Research on a Consortium Blockchain Private Electric Vehicle Charging Station Sharing Platform for New Energy Vehicles

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Abstract: In response to the challenges of increased demand for electric vehicle charging, issues related to insecure charging data and wastage of charging station resources, this study proposes a research on a consortium blockchain platform for sharing private electric vehicle charging stations for new energy vehicles. Firstly, the background and significance of the platform research are introduced. Subsequently, the relevant technologies involved in the platform are introduced. Furthermore, the design process of the platform is presented, along with the introduction of a charging station selection evaluation model. Finally, the feasibility of the system research is demonstrated by using a specific set of charging data as an example.

1 INTRODUCTION

In recent years, in order to further promote the dual carbon goals of "carbon peak" and "carbon neutrality," the country has vigorously developed new energy vehicles with low carbon emissions, minimal environmental pollution, and the ability to alleviate the petroleum energy crisis. It is estimated that by 2025, the number of new energy vehicles in China will reach 21 million. However, with the large-scale development of new energy vehicles, the problem of difficulties in charging these vehicles has emerged in an endless stream. According to the "Deep Report on New Energy Vehicle Charging Pile Industry" released by CITIC Securities, as of September 2022, China had a total of 1.49 million new energy vehicles and 4.488 million charging stations, resulting in a ratio of 2.56 vehicles per pile. There is still a significant gap in charging pile availability. In order to meet the charging needs of new energy vehicle users, the country has increased investment in charging infrastructure and advocated the orderly installation of private charging stations. Currently, the locations of new energy vehicle charging stations are scattered, and there are several issues, such as unattended charging facilities, difficulties for vehicle owners to find available charging stations, empty charging stations, challenges in sharing data and resources among enterprises, lack of transparency in charging transactions, privacy data breaches, and idle private charging stations. Therefore, there is a need to explore a more secure, efficient, and trusted shared private electric vehicle charging stations platform to improve the utilization rate of charging stations and meet the charging needs of vehicle owners .

Blockchain technology possesses characteristics such as decentralization, transparency, immutability, and multi-party consensus, making it a suitable combination with charging station applications. However, currently, most research combining blockchain with charging stations is limited to public charging station sharing models, with fewer considerations given to sharing private charging stations and optimal strategies for finding charging stations for new energy vehicles.

Based on this, this study proposes a research on a blockchain shared platform for private electric vehicle charging stations. Firstly, the relevant technologies of the platform research are analyzed, and the security and economic aspects of the platform are briefly discussed. Secondly, a platform model is constructed to complete the design of the platform workflow. Then, strategies are formulated based on the four influencing factors of charging duration, charging distance, charging cost, and charging pile reputation involved in the vehicle owner's selection of charging piles, in order to find the optimal charging pile. Finally, a case study is conducted. Experimental results demonstrate that the platform utilizes blockchain technology to enhance the security of vehicle owner charging transactions, match the optimal charging piles, reduce vehicle owner charging costs, and improve charging pile utilization.

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2 BLOCKCHAIN AND RELATED TECHNOLOGIES

2.1 Introduction to Blockchain

Blockchain is essentially a trusted, decentralized, immutable database stored in a chain-like structure. Each block on the blockchain records all transaction data within a specific time period, utilizing technologies such as asymmetric cryptographic security, hash algorithms to ensure the integrity of Merkle tree data structures, peer-to-peer distributed network architecture, and trusted consensus mechanisms between blocks. As a result, blockchain can be widely applied in scenarios such as electricity trading and energy exchange.

2.2 Key Technologies of Blockchain

Blockchain is primarily composed of four key technologies: distributed storage, asymmetric encryption algorithms, consensus mechanisms, and smart contracts. The technical implementation of a blockchain-based shared platform for charging stations is as follows:

1) Distributed Storage: In the platform, all charging users, charging stations, and grid companies form a distributed network as peer nodes. After a charging transaction is completed, users and charging station owners upload the transaction records to the shared platform via the Internet. The transaction information is distributed, updated, and supervised across various nodes in the network. A blockchain charging sharing platform does not have a specific central node. Users and transaction data of the platform are stored and distributed among various network nodes. In the event of a hacker attack or network failure, the system is less likely to experience a complete collapse, thereby improving fault tolerance and security.

2) Asymmetric Encryption: To prevent information leakage and tampering, the platform employs asymmetric encryption for transaction information. When a new energy vehicle user sends a charging request to the shared platform, they first sign and encrypt the data with their private key, then encrypt the signed data with the platform's private key, and finally send the encrypted data. Upon receiving the data, the shared platform decrypts the specific transaction information using the new energy vehicle user's public key and its own private key.

3) Consensus Mechanism: The consensus mechanism in a blockchain refers to the process where different nodes reach consensus on charging transactions through voting within a very short time. If unrelated nodes in the blockchain can reach consensus, the entire network can reach consensus. If a charging user node or charging station user node in the blockchain attempts to maliciously tamper with charging transaction records, they would need to possess 51% of the computing power to have a chance of success. However, when a node has 51% of the computing power, its benefits as an honest node outweigh those as a malicious node, thus ensuring the integrity of transaction information and enhancing the platform's security.

4) Smart Contracts: Smart contracts are computer protocols deployed on the blockchain that disseminate, verify, or execute contracts in an automated manner. They are computer code. In a shared charging station platform, smart contracts can define various scenarios for charging transactions between electric vehicle users and charging stations. For example, when an electric vehicle user completes charging within the reserved time, the charging station updates the real-time power information and calculates the charging cost. When users in the shared charging station platform meet the conditions set by smart contracts, charging transactions are generated, and the transaction information is uploaded to the smart contract. The smart contract automatically handles settlement, transfers, and records after charging is completed and broadcasts the transaction information to various master nodes. Master nodes with high computing power package the transaction data into blocks, forming the blockchain. The content of the smart contract includes the usernames of the parties involved in the transaction, transaction addresses, start time, transaction price, transaction power, and so on. Smart contracts allow trusted transactions without the need for a third party, and these transactions are traceable and irreversible.

3 IMPLEMENTATION OF CHARGING STATION SHARING SOLUTION

3.1 Physical Architecture of the Sharing Platform

The shared transaction platform in this paper is built using a consortium blockchain approach. The blockchain management in the consortium blockchain involves the participation of multiple institutions and organizations. Node participation requires strict qualification reviews, ensuring stronger security, higher consensus, and better privacy protection. The platform consists of nodes such as new energy vehicle users, charging station owners, government regulatory agencies, and power companies. The main physical architecture of the platform is shown in the following figure 1.

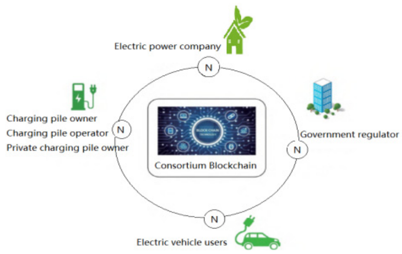

Figure 1: The main physical architecture of the platform.

The entities participating in the shared charging transactions on the new energy vehicle consortium blockchain are as follows:

1) Consortium Blockchain Platform. It is a decentralized, distributed, dynamically encrypted database that ensures data immutability, security, and reliability. It records relevant information of platform transactions, such as querying charging transactions, settlement and payment for charging transactions, and locating the optimal charging stations.

2) New Energy Vehicle Users. These are the users who utilize the charging stations. They register their personal information on the consortium blockchain platform. When in need of charging, they can publish their charging requirements or search for the optimal nearby charging stations. They complete the charging process and settle the payment for the charging fees.

3) Charging Station Owners. Charging station owners can be either private individuals or public charging station operators. They provide information on the consortium blockchain regarding the charging station models, locations, charging power, etc. By sharing the charging stations, they aim to increase the utilization rate of the stations and consequently enhance their revenue.

4) Government Regulatory Agencies. These agencies oversee the charging transaction process, validate the legitimacy of various nodes, and engage in rational planning and management of charging station deployment and quantity.

5) Power Companies. They ensure the safety and reliability of the charging equipment, control the charging load, and mitigate the impact of a significant number of charging stations on the power distribution network.

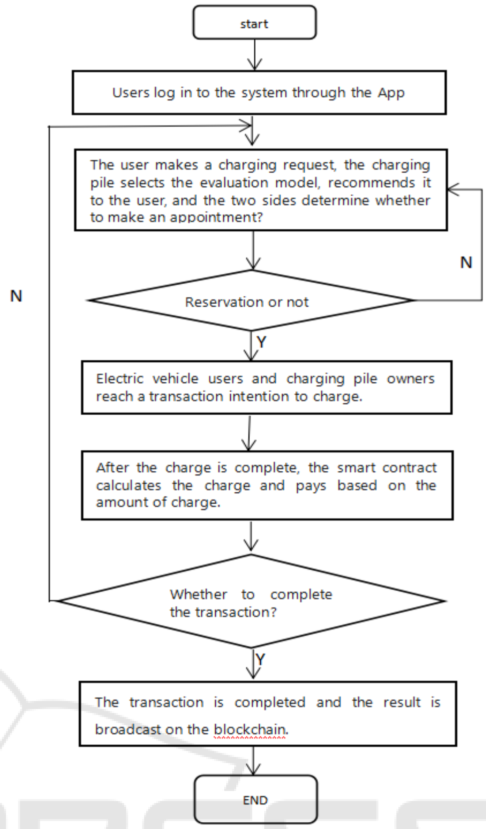

Figure 2: Blockchain New Energy Vehicle Charging Station Sharing Transaction Process.

3.2 Blockchain New Energy Vehicle Charging Station Sharing Transaction Process

The following is the translation of the content:

First, users log in to the charging station sharing platform via the mobile app. They send a charging request to the platform, providing information such as their current location, the remaining battery level of their new energy vehicle, and the desired reservation time for charging, charging price acceptable. After receiving the request from the charging user, the platform evaluates the model according to the selection of the charging pile, calculates the optimal charging pile and intelligently recommends it to the user. In order to ensure that the charging pile is not occupied by others, the charging user sends an appointment request to the platform after confirmation, and the platform communicates with the charging pile owner to confirm that the appointment is successful. The authentication contract between the charging user and the charging pile owner takes effect and starts to run.The platform issues an authentication code for the new energy vehicle to the charging station owner and sends the authentication code for the charging station, service token, and payment token to the user. The charging station authorizes the charging based on the vehicle authentication code provided by the owner and verifies that the user is the one who made the reservation based on the charging station authentication code provided by the user. Likewise, the user confirms that the charging station is the one they reserved based on the vehicle authentication code provided by the charging station. After successful bidirectional hash authentication between the two parties, the charging process begins. Once the charging is complete, the charging station calculates the charging cost based on the meter reading, and after the owner verifies the charging information, the user completes the payment. Upon completion of the charging transaction, the transaction result is broadcasted to the blockchain. The process is shown in the following figure 2.

3.3 Charging Station Selection Evaluation Model

In this study, the decision-making process for new energy vehicle users in selecting a charging station primarily considers four key factors: distance, time, cost, and reputation.

1) Distance. This refers to the distance between the electric vehicle and the charging station. When an electric vehicle experiences range anxiety due to battery consumption, a charging demand arises. In such cases, the user provides the battery consumption and remaining battery level of the electric vehicle to the platform. The platform calculates the maximum distance the electric vehicle can travel and selects charging stations within this range to ensure that the electric vehicle can reach a suitable charging station. The formula for calculating the maximum distance the electric vehicle can reach is as follows:

$$\mathrm{s}_i^{\max} = \frac{soc_i}{poc_i} \tag{1}$$

where soci represents the remaining battery level of electric vehicle i, and poci represents the battery consumption of electric vehicle i.

2) Time. This refers to the charging time and the time cost of driving to the charging station. Due to different charging powers of charging stations, the duration of fast charging and slow charging varies. Therefore, the duration of electric vehicle i charging at charging station j (T_i^j) is calculated as follows:

$$T_\mathrm{i}^j = \begin{cases} R_i / (\mathrm{p_f} * \lambda) + \Delta T_i^j, PML_j = 1 \\ R_i / (\mathrm{p_s} * \lambda) + \Delta T_i^j, PML_j = 0 \end{cases} \tag{2}$$

where Ri represents the charging demand of the electric vehicle, Pf represents the fast charging power, Psrepresents the slow charging power, λ represents the charging efficiency, and PMLj represents the charging station model, with 1 representing fast charging and 0 representing slow charging.

3) Cost. This refers to the charging fee, charging service fee, and mileage fee of the electric vehicle. The charging fee (C_{ij}^c) is determined by the charging duration, charging power of the charging station, and charging price. The charging service fee (C_{ij}^p) is determined by factors such as the geographical location of the charging station and resource competition. The mileage fee (C_{ij}^s) of the electric vehicle is determined by the distance between the charging station and the vehicle, battery consumption, and charging fees. The calculation formula is as follows:

$$C_{ij}^t = C_{ij}^c + C_{ij}^p + C_{ij}^s \tag{3}$$

where C_{ij}^c represents the charging fee, C_{ij}^p represents the charging service fee, and C_{ij}^srepresents the mileage fee of the electric vehicle.

4) Reputation of the Charging Station. To better recommend charging stations to users, after the completion of charging, users can rate their charging experience based on factors such as the stability of the charging station equipment, the reasonableness of the charging price setting, and charging incentives. The platform calculates the reputation of the charging station based on user ratings. Charging stations with higher reputation are more likely to be recommended to users, thereby gaining more revenue.

To ensure comparability among the four influencing factors in the evaluation model, it is necessary to normalize the variables. The normalization function is as follows:

$$\sigma(x) = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \tag{4}$$

The standardization of each indicator in the evaluation model can be represented as:

$$U_i^{j,k} = \frac{(u_i^{j,k} - u_i^{j,k,\min})}{(u_i^{j,k,\max} - u_i^{j,k,\min})} \tag{5}$$

where $U_i^{j,k}$ represents the standardized value,$u_i^{j,k}$ represents the evaluation index of electric vehicle i for charging station j regarding influencing factor k (k can take values 1, 2, 3, 4, representing distance, time, cost, and reputation), $u_i^{j,k,max}$ and $u_i^{j,k,\min}$ represent the maximum and minimum values of the evaluation index of electric vehicle i for charging station j regarding influencing factor k.

4 CASE SIMULATION AND CONCLUSION

4.1 Case Introduction and Data Preprocessing

In this paper, a typical traffic system in a city is selected as a case for simulation analysis. The parameter Settings of charging piles and new energy electric vehicles are shown in Table 1 and Table 2. According to the analysis and research, due to the charging load pressure, it is necessary to divide the time period on the basis of the benchmark electricity price, so the charging fees of most public charging piles on the market are obtained, as shown in Table 3;The charging unit price of the private household charging pile is shown in Table 4, and the private charging pile with charging service fee is shown in Table 5.

Table 1: Charging station parameter.

Parameters	Numerical
Charging station number	cpn
Fast charge power Pf/kw	30kw
Slow charge power Ps/kw	7kw
Charging state(charging：1, Free：0)	1 | 0
Charging time	0.5h - 12h
Charging service fee	0.6 yuan - 1.2 yuan
Charging price	0.9 yuan - 1.8 yuan
Reputation score	0-10 fen

Table 2: Electric vehicle charging parameters.

Parameters	Numerical
Electric vehicle number	cn
Battery capacity	54 - 60Ah
Power consumption per 100kilometers	13-16 kwh
Travel speed	60 km/h-120 km/h
Maximum charge waiting time	1h - 8h

Table 3: Charging price of public charging station at different time.

Periods of time	Numerical
Peak time: 8:00 - 11:00 18:00 - 23:00	1.6-1.8 yuan/kwh
Shoulder time: 23:00 - 7:00	0.9-1.2 yuan/kwh
Mean time: 7:00 - 8:00 11:00 - 18:00	1.3-1.5 yuan/kwh

Table 4: Electricity prices of different gradients at home.

Gradient	Unit price
First gradient(0kwh - 220kwh)	0.49 yuan
Second gradient(220kwh - 400kwh)	0.54 yuan
Third gradient(>400kwh)	0.72 yuan

Table 5: Charging electricity prices of different gradients at home.

Periods of time	Gradient	Cost
Peak time: 8:00-11:00 18:00-23:00	First gradient (0kwh - 220kwh)	1.32 yuan
	Second gradient(220kwh-400kwh)	1.46 yuan
	Third gradient (>400kwh)	1.52 yuan
Shoulder time: 23:00-7:00	First gradient(0kwh-220kwh)	1.17 yuan
	Second gradient (220kwh - 400kwh)	1.34 yuan
	Third gradient (>400kwh)	1.52 yuan
Mean time: 7:00-8:00 11:00-18:00	First gradient (0kwh-220kwh)	1.29 yuan
	Second gradient (220kwh-400kwh)	1.34 yuan
	Third gradient (>400kwh)	1.52 yuan

4.2 Transaction Simulation Verification

Assume that the owner of a charging pile has a 7 kW AC charging pile, and its electric vehicle is used as a daily work attendance tool to charge once every 5 days for 8 hours, and the personal utilization rate of the charging pile is 6.6%. In order to further fully improve the utilization rate of the charging pile, the charging pile owner will release his own charging pile on the alliance chain and realize sharing. In the consortium blockchain, let's assume the charging station is labeled as "cp100" and the charging service fee is 0.8 yuan/hour. The electric vehicle owner has a charging demand of 14 kWh, a maximum allowable distance of 3 kilometers, and is willing to pay a maximum electricity price of 0.8 yuan/kWh. The time slot for occupying the charging station is from 9:00 to 11:00. The electric vehicle owner sends their demand set {cp100, 9:00─11:00, 14, 3, 0.8} to the consortium blockchain. Based on the charging station selection evaluation model, the consortium blockchain matches the demand with the available time slot of charging station cp100. After confirmation, the AC charging process starts at 9:00 and ends after charging 14 kWh. At 11:00, the electric vehicle owner removes their vehicle from the charging station. In this transaction, the electric vehicle owner spends a total of 22.4 yuan, eliminating the hassle of finding a public charging station in the vicinity and saving time and costs. The charging station owner calculates the electricity cost expenditure using the first tier and earns a profit of 3.92 yuan, while using the second tier results in a profit of 1.12 yuan. The charging costs under different scenarios are shown in the following figure 3.

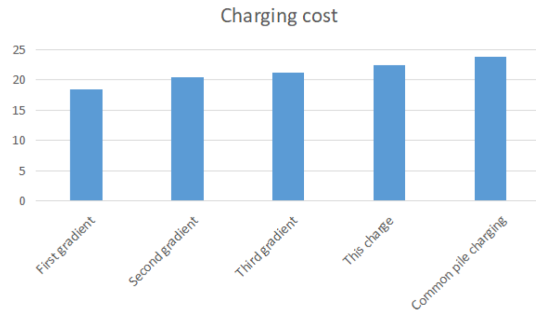

Figure 3: The charging costs under different scenarios.

Based on the above, the blockchain-based private charging station sharing platform for new energy vehicles makes full use of the advantages of trust established through blockchain technology. It enables charging transactions between electric vehicle owners and private charging station owners, reducing intermediaries in the transactions. Electric vehicle owners can charge at a lower electricity price, while charging station owners earn income by providing their idle charging stations, thereby increasing the utilization rate of the charging stations. This further promotes the dual carbon goals of "carbon peak" and "carbon neutrality".

5 CONCLUSION

With the continuous increase in the number of new energy vehicles, there is a need to further improve user charging demands. Traditional data storage methods cannot guarantee the security and reliability of massive data. In this study, we utilized the decentralized, traceable, and tamper-proof characteristics of blockchain, as well as technologies such as data encryption, smart contracts, distributed storage, and sharing mechanisms, to build a consortium blockchain-based platform for sharing new energy vehicle charging stations. This platform, through the intelligent selection evaluation model for charging stations, recommends the optimal charging stations to users and facilitates charging transactions. It effectively addresses the challenges of charging difficulties for new energy vehicles and the wastage of resources due to idle private charging stations, while also generating income for charging station owners. Through the case analysis, it is evident that the platform meets the daily charging needs of new energy vehicles, effectively safeguards user privacy information, and optimizes the allocation of charging station resources. This study provides valuable insights for future research on shared charging station applications.

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