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Research on Electric Vehicle Fast Charging Station Billing and Settlement System

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***Abstract*—In order to meet the trend of increasing scale and more complexly layout of electric vehicle(EV) fast charging station(FCS) ,as well as the development of urban intelligent city, this paper studied on use mobile Internet and mobile terminal to realize the intelligent billing and settlement system of EV FCS, which provided a integrated charging billing model based on time-of-use price, proposed a solution to achieve system that can scan identification through vehicle QR code, guide the charging vehicle orderly parking by APP, start charging process , and realized no card payment by the mobile terminal. At last, this paper gave experimental result to verify time-of-use price is the important influence factor to integrated charging fee, and the billing model which adopted optimized peak-valley segmentation method can instruct the customer to charge economically, a lot of users can save the cost of travel. The system can enhance the customer satisfaction and will help to improve the operational efficiency and service capability of EV FCS.**

Keywords- electric vehicle; fast charging station; integrated billing model;mobile; time-of-use price

I. INTRODUCTION

China's electric vehicle production and sales achieved explosive growth in 2015 [1]. China has surpassed American to become the world's largest electric vehicle market [2]. Depending on IEA statistics, the number of China's DC charging pile accounted for 44% of the world [3], far more than other countries. By the end of 2016, in order to serve the long-distance travel of electric vehicle users, the China State Grid Corp built a "six vertical and six horizontal second ring" highway as the core of fast charging network [4]. By 2020, China will build more than 12 thousand centralized charging station, among them, 8800 special vehicle charging station, 2400 city public charging stations, more than 800 highway fast charge station, will construct more than 4300 thousand charging piles in residential area and parking spaces [5]. According to China's electric vehicles development strategy and the current demanding for electric vehicles, fast charging mode is a very important way of stimulating vehicle energy supply [6]. Promoting charging infrastructure is a key strategic measure to promote energy consumption revolution. Construction of fast charging network, and the large-scale development of electric vehicles, is an important way to implement the national energy-saving and emission-reduction policies, accelerate alternative energy [7], prevention atmospheric pollution, and control fog and haze [8].

It is necessary to research on new billing strategy to guide fast charging EV users for rapid charging and achieve demand side management. This paper proposes giving an integrated charging billing model and carry out FCS intelligent billing and settlement system of electric vehicle, which can realize services such as the identification the car with QR code, automatic guide, mobile payment.

II. RESEARCH ON BILLING METHOD

Due to the characteristics of large power and fast charging, the fast charging pile is generally built-in large public places, such as transportation hub area, large charge stations [9]. Now, there are about two types of fast charging application: urban rapid charging station, high speed charging service area. These stations are providing rapid charging services to electric vehicles private users, electric buses, and electric taxis. There are different billing models under different scenarios. The fast charge station includes two typical applications: charging and parking. Billing model needs to calculate the parking costs and electric vehicle charging costs. The highway and public transport fast charging stations are dedicated charging stations, which the charging equipment is less, so they needn't consider parking fee in billing model.

A. Integrated Billing Strategy

To achieve the electric car's electricity costs, service fees and parking fees in real time that based on the fast charge station charge billing strategy (including energy billing, service billing strategy which according to the proportion of electricity charged fees, charge parking fees, overtime parking fees) by real-time measurement, real-time acquisition technology. According to the different types, The fast charging stations charging divided into $FCS=\{F_{public}, F_{special}, F_{highway}, F_{parking}\}$, F_{public} denoted the city fast charge station, $F_{special}$ denoted the special vehicle fast charging stations, such as bus, taxi, sanitation, logistics and other special vehicles fast charging station, in addition to fast charge some institutions and enterprises within the special station, $F_{highway}$ denoted the highway fast charging stations, $F_{parking}$ denoted the construction by the operator, equipped with fast charging pile the parking lot, parking garage etc..

$$W_{i,j,t} = W^E_{i,j,t} + W^S_{i,j,t} + W^P_{i,j,t} \tag{1}$$

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Where $W_{i,j,t}^{E}$ is charged energy fee at FCS j in time t, W_i^S is EV i charged service fee at FCS j in time t, W_i^P is EV i parking fees at FCS j in time t, includes overtime parking fees.

B. *Time-of-use Price Based Billing Model*

In the time-of-use electricity price model [10], it is possible to let the electric vehicle charge at a low price (usually a lower period of the grid load). According to the time price, the 24 hours evenly divided into Y time period [11-13], M for the time attribute set, $M=\{T_h, T_{pk}, \dots T_f, T_l\}$, Respectively, the peak period, peak period, flat period , valley period and other periods, suppose that n periods belong to the peak period, $T_h=\{t_{h1}, \dots t_{hn}\}$,Similarly, $T_{pk}, \dots, T_f, T_l$ both have several periods. The collection of the time length of each price attributes $X=\{\Delta T^h, \Delta T^{pk}, \dots, \Delta T^f, \Delta T^l\}$. C is the time-of-use price, $C=\{C_h, C_{pk}, \dots, C_f, C_l\}$; C_h, $C_{pk}, \dots, C_f$, C_l respectively electricity price of the peak period, peak period, the flat period and the valley period. $Q_{i,j,k}$ is the charge power of i^{th} electric vehicle in FCS j at period k. t^a for the entry time, t^b for the start of charging time, t^c for the end of the charging time, t^d for the outbound time.

Charging time length: $\Delta t = t^b - t^c$. Divided into the peak, the valley can be expressed as $\Delta t = \sum_{j \in X'} \Delta t^j$, $X' = \{\Delta t^h, \Delta t^{ph}, \dots, \Delta t^f, \Delta t^l\}$, X' is the collection of each price attribute from time point t^a to time point t^d of i^{th} electric vehicle in FCS j . Electricity fee of time period k can be formulated as

$$W_{i,j,k}^{E} = f\left(C_{m,k}, Q_{i,j,k}\right), \forall m \in C, k \in X'; \tag{2}$$

$$Q_{i,j,k} = SOC_{j+1}^{a} - SOC_{j}^{b} \tag{3}$$

The i^{th} electric vehicle's electricity fee of the whole charging period is calculated as follows:

$$W_{i,j,t}^{E} = \sum_{k \in X'} \sum_{m \in C} \left(C_{m,k} Q_{i,j,k}\right) \tag{4}$$

Charge service fee can be formulated as

$$W_{i,j,t}^{S} = \sum_{k \in M} (\mu_{j,k} \cdot Q_{i,j,t}) \tag{5}$$

where, $\mu_{j,k} > 0$, $\mu_{j,k}$ is charging service factor which is a constant. Each period attribute corresponds to a different coefficient, $\mu = \{\mu_h, \mu_{pk}, \dots, \mu_f, \mu_l\}$, $\mu_{j,k} \in \mu$.

Parking fee can be formulated as

$$W_{i,j,t}^{P} = \begin{cases} \rho_j \cdot (|t^d - t^a - t^c + t^b| - \theta) \cdot \beta; t^d - t^a > \theta, \forall j \in FCS \\ \rho_j \cdot |t^d - t^a| \cdot \beta; \exists\, t^b = t^c, \forall j \in FCS \cup j \notin \{F_{special}\} \\ 0 < \rho_j \leq 1 \\ 0; t^d - t^a \leq \theta, \forall j \in \{F_{public}, F_{highway}\} \\ 0; \forall j \in \{F_{special}\} \end{cases} \tag{6}$$

where, $\theta > 0$, θ is a free parking period of time, FCS get parking fees over θ time slot (such as 0.5 hours) ,the value of θ is developed by the fast charging station operators. $\beta > 0$, β is basic parking fee and is not more than government referential price. ρ_j denoted parking discount coefficient, directed by the FCS operators.

From (6),we know that for the special bus fast charging station and the government internal parking lot, the fast charging pile is limited opened and does not charge the parking fee. For highway fast charging station and city station, parking fees are free in the θ period, otherwise according to the discount coefficient ρ over θ period. For the vehicle that no charges only parking, the parking charge is charged for full-time periods. $\exists\, t^b = t^c, \forall j \in FCS \cup j \notin \{F_{special}\}, \rho_j = 1$. For the parking lot which built by a variety of private funds, the parking fee is charged for full period time. $\forall j \in \{F_{parking}\}, 0 < \rho_j \leq 1$. From (1), (4)~(6), time-of-use price based billing model can be formulated as:

$$W_{i,j,t} = \sum_{k \in X'} \sum_{m \in C} \left(C_{m,k} Q_{i,j,k}\right) + \sum_{j \in FCS, k \in M} (\mu_{j,k} \cdot Q_{k,j,t}) + W_{i,j,t}^{P} \tag{7}$$

III. Billing and Settlement System Implementation

A. *System Flow*

The city fast charging station is large and complexly, In order to enhance the user experience, the intelligent billing and settlement system needs vehicle guidance and also consider other related functions, for example, the system should have a charge status reminder function, promptly remind the user to take timely removal of the vehicle, reduce other users waiting time. Inbound and outbound require vehicle identification. Before the EV entered the station they have been booked charging piles through the mobile APP client of the FCS's billing and settlement system. The specific process is as follows (Figure 1):

- When EV drove into the station, the system's QR Droid Private scanned EV's QR code on mobile phone APP, the system recognized license plate, called out the user's expected leave time, the battery capacity and the state of charge (SOC) and other information.
- The system queried the current parking status database to determine the optimal parking spaces. According to the current station parking status and destination parking position, it generated vehicle driving route map for path planning, sent to the mobile phone APP.
- APP guided EV to the correct parking spaces, system updated parking status.
- Customers scanned the charge pile's QR code to start charging process. The system regularly sent charge quantity and estimated time of completion to the customer's mobile APP. After charging finished, when EV drove out of the station, the system scanned the vehicle's QR code for identity

authentication, and time-sharing billing module calculated the integration cost of electricity bill, the charging fee and the parking fee. If only parking vehicle, we needn't pay for charging.

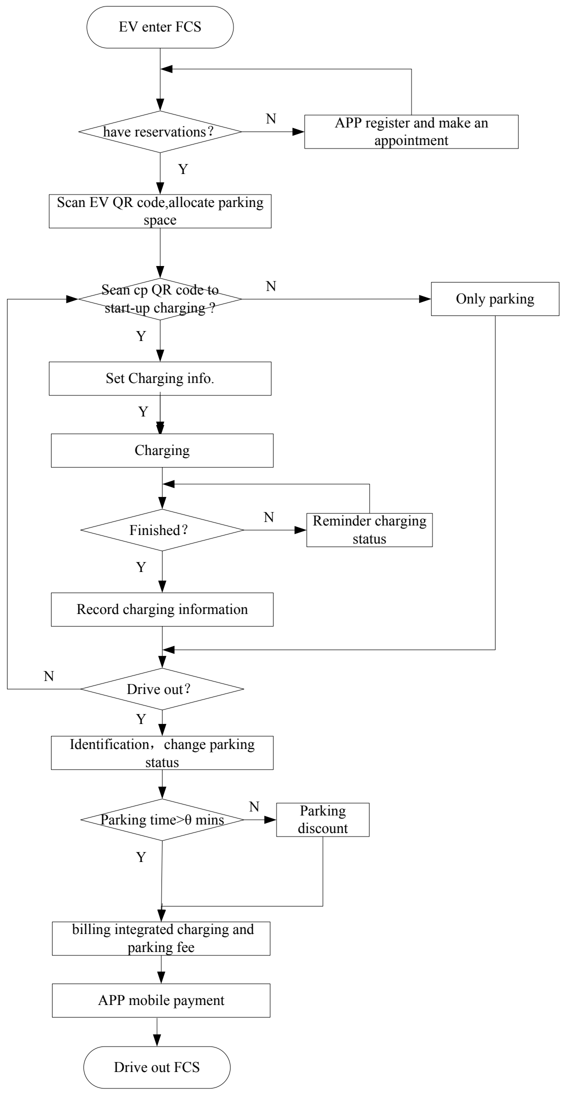

Figure 1. The flow chart of billing and settlement system.

- APP is called mobile payment module to complete the payment, the system received successful tips, then sent lift command to the outbound device controller, and recorded the related charge data.

B. System Communication Structure

The communication server determines the capacity of the charging pile of the platform, In Figure 2, system communicate with inbound, outbound device by RS485,communicate with parking detector, QR Droid Private by WIFI or cable, The charging pile and the server are designed to establish TCP and Socket connection to realize asynchronous communication. APP communicated with the system using a Web service method.

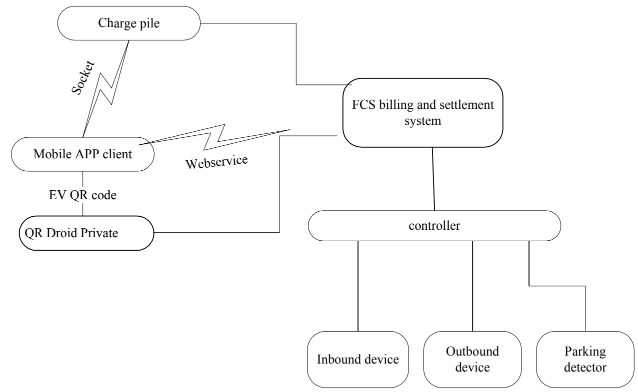

Figure 2. The communicate structure chart of FCS billing and settlement system.

IV. EXPERIMENTAL VERIFICATION

A. Sensitivity Analysis of the Factors

In order to consider the influence of time-of-use price,μ_h, θ, ρ of integrated billing model, this paper made the sensitivity analysis of these factors. As can be seen in Figure 3, while the range of effect was ±20%, the adjustment of time-of-use price is more important to the integrated charging electricity fee than other factors.

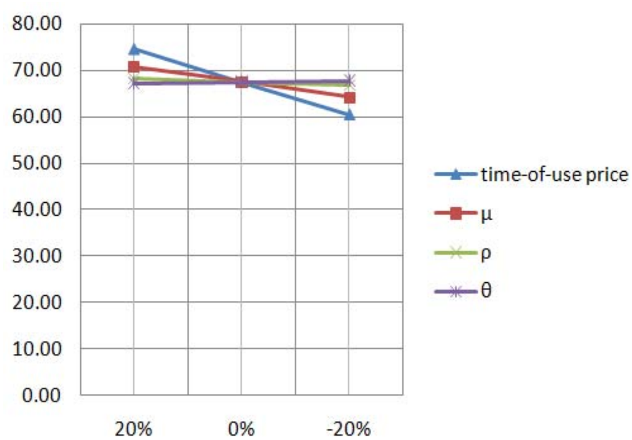

Figure 3. Sensitivity analysis of influencing factors on the impact of integrated billing model.

B. Comparison of Charging Costs for Different Charging Periods and Different Time Division Method of Time-of-Use Price

In order to verify the cost difference and influencing factors of the billing model in the system at different charge time, this paper takes a private car in the southern part of Hebei Province and Beijing city as an example. Based on the four-stage time-of-use electricity price of Hebei Province(Table 1), and the three-stage time-of-use electricity price of Beijing(Table 2), the charging costs are calculated.

TABLE I. THE FOUR-STAGE PEAK-VALLEY TIME-OF-USE PRICE

section	Critical peak period	Peak period	Flat period	Valley period
time	11:00-13:00; 16:00-18:00;	10:00-11:00; 13:00-16:00; 18:00-21:00;	7:00-10:00; 21:00-23:00;	23:00-7:00
charge electricity price(RMB/kWh)	0.9378	0.8255	0.6011	0.3767

TABLE II. THE THREE-STAGE PEAK-VALLEY TIME-OF-USE PRICE OF BEIJING

section	Peak period	Flat period	Valley period
time	10:00-15:00; 18:00-21:00;	7:00-10:00; 15:00-18:00; 21:00-23:00;	23:00-7:00
charge electricity price(RMB/kWh)	1.0044	0.6950	0.3946

Take two ordinary times as example: 9:30~10:30 and 22:30~23:30, assuming the car through the fast charge full of electricity with battery power of 41.4 kWh, fast charging time: 1 h, parking time :2h, Parking fees charged standard: the first 1 hours free of charge, more than 1 hours: RMB 3/h, bring into (7), the results are shown in Table 3. Charging service charge standard is 0.8 RMB/kWh.

TABLE III. COMPARISON OF COSTS IN DIFFERENT CHARGING PERIODS AND DIFFERENT TOU PRICE DIVISION METHOD

No.	Charging time	Section		Integrated Charging fee(RMB/kWh)	
		four-stage	*three-stage*	*four-stage*	*three-stage*
1	9:30~10:30	peak\ flat period	peak\ flat period	61.38	67.19
2	22:30~23:30	flat\valley period	flat\valley period	52.09	54.38

If you choose 22:30~23:30 charge, you'll save 9.29, 13.81 RMB than 9:30~10:30, obviously better than charging at the peak level. Table 3 show that the cost of flat-valley time section is respectively 24% and 18% lower than that of peak-bottom time section, and that will be greater between the charging time of the valley time and the peak time.

In table 3, we can see that the four-stage time-sharing type respectively saves 5.81 RMB and 2.29 RMB than the three-stage type during the 9:30~10:30 and 22:30~23:30 charging period. Obviously, the four-stage method has more influence on the integrated charging model than the three-stage method, and the optimized time-sharing section method can better guide the user time-sharing charging.

From the above analysis, we can note that differently divided methods of pricing are also for impact on integrated fee; optimal segment classification method is more economical.

V. CONCLUSION

This paper research on EV FCS's integrated billing model and use mobile terminals and mobile technology to build electric vehicle fast charge station intelligent billing and settlement system. Experiments show the billing and settlement system can better guide the orderly charging of electric vehicle users, and the billing model is effectively and economically. The system can be efficacious guide the electric car to complement the fast charging and mobile payment. The system enhances user satisfaction and EV FCS's intelligence level. The research in this paper will help to improve the operational efficiency and service capability of EV FCS, optimize the operation mode and the economic benefit of FCS.

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