Research on the Transmitting End Billing Mode and the Receiving End Billing Mode for Wirelessly Charged Electric Vehicles

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Abstract. In this paper, the pricing and transaction methods of wireless charging for electric vehicles are studied based on the two billing modes: transmitting side billing mode and receiving side billing mode. Two kinds of electric vehicle wireless charging service transaction methods are proposed: the power supplier directly trades with the user and the power supplier trades with the user through the intermediary. Aiming at the above two billing modes and trading modes, the corresponding pricing model and the price guiding strategy for charging mode selection for different charging users are proposed respectively, which provides a reference for the commercial operation billing mode of electric vehicle wireless charging.

1. Introduction

Today, the world is facing the problem of energy shortage and environmental pollution. Energy conservation and emission reduction is undoubtedly the direction of the future development of the automotive industry. Depends on its zero-emission advantage, electric vehicle is becoming an important solution towards today's energy and environmental problems [1-5]. At present, the most common energy replenishment methods for EVs are wired charging and battery swapping. In the traditional wired charging mode, the plugging at the charging interface generates an electric spark, which jeopardizes the safety of the equipment and the system, and accelerates the device loss. With the development of wireless charging technology, many countries have launched research on wireless charging technology for electric vehicles. Many electric vehicles in the world which use wireless charging have started small-scale operation [6-7]. As the research continues to deepen, the process of popularization of technology needs to continuously improve related supporting service. However, the research on the wireless charging billing mode of electric vehicles is almost blank. At present, research and practice on charging and billing services for electric vehicles are continuously carried out. Research on pricing and billing mode of electric vehicle wireless charging service can also refer to the experience of the existing EV charging facilities.

At present, the charging service pricing scheme adopted by the electric vehicle wired charging station mainly has the following four types, namely, the mileage billing mode, the charging amount billing mode, the charging time billing mode, and the battery group charging mode. The mileage
billing mode is actually to calculate the charging cost according to the mileage unit price after indirectly converting the charging amount into mileage. The charging amount billing mode is to calculate the charging fee according to the actual charging amount of the electric vehicle multiplied by the charging unit price. Charging time billing mode means that the fee paid by the user is fixed for every single charging [8]. Literature [9] proposed a billing mode for electric vehicle charging service based on the charging vehicle's battery SOC to set step tariff, which is beneficial to improve the service life of the battery pack and the economic efficiency of charging service. Literature [10] proposed an electric vehicle charging business model that promotes EV charging service by providing various power derivatives and value-added services that meet the needs of users. Literature [11] compared cost plus benefit pricing method and alternative energy pricing method from the perspective of user's withstanding ability, implementation difficulty and applicability of electric vehicle development in different periods. Literature [12] summarized the basic principles and major obstacles in the current formulation of charging policies for EV charging services. Combined with the characteristics of different charging stations, it proposes different charging station modes such as the Group's large-scale self-use charging stations, social public charging stations, and charging stations rebuilt from parking garages. According to literature [13], for the charging service, the charging amount billing mode is applicable to various types of vehicles and various types of charging and discharging methods. The mileage billing mode should be selectively adopted according to the model and the charging method. Literature [14] analyzed the construction of electric vehicle billing and related billing elements such as self-funded, preferential, product, and package. Literature [15] introduced the current status of EV charging services in China. Taking the fast-changing electric bus in the pilot city of “Ten Cities and Thousand Vehicles” as an example, the charging standard of charging service was calculated.

In this paper, transmitting side billing mode and receiving side billing mode for the EV wireless charging service are studied. At the same time, the corresponding price guiding strategies for public transportation users and private users are studied.

2. Modeling and analysis of charging mode

The EV wireless charging technology transmits the electric energy to the vehicle-mounted energy pick-up coil through the power supply coil buried under the ground in the form of a high-frequency alternating magnetic field, thereby supplying power to the vehicle-mounted energy storage device.

The circuit diagram of EV wireless charging system adopting the series compensation topology of the transmitting end and the receiving end is shown in Figure 1, where $U_{in}$ is the output voltage of the high frequency inverter power supply, $R_w$ is the internal resistance of the power supply, $R_T$ and $R_R$ are the internal resistance of transmitting side coil and the receiving side coil respectively. $L_T$ and $L_R$ are the inductance values of the transmitting side coil and the receiving side coil respectively, $C_T$ and $C_R$ are the compensation capacitance values of the transmitting side and the receiving side respectively, the mutual inductance between the two coils is $M$, and the resonant frequency of the system is $f$. The angular frequency is $\omega = 2\pi f$ and the expression of the compensation capacitor can be written as $C_T = \frac{1}{\omega^2 L_T}$ and $C_R = \frac{1}{\omega^2 L_R}$ respectively.
It can be deduced from the circuit theory that the equivalent circuit of the transmitting loop and the receiving loop of the circuit shown in Fig. 1 are shown in Fig. 2.

Where $Z_T$ is the impedance value of the transmitting loop, $Z_R$ is the impedance value of the receiving loop, $Z_{TR}$ is the equivalent impedance value of the receiving loop from the transmitting side, and $Z_{RT}$ is the equivalent impedance value of the transmitting loop from the receiving side. The expressions for the above parameters are as follows.

\[
\begin{align*}
Z_T &= R_T + j\omega L_T - j\frac{1}{\omega C_T} \\
Z_R &= R_R + j\omega L_R - j\frac{1}{\omega C_R} \\
Z_{TR} &= \frac{(\omega M)^2}{Z_R + R_L} \\
Z_{RT} &= \frac{(\omega M)^2}{Z_T}
\end{align*}
\]

(1)

(2)
energy emitting side, which is, the transmitting side billing mode; the other is to install the energy meter on the vehicle side, which is, the receiving side billing mode.

**Figure 3.** Schematic diagram of installation position of metering device for EV wireless charging.

The transmitting side billing mode facilitates the measurement of the total power consumption of the EV wireless charging system. When the EV wireless charging service objects are vehicles that are uniformly managed and used for public transportation, such as bus, shuttle bus, etc., the daily operation route, operation period, and power consumption of the vehicle are relatively fixed. In this case, we can choose transmitting side billing mode for the charging settlement.

The receiving side billing mode needs to install the metering device in the car in advance, and this charging mode can specifically charge the electric vehicle individually in the process of dynamic EV wireless charging. This billing mode is applicable to individual electric vehicle with different specifications and models to perform one-to-one electricity bill settlement when having dynamic wireless charging service.

Referring to Fig. 2 and Fig. 3, the power measurement positions of the two billing modes are as shown in Fig. 4.

**Figure 4.** Equivalent circuit of measurement positions of two billing modes of EV wireless charging.

The power measured by the transmitting side billing mode is the power transmitted by the transmitting coil, being transferred by the high frequency rectification from the AC source, and its expression can be written as

\[ P_{\text{t}} = \frac{U_{\text{t}}^2}{Z_\text{t} + Z_{\text{rec}}} \]  \hspace{1cm} (3)
The receiving side billing mode measures the power received by the load, and its expression is

$$P_{\text{out}} = \frac{(j\omega M \frac{U_m}{Z_T})^2}{(Z_R + R_L) + Z_{RT}} \cdot \frac{R_L}{(Z_R + R_L) + Z_{RT}}$$  \hspace{1cm} (4)

The efficiency expression of EV wireless charging is as follows

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{(\omega M)^2 \frac{R_L}{(Z_R + R_L) + Z_{RT}}}{(Z_R + R_L) + Z_{RT}} \times 100\%$$  \hspace{1cm} (5)

Compared with the wired charging method, the transmission efficiency of EV wireless charging is much lower, and the loss caused by the efficiency cannot be ignored in the billing process. If the unified charging unit price is used for wireless charging service settlement, no matter which charging mode is adopted, either the power supplier or the charging user must undertake the loss caused by the transmission efficiency. Combined with the above two types of billing mode, in order to offset the impact of the installation position of the metering device to the wireless charging process, this paper proposes a pricing model to ensure the operating profit of the power supplier.

3. Analysis of EV Wireless Charging Pricing Model

EV wireless charging transactions can be carried out directly between the grid and the owner of the charging user. The grid and the owner can also conduct indirect transactions through an intermediary that provides wireless charging services. Considering the transmission power of wireless charging and the characteristics of charging system operation, in this paper we use charging amount billing method for the billing of EV wireless charging, and the specific analysis is as follows.

3.1. Direct transaction between the grid and the user

When the grid directly deals with the user, the unit price of charging service must be determined to ensure the profit of the supplier. The product of the unit price of the wireless charging service and the quantity of electricity measured by the metering device shall be equal to the product of the unit price of the grid side and the amount of power supplied.

When using the transmitting side billing mode for charging settlement,

$$C_1 \cdot \frac{a}{\eta} = C \cdot \frac{a}{\eta} \cdot (1 + m)$$

$$C_1 = (1 + m) \cdot C$$  \hspace{1cm} (6)

Where $C_1$ is the unit price of the transmitting side billing mode when the grid directly deals with the user, $C$ is the cost unit price, $a$ is the total charge amount of EV, and $m$ is the operating margin of the power supply side.

Similarly, in this case, the unit price expression of the receiving side billing mode is

$$C_2 = \frac{(1 + m)}{\eta} \cdot C$$  \hspace{1cm} (7)

When the grid directly transact with the user, the total charging cost of transmitting side billing mode is defined as $W_1$, and the total charging cost of the receiving side billing mode is defined as $W_2$, then
\begin{align}
W_1 &= C_1 \times \frac{a}{\eta} = \frac{(1+m)}{\eta} \cdot C \cdot a \\
W_2 &= C_2 \times a = \frac{(1+m)}{\eta} \cdot C \cdot a
\end{align}
(8)

3.2. Indirect transaction between the grid and the user through intermediaries
When the grid indirectly deals with the user through intermediaries, the unit price of charging service must be determined to ensure the profit of both the grid and the intermediary. The product of the unit price of the wireless charging and the amount of electricity measured by the metering device shall be equal to the product of the power supply side power price and the power supply amount after adding the operating profit of the grid and the intermediary.

When using the transmitting side billing mode for charging settlement,
\begin{align}
C_3 \cdot \frac{a}{\eta} &= C \cdot \frac{a}{\eta} \cdot (1+m)(1+n) = \frac{(1+m)(1+n)}{\eta} \cdot C \cdot a \\
C_3 &= (1+m)(1+n) \cdot C
\end{align}
(9)

Where \( C_3 \) is the unit price of the transmitting side billing mode when the grid indirectly deals with the user through the intermediary, \( n \) is the operating margin of the intermediary.

Similarly, in this case, the unit price expression of the receiving side billing mode is
\[ C_4 = \frac{(1+m)(1+n)}{\eta} \cdot C \]
(10)

When the grid indirectly transact with the user through the intermediary, the total charging cost of transmitting side billing mode is defined as \( W_3 \), and the total charging cost of the receiving side billing mode is defined as \( W_4 \), then
\begin{align}
W_3 &= C_3 \times \frac{a}{\eta} = \frac{(1+m)(1+n)}{\eta} \cdot C \cdot a \\
W_4 &= C_4 \times a = \frac{(1+m)(1+n)}{\eta} \cdot C \cdot a
\end{align}
(11)

4. Price guiding strategy that affects user’s selection of billing mode
It can be seen from the above analysis that whether the grid deals with the user directly or indirectly, although the charging unit price of the transmitting side charging mode and the receiving side charging mode differs due to the difference in system charging efficiency, The total charging cost of the two billing mode above are actually the same. Therefore, the user's selection towards billing mode can be guided by re-adjusting the charging unit price.

For the case where the grid directly deals with the user, in order to guide users to make a choice between the two charging modes by adjusting the charging price, it is necessary to simultaneously display a certain price advantage in both the unit price and the total price of a certain mode. Therefore, here we consider multiplying the charging unit price by a single adjustment factor for price adjustment.

For public transport vehicles with uniform specifications and unified management, it is more time-saving and labor-saving to uniformly conduct the billing at the transmitting side. On the premise of
ensuring the profit on the grid, consider multiplying $C_2$ by an adjustment factor $k_1$. The adjusted receiving side billing unit price $C_2'$ and total price $W_2'$ are as follows.

$$
\begin{align*}
C_2' &= \frac{(1 + m) \cdot k_1}{\eta} \cdot C \\
W_2' &= C_2' \cdot a = \frac{(1 + m) \cdot k_1}{\eta} \cdot C \cdot a
\end{align*}
$$

(12)

By multiplying the adjustment factor, let

$$
\begin{align*}
C_1 < C_2' \\
W_1 < W_2'
\end{align*}
$$

(13)

We can know that the requirement for the adjustment factor $k_1$ is

$$
k_1 > 1
$$

(14)

For private EV users, the difference in EV model specifications and charging habits makes the one-to-one receiving side billing method more suitable. After considering multiplying $C_2$ by an adjustment factor $k_2$, the adjusted transmitting side billing unit price $C_1'$ and total price $W_1'$ are as follows.

$$
\begin{align*}
C_1' &= (1 + m) \cdot k_2 \cdot C \\
W_1' &= C_1' \cdot a = \frac{(1 + m) \cdot k_2}{\eta} \cdot C \cdot a
\end{align*}
$$

(15)

By multiplying the adjustment factor $k_2$, let

$$
\begin{align*}
C_1' > C_2 \\
W_1' > W_2
\end{align*}
$$

(16)

We can know that the requirement for the adjustment factor $k_2$ is

$$
k_2 > \frac{1}{\eta}
$$

(17)

For the case where the grid transact with users through the intermediary indirectly, under the premise of ensuring the profit on the power supply side, the price guidance can be realized by adjusting the service selling profit of the intermediary. The intermediary's profit margins of the transmitter-side billing mode and the receiver-side billing mode are respectively set to $n_1$ and $n_2$, the adjusted transmitting side billing unit price $C_3'$ and total price $W_3'$, receiving side billing unit price $C_4'$ and total price $W_4'$ are as follows.
According to the above price guiding strategy, when the charging vehicles are mainly public transportation, in order to guide the users to select transmitting side billing mode for settlement, the charging unit price and the total price of the transmitting side billing mode can be adjusted to be smaller than those of the receiving side billing mode by adjusting $n_1$ and $n_2$. The relationship between $n_1$ and $n_2$ is

$$n_1 < n_2$$

(19)

On the contrary, when the charging vehicles are mainly private cars, in order to guide the users to select receiving side billing mode for settlement, the relationship between $n_1$ and $n_2$ should be

$$n_1 + 1 > \frac{1}{\eta}(n_2 + 1)$$

(20)

The charging price adjustment method for different guiding objects under different trading modes is shown in Table 1.

| Trading mode                           | Charging user         | Adjustment method     |
|----------------------------------------|------------------------|-----------------------|
| the grid directly deals with the user  | EV for public transportation | $k_1 > 1$            |
|                                        | Private EV             | $k_2 > \frac{1}{\eta}$ |
| the grid indirectly deals with the user through intermediaries | EV for public transportation | $n_1 < n_2$          |
|                                        | Private EV             | $n_1 + 1 > \frac{1}{\eta}(n_2 + 1)$ |

In summary, the price guiding strategy proposed in this paper is to raise the charging price of the opposite billing mode and guide the user to select the billing mode suitable for themselves on the premise of ensuring the profit of the power supplier.

5. Case analysis
The following is for the above price guiding strategy to bring in relevant data for analysis, the specific parameter settings are shown in Table 2.
Table 2. Related parameters.

| Parameter | Parameter description | Value       |
|-----------|-----------------------|-------------|
| C         | Cost charging price   | 0.5 yuan/kWh|
| a         | Total charging amount of EV | 50kWh |
| η         | Wireless charging efficiency of EV | 80% |
| m         | Operating profit margin of the grid | 50% |
| n₁        | The intermediary's profit margins of the transmitting side billing mode | 0~100% |
| n₂        | The intermediary's profit margins of the receiving side billing mode | 0~100% |

Bring the parameters in Table 2 into equations (6) to (12), when the grid transacts with users directly, the relationship of the unit price and the total price of EV wireless charging service with the change of price adjustment coefficient $k₁$ under the circumstance of the price guidance is for the transportation users is shown in Fig.5.

![Figure 5](image)

**Figure 5.** The unit price and total price of wireless charging for public transportation users under the direct transaction situation between the grid and the user with the change of $k₁$.

It can be seen from Fig. 5 that in the case of the grid transacts directly with the users, when $k₁ > 1$, $C₁ < C₂$ and $W₁ < W₂$, can be realized at the same time, that is, the unit price and the total price of the transmitting side billing mode are lower than those of the receiving side billing mode.

When the grid transacts with users directly, the relationship of the unit price and the total price of EV wireless charging service with the change of price adjustment coefficient $k₂$ under the circumstance of the price guidance is for the private EV users is shown in Fig.6.
Figure 6. The unit price and total price of wireless charging for private EV users under the direct transaction situation between the grid and the user with the change of $k_2$.

It can be seen from Fig. 6 that in the case of the grid transacts directly with the users, when $k_2 > 1/\eta$, $C_2 < C_1'$ and $W_2 < W_1'$ can be realized at the same time, that is, the unit price and the total price of the receiving side billing mode are lower than those of the transmitting side billing mode.

Bring the parameters in Table 2 into equations (18), when the grid transacts with users indirectly through the intermediary, the relationship of the unit price and the total price of EV wireless charging service with the change of the ratio of $n_1$ and $n_2$ under the circumstance of the price guidance is for the transportation users is shown in Fig.7.

Figure 7. The unit price and total price of wireless charging for public transportation users under the indirect transaction situation between the grid and the user with the change of the ratio of $n_1$ and $n_2$.

It can be seen from Fig. 7 that in the case of the grid transacts indirectly with the users, when $n_2 < 1$, $C_3 < C_4'$ and $W_3' < W_4'$ can be realized at the same time. That is, the unit price and the total price of the transmitting side billing mode are lower than those of the receiving side billing mode.

When the grid transacts with users indirectly, the relationship of the unit price and the total price of EV wireless charging service with the change of the ratio of $n_1 + 1$ and $n_2 + 1$ under the circumstance of the price guidance is for the private EV users is shown in Fig.8.
Figure 8. The unit price and total price of wireless charging for private EV users under the indirect transaction situation between the grid and the user with the change of the ratio of $n_1 + 1$ and $n_2 + 1$.

It can be seen from Fig. 8 that in the case of the grid transacts indirectly with the users, when $n_1 + 1 > \frac{1}{\eta}$, $C_4' < C_3'$ and $W_4' < W_3'$ can be realized at the same time. That is, the unit price and the total price of the receiving side billing mode are lower than those of the transmitting side billing mode.

The above conclusions are consistent with the results derived from the formula, which verifies the correctness of the aforementioned price guiding strategy.

6. Conclusion

This paper studies the two billing modes of transmitting side and receiving side charging for EV wireless charging. Under the premise of ensuring the operating profit of the power supplier, the wireless charging pricing model is developed for the direct transaction between the power supplier and the user and the indirect transaction of the power supplier through the intermediary and the user. The price guidance strategy for public transportation vehicle users and private car users is proposed. The correctness of the strategy is verified by an example, which provides a way of thinking for the commercial operation charging method of electric vehicle wireless charging.

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