in advance.
- EV Users: As power purchaser, submit a charging reservation to the charging station in advance. Report relevant information: (1) Required charging power, (2) Location of CS, (3) Charging time period.

Blockchain network serves as an information interaction channel for transaction subjects, enabling secure and transparent transactions. The immutability of the blockchain ensures that all transaction information is true and valid. Moreover, the decentralized nature of blockchain allows transactions without the intervention of third parties, ensuring the transparency of transactions and facilitating the unified price regulation of the electricity market.

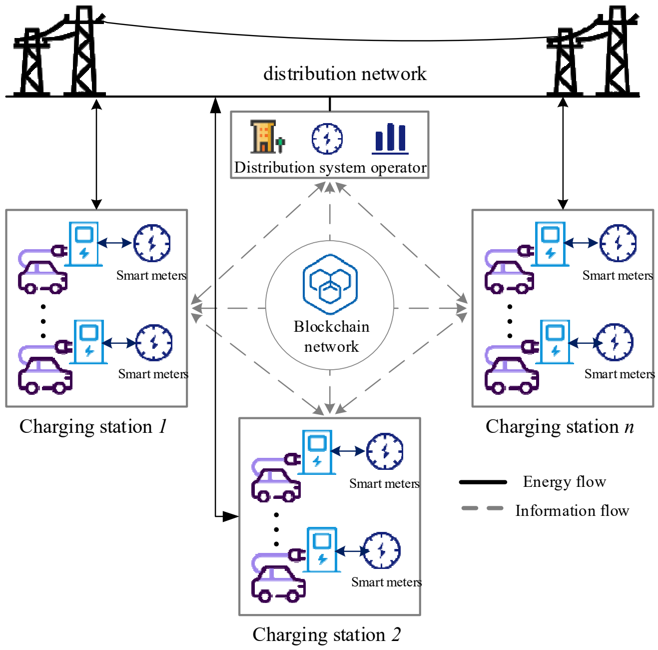

Fig. 1. Blockchain-based charging rights trading framework

B. charging right trading process based on demand-side response

In recent years, the number of electric vehicles has increased sharply. On the premise of ensuring the stability of the grid voltage, it has become a current research hotspot to maximize the charging demand of EV users. The time and state of electric vehicle load connected to the grid are uncertain, and the capacity of the PDN to accommodate charging facilities is limited. Especially during the peak hours of electricity consumption, if the charging load is too high, it will bring obvious impact to the grid. For example, during the peak load period, if all the charging piles of the CS are fully loaded, the capacity of the CS may be exceeded, thus posing a threat to the safe operation of the power grid. Therefore, it is necessary to design a flexible charging and distribution strategy to avoid overloading of power distribution equipment. This paper designs a charging right trading mechanism based on demand-side response to the problem of charging right allocation at CS. In the market allocation of charging rights, user creditworthiness files are introduced, and the credit value of EV users is used as a reference for the PDN to allocate charging rights to CS within a certain period of time.

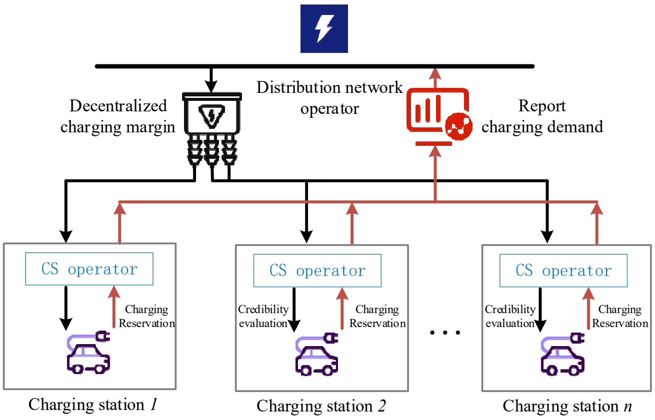

Fig. 2. Trading of electricity rights considering demand-side response

In this scheme, the previous transaction information records between EV users and CS are used as the basis for the creditworthiness rating of EV users. CS need to plan in advance the required power at different time periods. If EV users fail to comply with the agreement, they will cause power loss. Therefore, if the electric vehicle is charged according to the agreement, the creditworthiness will be increased, otherwise, the creditworthiness will be reduced. When decentralizing the charging margin, the PDN will prioritize the power demand of CS with high customer creditworthiness. Since all transactions are implemented in the blockchain network, the authenticity of the transactions is guaranteed. Therefore, it is highly reliable to build a user's charging creditworthiness files based on the historical transaction information recorded in the blockchain. Under this scheme, electric vehicle users go to the appointed location within appointed time period to charge the appointed amount of electricity according to the reservation information on the application platform. Creditworthiness is calculated as follows:

$$C_{\text{user}} = \sum_{i=1}^{3} w_i A_i \tag{1}$$

$$A_i = \begin{cases} 1 & \textit{actual behavior} = \textit{agreement} \\ -1 & \textit{actual behavior} \neq \textit{agreement} \end{cases} \tag{2}$$

Where, A_i represents the satisfaction of the user in three aspects: reservation time, location, and the amount of electricity. If the actual behavior of the user conforms to the agreement, the value of A is 1, and if not, it is -1. w_i represents the influence weight of reservation time, location, and electricity on user's reputation. we use analytic hierarchy process (AHP) [18] to calculate w_i. First, determine the importance of appointment time, location, and electricity. Among them, time is the most important, because the charging time determines when to allocate the charging margin. The second is the location, which determines the power dispatching between local grids. The last is the electricity, which determines the amount of power distribution. Using the AHP to calculate the weights, it can be obtained that the weight of the electricity is 8.096%, the weight of the location is 18.839%, and the weight of the time is 73.064%. Finally, the sum of the creditworthiness of a certain charging station can be obtained as:

$$C_{\text{station}} = \sum_{j=1}^{N} \sum_{i=1}^{3} w_i A_{ij} \tag{3}$$

Where j represents the j_{th} EV user, and there is a total of N EV users. To sum up, the power trading model process is as follows:

- Step 1: CS count the reservations of EV users within a certain time period.
- Step 2: Forecast power demand for future time periods by combining user reservations and historical load curves.
- Step 3: CS reports the reservation user's creditworthiness and charging power demand to the PDN.
- Step 4: PDN decentralizes charging rights based on the information of each CS, prioritizes the stations with high creditworthiness, and completes distribution transactions.
- Step 5: CS and EVs complete peer-to-peer charging transactions.

C. Smart contract-based charging rights trading process

Smart contract is a program deployed on the blockchain that can be automatically executed by a computer. Smart contracts can realize credible transactions without the participation of third-party institutions, and guarantee the authenticity and traceability of transaction results. This paper designs a smart contract for EV charging right trading. The contract is divided into market access stage, charging reservation stage, charging demand reporting stage, charging right P2P transaction stage, and transaction settlement.

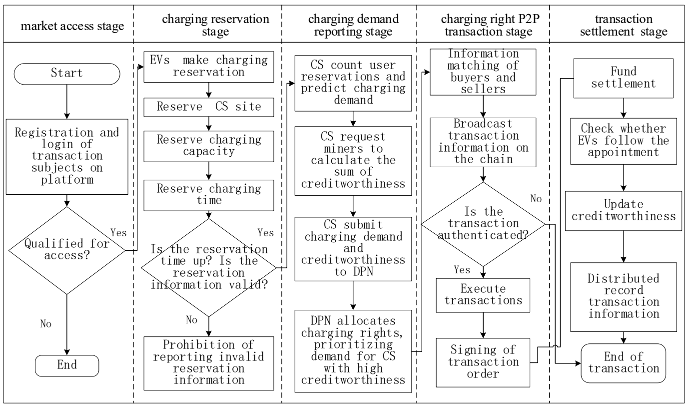

Fig. 3. Smart contract-based charging right transaction process

- Market access: First, DPN operators, CS managers and EV users need to register on the application platform. The system will generate a key pair (public key and private key) for registered users. In order to ensure the authenticity of the transaction node, all users need to be registered with the market supervision agency, meet the access conditions and obtain the corresponding digital signature certificate to enter the trading market.
- Charging reservation: EV users submit charging requests in advance. Reserve the time, location, and electricity to be charged. This information is encrypted by the Hash algorithm and reported to the smart contract. To avoid invalid reservation information being packaged into the block, the smart contract will verify whether the location, electricity, and time information meet the regulations. The timeliness is judged by the timestamp in the smart contract, and non-compliant reservation information will not be packaged into the block.
- Charging demand reporting: CS counts the user reservations in the station in the future time period, and combines the historical load curve to predict the charging power required by the station. Besides, the smart contract will invoke the creditworthiness function to calculate the sum of the creditworthiness of the CS. CS uploads the power demand and user creditworthiness to the blockchain system, which is also encrypted by Hash and sent to the PDN operator. According to the reported information, the PDN allocates a certain charging quota to each CS. CS with high creditworthiness will be satisfied first.
- Charging right P2P transaction: In this stage, the system will match the information of the purchase and sale subjects. Users verify the matching results with signatures. The signature verification process ensures the unique end-to-end confirmation, ensures that both parties are responsible for the transaction, and avoids transaction disputes. After the signature verification is successful, the transaction information will be broadcast on the blockchain to reach a consensus among nodes. Thereafter, the smart contract will automatically execute the consensus transaction.
- Transaction settlement: When both parties to the transaction sign a valid order, the smart meter completes the transmission of electric energy according to the signed order, and uploads the actual transaction information to the smart contract simultaneously. The smart contract automatically executes the settlement of the charging fee, and judges whether the user's charging behavior is consistent with the reservation according to the pre-set conditions. According to the creditworthiness calculation method proposed in this paper, the personal creditworthiness value of EV users is updated. Finally, the transaction information of nodes within a certain period of time will be packaged into blocks and sent to all nodes to complete the chain operation of transaction information.

III. EXPERIMENTAL RESULTS

In order to verify the effectiveness of the transaction mechanism of EV charging rights based on blockchain technology, this paper publishes the smart contract to the Ethereum blockchain platform in the laboratory environment to simulate the charging right transaction scenario of EVs. The set scenarios include 1 DPN operator and 4 CS operators. The host configuration of the test in this section is Windows 10Intel i7-6700k CPU@3.2GHz, 16GB.

TABLE I. PARAMETERS IN CHARGING DEMAND REPORTING STAGE

CS	Charging power demand(kw)	Total creditworthiness	Charging rights (kw)
A	380	90.87	296.95
B	701	165.33	655.35
D	1120	256.74	1090.50
E	991	233.18	957.18

TABLE II. EVS USER RESERVATION DETAILS

EVs users	reserved CS	Reserved power(kw)	Reserved time period	creditworthiness
$user_1$	A	32	11:00-12:00	8.25
$user_2$	D	34	13:00-14:00	6.73
$user_3$	B	40	14:00-15:00	9.21
$user_4$	E	30	15:00-16:00	7.65
$user_5$	C	36	17:00-18:00	8.34

Table 1 shows the charging demand counted by each CS during the time period 11:00-12:00. It can be seen from the table that the total demand for charging power is 3192kw. The total charging capacity of this area during this time period is 3000kw. Obviously, the charging capacity cannot meet the charging demand. In this situation, PDN will be more inclined to meet the charging demand of CS with high creditworthiness. Therefore, the charging demand of the charging station D is satisfied to the greatest extent.

Table 2 shows the charging reservation status of 5 EV users and the creditworthiness at reservation time. A user's creditworthiness value is capped at 10. Table 3 shows the transactions of these 5 users. The smart contract clears the user's creditworthiness value according to the user's actual transaction situation. The calculation method of creditworthiness is referred to Section II. If the transaction electricity fluctuates within 10% of the reservation, it is considered to meet the reservation situation. From Table 3, the charging behaviors of $user_5$ and $user_4$ both meet the requirements of the reservation. The transaction time of $user_1$ and $user_3$ violates the reservation requirements, so their creditworthiness are both reduced. Although $user_2$ charging location is inconsistent with the reservation, the creditworthiness has still increased. This is because we believe that charging time is the most important factor, while charging location is relatively secondary. This fits exactly with the weight assignment we described in Section II.

TABLE III. P2P NODE TRANSACTION INFORMATION

Node info	Traded address	Traded power (kw)	Traded Time Period	Traded CS	credit worth iness
1($user_1$)	0x21F25c…	34.35	10:00-11:00	A	7.79
3($user_2$)	0xe0b24f…	36.56	13:00-14:00	C	7.35
8($user_3$)	0x287bEc…	32.33	15:00-16:00	B	8.59
10($user_4$)	0x11B467…	31.64	15:00-16:00	E	8.65
11($user_5$)	0x80c39a…	35.89	17:00-18:00	C	9.34

IV. SUMMARY AND OUTLOOK

This paper proposes a trading scheme for EVs charging rights based on blockchain technology. This scheme takes into account the impact of demand-side response on power resource allocation. To this end, charging reservation mechanism and user creditworthiness evaluation mechanism are designed as the basis for the DPN to distribute charging power to CS. Finally, this paper utilizes the Ethereum blockchain to verify the fairness and efficiency of the proposed EVS charging transaction scheme. At present, the application of blockchain technology in the field of electricity market transactions has achieved initial results. In the future, we will focus on the application of blockchain in energy trading security in the future.

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