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Distributed Electric Vehicle Control Model Based on Blockchain

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Abstract. With the global energy crisis and environmental problems in recent years, the calls for energy conservation and emission reduction is getting higher and higher, and while the research on smart grid in various countries is deepening, The development of electric vehicle-electric grid (Vehicle to Grid, V2G) has become the focus of all countries in the world. This paper first expounds the background and related concepts of V2G generation, and proposes the key point in V2G: V2G control model. The second section of the article introduces the work related to the traditional V2G model. In the third section of the article, the new technologies such as blockchain are introduced and combined with the traditional V2G control model, and finally proposes a new blockchain-based model of distributed electric vehicle control system.

1. Introduction

There are two obvious shortcomings in today's power networks: high cost and lots of waste [1], both of which are the main reasons for the inefficiency of today's power networks. One solution today is to use intermittent renewable energy (solar, wind and water) as an auxiliary for the grid, but the problem with renewable energy is that the power generated by it is unstable and discontinuous, which cannot achieve the purpose of stable power supply. Based on the above situation, related research propose the concept of Vehicle to Grid (V2G), which uses a large number of electric vehicles (EVs) as a distributed energy storage system and acts a buffer for the grid. When the grid load is too high, the EVs feeds the grid, and When the grid load is low, use EVs to store excess power generation in the grid to avoid waste. Because of the advanced technology about Li-ion battery and hybrid electric vehicle, there is a large potential of V2G [2].

The focus of V2G is to control the interaction between the EVs and the grid. Traditional control schemes fall into three categories: centralized, switched and distributed [3]. When using a centralized control model, the scheduling strategy of electric vehicles in the area often needs to deal with the problem of multi-objective optimization. If only simply forcing all the EVs in the area to be concentrated in one charging pile for management, not only will the load of the single charging pile be too high, but also the resource utilization will be insufficient, so that the demand of the power grid cannot be solved in time; However, due to the lack of battery-related unified standards in the industry,



the actual application scale and scenario are still to be discussed; Distribution is one of the three kinds, which are developed and mature. It is also described in detail later. There are many ways to implement distributed, and blockchain, as the concrete representative of the emerging distributed implementation, meets the potential for security, privacy and payment transaction requirements in distributed energy switching systems [4]. In this paper we proposed a new distributed EV control model based on blockchain. The control model adopts the blockchain as a specific implementation scheme of the distributed control model, and combines the advantages of the blockchain to improve the security, synchronization and real-time of the EV control model; The model also uses smart contracts to control the interaction between the EVs and the charging pile, the grid and the charging pile, thereby achieving interactive controllability at the code level. The remainder of this paper introduces the related work of the traditional distributed control model in the second section, the third section introduces the blockchain related technology, and the fourth section elaborates the architecture and implementation of the distributed EV control model based on the blockchain.

2. Related work

The distributed EV control model generally refers to the use of a vehicle-mounted smart charger or other control means to enable the EVs to release the available and reactive power demand and price information according to the power grid due to the fact that the EVs are scattered in various places and cannot be managed centrally, Or V2G operation can be realized automatically according to the electrical characteristics of the grid output interface (such as voltage fluctuation) and combined with the state of the EV itself such as the current battery SOC (the power contained in the battery) [3].

Yutaka Ota et al. from the University of Tokyo proposed a distributed V2G control model based on a car charger in [5]. The system receives the electrical characteristics of the grid output through the vehicle charger and acquires the SOC state of the EVs through the intelligent interface controller, and receives the scheduling related commands and adjusts the behavior of the EVs through the power regulator.

An improved autonomous distributed V2G model based on charging request and battery condition is proposed in [6]. The model obtains the supply and demand information of the grid through the system frequency deviation, and determines the charge and discharge direction and behavior of the EVs according to the set value after mathematical modeling and the battery state of the EVs.

In [7], a distributed V2G control scheme for grid-connected EV is proposed, which encapsulates V2G controllers into automotive electronic circuits and electrical control units (ECUs) to build an automated distributed “smart storage” system. A real-time distributed control model based on dual-priority AIMD algorithm is proposed in [8]. The advantage of this model is that the central controller does not need any information from the connected EVs, nor does it need to make a separate model or behavior prediction for each EVs. In [9], a distributed EV coordinated control model based on short-term network demand forecasting and RES production forecasting is proposed. [5]-[9] and the traditional distributed EV control model is typically based on a smart car charging device or a smart plug. These type of control model implements a series of interactions, scheduling, and control through smart devices. The intelligent in-vehicle device not only realizes the hardware interface of charging and discharging, but also can interact with the load dispatching center through the regional network, and also accepts the frequency output from the power grid, and determines the charging and discharging behavior according to the system frequency deviation. Such distributed control model tends to implement interactive control at the hardware level, that is, the intelligent device receives the changed electrical signal to determine the specific behavior of the EVs.

3. Distributed electric vehicle control model based on blockchain

3.1. Blockchain technology

Blockchain technology is a new way of distributed infrastructure and computing. It uses the block data structure chain to validate and store the data to generate a consensus algorithm for the use of

distributed nodes and updating data, the safe use of cryptography to ensure that data transmission and access ways, the use of smart contract by the intelligent automation script code consisting of programming and operating data [10]. Blockchain has the following features: programmability, decentralization, autonomy and non-destructive modification. Blockchain relies on its real-time validation transactions to ensure the integrity of transactions through secure encryption technology, which has aroused widespread interest and attention in various industries. However, since the blockchain is a relatively low-level technology, there is a lot of inconvenience in directly utilizing and developing it. Therefore, the Ethereum platform is generated based on the blockchain technology as the underlying architecture. Ethereum is a new open blockchain platform that allows anyone to build and use blockchain technology in the platform to quickly and easily run decentralized applications.

The above characteristics of the blockchain bring new solutions to the problems in the energy industry. Such as multifarious market transactions involved in the energy sector, which in addition to energy trading, V2G also brought in the energy industry such as financial transactions, this needs a credible, do not tamper with the trade certification process, and the mathematical principle of blockchain and its public authentication mechanism to ensure the security of transactions in the energy industry and tamper-resistant; In addition, today's energy trading are mostly centralized model, the trading system has a natural bottleneck, and future trend of the energy industry trade is diversified, the blockchain trading systems is shared by all nodes, without central agency trading patterns, which greatly reduces the transaction cost, improves the throughput of trading systems; As more and more distributed new energy sources are connected to the power grid and become the auxiliary of the power grid, the traditional centralized system scheduling must also be transitioned to distributed. Real-time sharing of power demand information and real-time prices facilitates the creation of an ecological, self-operating power network.

3.2. Model design

As more and more EVs are connected to the grid as a distributed backup energy reserve, it poses great challenges to traditional grid operation and trading mechanisms. How to control the organizational and structural relations and interaction between EVs, charging pile and power grid, so as to achieve the requirements of each EV and power grid, is of great significance for the development of power system towards cleaner and higher efficiency and the establishment of a good power ecological network. The secure transaction and authentication mechanism of blockchain itself and the distributed network model of P2P structure provide a good candidate for this problem.

Based on the above problems, we proposes a new distributed EV control model based on blockchain. The system consists of three parts: EVs, P2P charging pile network based on blockchain architecture and power grid. Among them, EVs, as participant in the system, have both charging and discharging behaviors and can set the expected charging time and expected discharge time, EVs can also alleviate grid pressure by discharging to the grid and receive rewards based on real-time prices or choose to charge to ensure normal use or storage of excess energy in the grid. The charging pile network is the dispatching center of the whole system, its core is a blockchain-based P2P network. Each charging pile in the network acts as a single node, and the node obtains the demand information from the grid and the real-time discharge reward price and dispatches the corresponding EVs to execute charging and discharging behavior, and generates corresponding transaction records according to EV charging and discharging behavior and writes them into the blockchain. The power grid is the demand distributor in the system.

The entire system is a forward feedback automated power network system. When the grid load is high, the EV can be used as a distributed energy storage system to deliver idle power to the grid, which alleviates the high cost caused by high load to some extent. When the grid load is low, the storage system EV can store excess power, which avoids waste and can benefit from the user when the power is supplied to the grid, so that the whole system is constantly in a positive feedback. In the cycle, it is conducive to the development of the grid towards clean, efficient and flexible.

The overall system architecture is shown in Figure 1.

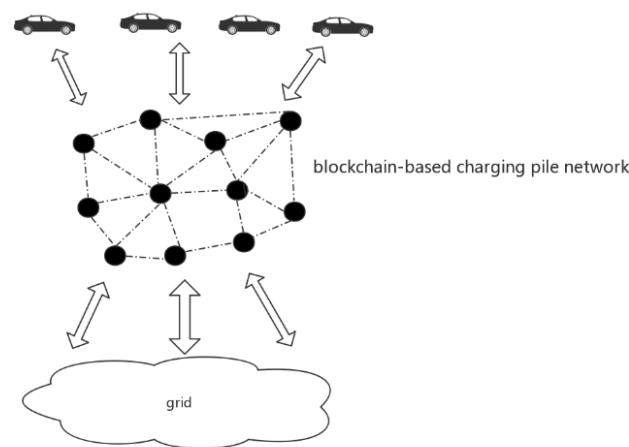


Figure 1. System architecture.

3.3. Interaction

It is assumed in this model that the power grid can interact with the charging pile and release corresponding supply and demand information by itself, and EVs charging/discharging process is realized through programmable charging device so that EVs can receive the control order from the charging pile, and the system execution process is shown in figure 2.

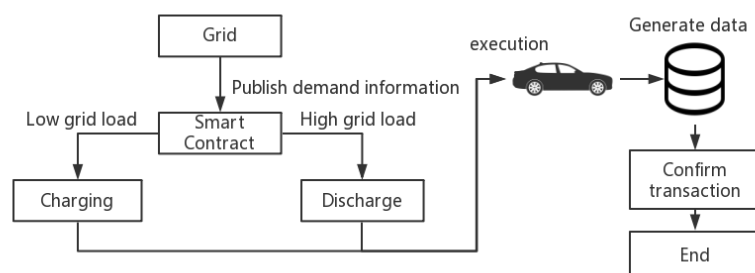
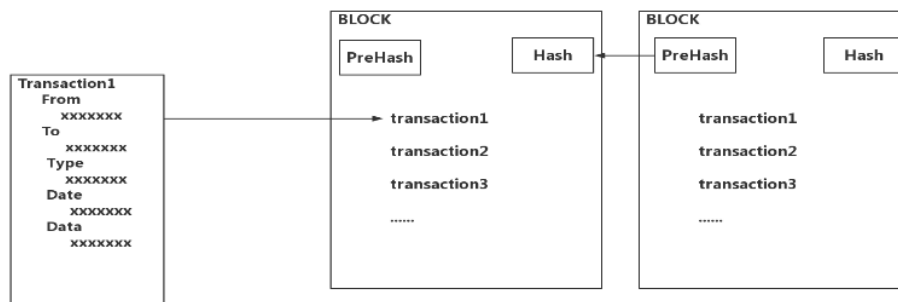


Figure 2. System flowchart.

As the bridge between the grid and EV interaction in this model, the charging pile is also the core of the model. It is divided into two parts: software layer and hardware layer. The hardware layer specifies the electrical characteristics of the charge and discharge process and implements a hardware interface for charge and discharge. On the one hand, the hardware layer interacts with the power grid and the electric vehicle to realize a specific charging and discharging process; On the other hand, the hardware layer interacts with the software layer to accept specific charging and discharging commands. The software layer consists of three parts, the underlying blockchain, the Ethereum platform, and the smart contract. The blockchain serves as the basis for the entire project and is responsible for recording and maintaining transaction records that occur throughout the control model. All charging and discharging will form a separate charge and discharge transaction record, which is recorded in the blockchain by the charging pile software layer and updated synchronously through the blockchain technology. The block structure information in the blockchain is shown in Figure 3.

**Figure 3.** Block structure information.

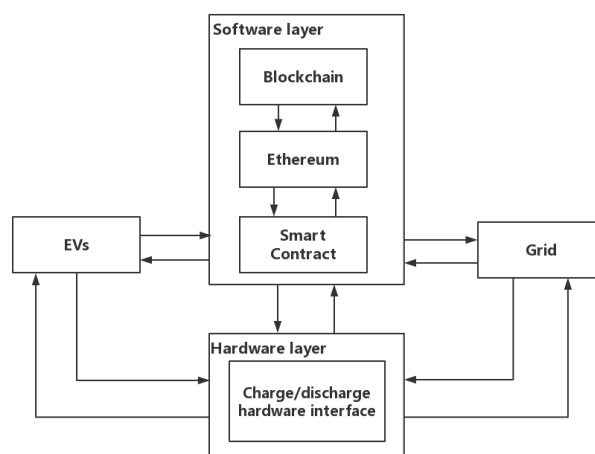
The relevant field definitions in transaction are shown in Table 1.

Table 1. field definitions.

Name	Description	value
From	Transaction originator address	Generated by a public key through a one-way Hash function
To	Transaction receiver address	Generated by a public key through a one-way Hash function
Type	Transaction Type	0 (discharge transaction) 1 (charge transaction)
Date	Transaction time	Timestamp
Data	Transaction note	Remarks in the transaction

The Ethereum platform provides the operational foundation for smart contracts. In this model, the interaction between the grid and the electric vehicle and the charging pile software layer is mainly completed through three contracts: charging transaction contract, discharge trading contract, demand status and value renewal contract. The demand status and value update contract is responsible for issuing demand information and current discharge reward information to the charging pile. The charging transaction contract is responsible for recording the trading information of the grid to the electric vehicle discharge, and the discharge trading contract is responsible for recording the trading information of the electric vehicle to the grid discharge.

The specific interaction process between a single charging pile and an electric vehicle and the power grid is shown in Figure 4.

**Figure 4.** interaction between a single charging pile, an EV and grid.

The specific demand information released by the grid to charging piles can be divided into two categories. First, the grid has high load, and EV discharge is required to reduce the pressure of the grid. The second is the low load of the grid, which allows the EV to store the excess energy of the grid. Depending on the demand, different smart contracts in the charging pile will receive the demand information from the grid and convert it to the corresponding command and transmit it to the EV connected to it. After the EV receives the command from the charging post, Then, the corresponding charging and discharging operation is performed, and each charging and discharging operation of the EV forms a transaction record, which is processed by the underlying blockchain system to be packaged and generated, and then updated on the entire network. All EVs charge and discharge records will be stored in blocks in mathematically encrypted form and are traceable.

When the EV is connected to the charging post, the software layer of the charging post collects the relevant status of the electric vehicle. Table 2 lists the relevant state variables for a single electric vehicle.

Table 2. state variables for a single electric vehicle.

Variable	Description
SOC_{start}	SOC status at the start of charging
SOC_{exp}	Expected SOC state at the end of charging
SOC_{end}	Actual SOC state at the end of charging
$Battery$	Battery capacity
P_{rated}	Rated charging power
η_{rated}	Charging efficiency
T_{start}	Start charging time
T_{rated}	Estimated charging time
T_{end}	Actual charging time
T_{set}	User set charging time
T_d	Difference time
M	User daily mileage
$Price$	Reward price
R	User rewards

The estimated end time T_{rated} can be calculated by the following formula:

$$T_{rated} = (SOC_{exp} - SOC_{start})Battery / (P_{rated}\eta_{rated}) \quad (1)$$

T_d can be calculated by the following formula:

$$T_d = T_{set} - T_{rated} \quad (2)$$

Assuming that the user's daily mileage M is linear with the current value x of the SOC and refer to [11], the following formula is obtained:

$$M = -1.128x + 112.64 \quad (3)$$

Define the minimum SOC guaranteed value λ according to (3):

$$\lambda = \frac{M - 112.64}{-1.128} \quad (4)$$

The lowest SOC guarantee value λ is the lowest SOC state calculated by the user daily mileage M , when the SOC state can satisfy the minimum travel requirement of the user, the discharge is allowed only when the SOC state of the EV is greater than λ , and the SOC state after the discharge is not lower than λ .

Assuming that the unit price $Price$ of the reward power generated by the grid discharge is a fixed value, the reward R obtained by the user discharge can be calculated by the following formula:

$$R = T_d * Price \quad s.t. T_d > 0 \quad (5)$$

The software layer interacts with the grid at regular intervals (for example, 30 minutes) to obtain current demand information for the grid.

When the current grid is in a high load state, EVs are required to discharge to the grid. According to the needs of users, it is divided into the following situations. The first case is the user's initial setting of charging behavior. So if $T_d \leq 0$, then EVs will only charge for time T_d . If $T_d > 0$, then EVs are first charged with a duration of T_{rated} , and discharged during the remaining T_d time, and a corresponding reward R is obtained, and when T_d is over, there is $SOC_{end} \geq \lambda$. The second case is that the user initially sets the discharge behavior. So if $SOC_{start} \leq \lambda$, In order to avoid affecting the daily travel of the user and causing loss to the battery, the EVs are not allowed to discharge in this case. If $SOC_{start} > \lambda$, at this time, the EVs will continue to discharge until the $SOC_{start} = \lambda$, the discharge behavior is stopped, and the user receives the reward R .

When the grid is under low load, the charging pile issues a charge order to the EV connected to it. If the user initially sets the charging behavior. At this time, the EVs will perform the charging behavior of $\min(T_{set}, T_{rated})$. If the user is initially set to discharge behavior, However, since the grid is in a low load state at this time, the demand for easing the grid pressure by the EVs discharge behavior is small, so the EVs will not be allowed to discharge.

Through the above interaction process, the original purpose of the model can be achieved, that is, when the grid load is high, the grid pressure is relieved by the discharge behavior of the EV, and the incentive mechanism for the user is increased through the reward mechanism. When the grid load is low, the EV is used as a distributed energy storage device to avoid waste of energy; The whole process meets the user's actual travel requirements, and on the basis of meeting the basic travel requirements of the users, the energy flow between the power grid and the EV is promoted, and the power grid system is developed toward high efficiency and flexibility.

3.4. Evaluation

The model proposed in this paper has the following advantages. First, traditional distributed EV control models are mostly based on smart car chargers or smart jacks, which are biased towards EV behavior control at the hardware level, which is neither easy to maintain nor very controllable, but in the EV control model of this paper, the hardware level only accepts the electrical behavior of the instruction to achieve charging and discharging, and the logic control layer is implemented in the intelligent contract in the software layer, which has code controllability and is convenient for future maintenance and adjustment. Second, traditional distributed EV control model does not retain any information after charging and discharging, and cannot meet the development trend of today's big data and smart grid. All the charge and discharge and user setting information in this model are recorded in the blockchain and are traceable. The rich information contained in the block is of great significance for the future analysis of the power grid, optimization of the architecture and services, and implementation of the smart grid. Last, in the EV control model of this paper, each time a new block is generated, a full network synchronization update is performed. Synchronous update of the whole

network avoids the loss of transaction record information caused by the damage of a single charging pile, and the simultaneous update of the whole network ensures the accuracy and security of the grid data and avoids the potential tampering data threat. For EVs owners, the completeness of the data also ensures that the legitimate rights and interests of the owner are not easily violated.

4. Conclusion

In this paper, a distributed EV control model based on blockchain technology is proposed, and the basic architecture and interaction model of the control model are given. Combined with the advantages of blockchain and smart contracts, this model reduces the over-centralized pressure in the traditional distributed EV control model, optimizes the interaction between the power grid and charging piles, makes the charging piles more intelligent and the interaction process with the power grid more rapid. And this model can store detailed information and transaction record of EV interaction, providing abundant data for future intelligent and automatic power grid, which is of great significance for the development of smart power grid.

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