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A blockchain-based electric vehicle energy trading scheme for electric vehicles

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Abstract: The issue of charging has become increasingly prominent with the growing number of electric vehicles (EVs), posing a challenge to the popularization and development of EVs. To enable EVs to charge when charging stations are not available, and to alleviate the transmission pressure on the power grid during peak periods, an alliance-based The peer-to-peer (P2P) energy trading scheme of the block chain is proposed for the energy trading between electric vehicles. In our scheme, the social welfare maximization problem (SWM) is used for modeling, and obtain a nonlinear optimization model. We use mathematical modeling to establish a system of equations about SWM, and then seek the optimal solution to this problem, which is the energy distribution scheme we determine, and then use an iterative double auction mechanism to set prices for energy trading.

1. Introduction

Electricity is the preferred source of energy for motor vehicles because it can provide greater comfort, design simplicity, and operational efficiency. Electric vehicles have been known since the mid-19th century, but it was only in the 21st century that people began to pay more attention to them due to environmental concerns[1]. Currently, the main ways to charge electric vehicles are through home charging using the power grid and solar panels, as well as charging at charging stations (CS). However, vehicle-to-vehicle (V2V) charging is a new type of electric vehicle charging. In developing countries or remote areas where charging stations may not be available or where some electric vehicle owners can use cheap renewable energy to charge and then provide cheap electricity to other electric vehicles, this method can be useful[2]. To facilitate this V2V energy transaction, we need to devise a new trading scheme. In traditional trading schemes, both parties usually need to submit transaction information to a server that processes transactions. In this centralized trading system, if there is a problem with the cloud server, it can affect the entire network, and its security vulnerabilities can also affect user privacy and security[3]. Currently, the emerging trend is blockchain-based trading schemes. In [4], the author considers the randomness of electric vehicle's demand for electricity, and therefore incorporates elements of reverse auction into their designed scheme based on dynamic pricing to increase the profits of both parties. This scheme can ensure that all allocated transaction volumes are completed through dynamic pricing strategies, and can also directly trade with the power grid when electric vehicles do not participate in V2V transactions. However, this scheme did not consider social welfare. In [5], the authors proposed a V2V energy trading decision-making algorithm using a greedy algorithm to calculate the unit transaction costs and profits of each buyer and seller, sort them in ascending order, select the optimal match according to rules, update the sequence, and then select the optimal match in the new sequence until all electric vehicles are successfully matched. This algorithm not only considers energy cost but also takes into account energy volume and social welfare, ensuring that all allocated transaction volumes are completed. However, this scheme did not consider the aspect of trading with the power grid. In [6], the energy trading scheme proposed by the authors is based on Bayesian games. They determine the specific scheme by solving the constructed SWM problem and optimizing the power utility based on the KKT conditions, and determine the transaction price through a price mechanism based on Bayesian games. However, if the optimal selling price of the seller is higher than the optimal buying price of the buyer in this scheme, it will result in incomplete allocation of transaction volumes and some vehicles may not meet their minimum requirements. Additionally, this scheme did not mention trading with the power grid.

Based on these problems, this paper conducts relevant research on blockchain-based electric vehicle energy trading schemes.

The following content of this article includes: Section 2 is the basic knowledge. Section 3 describes the electric vehicle energy trading model and trading process. Section 4 introduces the V2V energy trading scheme. Section 5 summarizes this article.

2. Related technology

2.1. Consortium Blockchain

The consortium blockchain operates under the leadership of a group of entities to achieve collaborative transformation involving multiple organizations. Sometimes it is also referred to as a permissioned blockchain, where participant identities are not arbitrary and require identity verification. Compared to public blockchains, consortium blockchains offer better security guarantees and have advantages in terms of throughput. Additionally, they are more friendly towards smart contracts.

2.2. Dominant strategy double auction

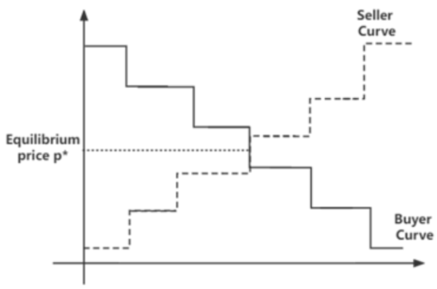

Figure 1: Transaction price function.

The pricing decision scheme described in reference [7] is adopted in this article, as shown in Figure 1.

1) Sort all seller quotes in ascending order $sp_1 \leqslant sp_2 \leqslant ... \leqslant sp_m$.

2) Sort all buyer quotes in descending order $bp_1 \geqslant bp_2 \geqslant ... \geqslant bp_n$.

3) Define a k, where $k \leq \min\{m, n\}$, and m and n are respectively the number of sellers and buyers. k satisfies $bp_k \geqslant sp_k$,and $bp_{k+1} < sp_{k+1}$. $p = (bp_{k+1} + sp_{k+1})/2$.

4) If $p \in [bp_k, sp_k]$,Sellers with quotes $sp_1, sp_2...sp_k$ and buyers with quotes $bp_1, bp_2...bp_k$ can complete the transaction at price p. The equilibrium price is $p^* = p$, If $p \notin [bp_k, sp_k]$,sellers with quotes $sp_1, sp_2...sp_{k-1}$ can complete the transaction with buyers who quote $bp_1, bp_2...bp_{k-1}$.Buyers need to pay an amount of bp_k to the auctioneer, and the auctioneer pays an amount of sp_k to the seller. The equilibrium price for the buyer is $p^* = bp_k$ and the equilibrium price for the seller is $p^* = sp_k$. The difference between sp_k and bp_k is the profit of the auctioneer.

Where sp_i is the quotation of electricity seller j to sell electricity. bp_i is the quotation of electric energy buyer i to purchase electric energy.

3. Scheme design

3.1. Scheme model

Figure 2 shows the schematic diagram of the structure of electric vehicle energy trading. Electric vehicles serve as mobile storage carriers for electricity and can both charge and discharge. Electric vehicles are equipped with smart meters that can measure the amount of electricity consumed or generated by the electric vehicle. The agent, as the transaction organizer in the system, is responsible for collecting and verifying requests from electric vehicles, executing deployed smart contracts, providing feedback on transaction volume information to electric vehicles, and ultimately verifying and recording transactions.

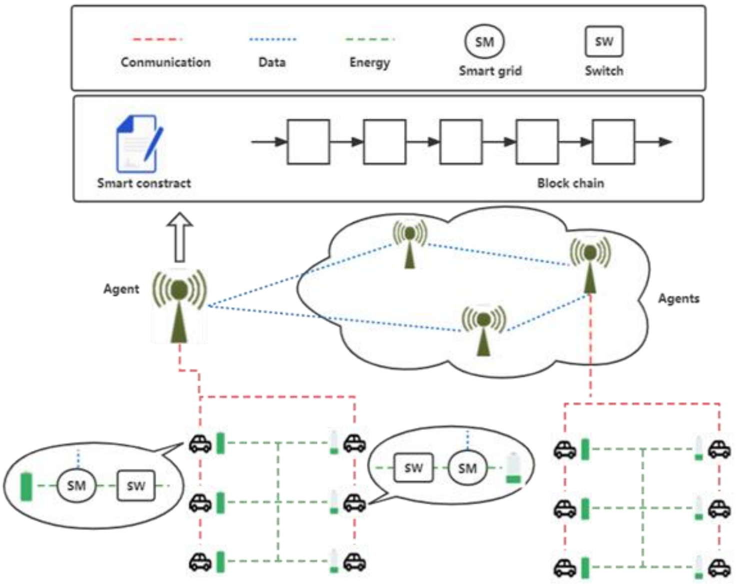

Figure 2: Schematic diagram of electric vehicle energy trading structure.

3.2. Scheme implementation process

① Discharging electric vehicles submit selling electricity applications to local agents.

② Charging electric vehicles submit purchasing electricity applications to local agents.

③ Local agents collect and verify the requests submitted by electric vehicles, and execute smart contracts within the specified time frame.

④ Local agents broadcast the results of the smart contract calculations to the electric vehicles that requested the transaction.

⑤ Electric vehicles conduct energy trading.

⑥ Smart meters provide feedback to local agents on the amount of energy traded.

4. Scheme implementatio

4.1. System structure

In the electricity trading market, Ser represents the set of sellers {1, 2, 3...m}, and Ber represents the set of buyers {1, 2, 3...n}. Seller j ∈ Ser and buyer i ∈ Ber. The amount of electricity a seller wishes to sell is denoted by s_i , while the amount a buyer wishes to purchase is denoted by $b_i . b_i \in \left[b_i^{\min}, b_i^{\max} \right]$, where $b_i^{\min}$ represents the minimum amount of electricity required for buyer i next trip with their electric vehicle, and $b_i^{\max}$ represents the maximum amount of electricity that can be purchased by the electricity buyer i.

The selling price of electricity for seller j is sp_i, with $sp_i < f^{in}$,The buying price of electricity for buyer i is bp_i, with $bp_i > f^{out}$.

At a certain moment, the amount of electricity that seller j sells to buyer i is s_{ji} , at a corresponding trading price of sp_{ji}. The quantity purchased by the electric energy buyer i from the electric energy seller j is d_{ij}, with a corresponding trading price of bp_{ij} .

When there is excess or insufficient electricity, the demand for V2V energy trading can be balanced by directly trading with the main power grid. When the total supply of electricity from sellers in V2V energy market is not enough to meet the needs of buyers, Electric vehicles with electricity demand can purchase electricity directly from grid companies at a price of f^{in}. When the total supply of electricity from sellers in V2V energy market exceeds the demand of buyers, sellers can sell their electricity to the main power grid at a price f^{out}.

The cost for an electric seller comes from energy consumption during the transaction process. According to [8], we can model energy loss as a quadratic function. Therefore, we can obtain a cost function for electric seller j in the electricity trading process.

$$C(s_j) = l_1 \sum_{i=1}^{n} (1-\alpha)(s_{ji})^2 + l_2 \sum_{i=1}^{n} (1-\alpha)(s_{ji}) \tag{1}$$

Electricity buyers all wish to maximize their utility. According to [9], modeling the utility function of electricity customers using the natural logarithm function is a good choice. Therefore, We obtain the return function of buyer i during the transaction process as follows:

$$U(b_i) = \lambda_i ln\left(\alpha \sum_{j=1}^{m} b_{ij} - b_i^{min} + 1\right) \tag{2}$$

Where λ_i represents the willingness of electricity buyer i to participate in the V2V electricity market, α represents the average transmission efficiency of electric vehicle electricity transactions.

V2V electricity trading prices are between the grid electricity price f^{out} and the retail electricity price f^{in}. Both buyers and sellers in the V2V electricity trading market can benefit, and the more transactions, the greater the benefits for both parties. From a societal perspective, local V2V electricity trading should be utilized as much as possible to maximize social welfare and achieve effective internal market equilibrium [10]. In order to maximize social welfare, we need to improve the utility function of maximizing buyers and minimize the cost function of sellers. Therefore, we obtain the final SWM function:

$$\begin{aligned} SWM: &\max_{b_i,s_j}\left\{\sum_{i=1}^{n}U\left(b_i\right)-\sum_{j=1}^{m}C\left(s_j\right)\right\} \\ s.t.\ & b_i^{min}\le\alpha\sum_{j=1}^{m}b_{ij}\le b_i^{max} \\ & \sum_{i=1}^{n}s_{ji}\le s_j \\ & b_{ij}=\alpha s_{ji}\ge 0 \end{aligned} \tag{3}$$

4.2. Price mechanism based on Dominant strategy double auction

Before executing the transaction algorithm, the auctioneer collects auction requests from both buyers and sellers. Once the auction begins, the electricity distribution is allocated based on a preset algorithm.

① In the first iteration, users submit their initial bids. The buyer's bid must be higher than the purchase price of the power grid, as it is impossible for a seller to be willing to sell below this price. Similarly, the seller's price must also be lower than the retail electricity price of the power grid, because if it is higher than this price, the buyer does not have to purchase electricity from other electric vehicle owners. After receiving the bid, the auctioneer obtains the transaction scheme by solving Equation (3), and then determines the transaction price based on the price mechanism.

② The system provides users with the allocated transaction plan and the equilibrium price p^* obtained from the first iteration as feedback.

③ Sellers and buyers who failed to trade update their bids based on the market equilibrium price and submit them in the next iteration, as described in equation (5).

$$p_k^{'}=p_k-\omega_k[p_k-p^*] \tag{4}$$

Here, p_k is the bid submitted by user k in the first iteration. p^* represents the equilibrium price obtained in the first iteration. ω_k is a price adjustment factor with $\omega_k > 1$.

The remaining value after subtracting the equilibrium price from the bids of the buyer and seller after experiencing price updates is:

$$p_k-p^*\left(n\right)=\left(1-\omega_k\right)\left(p_k-p^*\right)\begin{cases}>0 & buyers\\ <0 & sellers\end{cases} \tag{5}$$

This means that after the bid update, any buyer i's bid is higher than seller j's bid, ensuring that all energy allocation plans can be completed.

④ After updating the bids, they are resubmitted to the auctioneer. The auctioneer finds the lowest bid bp_i among all buyers and the highest bid sp_j among all sellers after receiving the bids, and then provides feedback on the new transaction price to users. All buyers need to pay the amount of bp_i to the auctioneer, while the auctioneer pays out sp_j to the seller. The difference sp_k-bp_k is kept as profit by the auctioneer.

5. Conclusions

V2V power trading can not only alleviate the problem of insufficient charging stations, but also help the power grid relieve pressure during high load periods and assist electric vehicles that cannot charge through traditional methods. In order to reasonably allocate electricity trading volume and prices, a rational power trading scheme is required. The double auction-based electricity trading scheme adopted in this article can maximize social welfare. At the same time, the price mechanism designed in this article can ensure that all traded electricity is allocated and takes into account a fixed price for transactions between electric vehicles and grid entities.

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