A Survey of Charging Prices for Electric Vehicles

Zhe Zhou[a], Kai Zhang[a,b,*], Zhiheng Li[b], Yuping Lin[a], Qinglai Guo[a,c], Hongbin Sun[a,c,*]

[a]Tsinghua-Berkeley Shenzhen Institute (TBSI), Shenzhen 518055, Guangdong, China
[b]Research Center for Modern Logistics, Graduate School at Shenzhen, Tsinghua University, Shenzhen 518055, China
[c]Department of Electrical Engineering, State Key Laboratory of Power Systems, Tsinghua University, Beijing 100084, China

Abstract

The transportation industry is developing toward sustainability and intelligence, leading to the increasing popularity of electric vehicles. The price of electricity, which acts as the core mechanism of the modern power market, will directly influence the economic benefits provided to both car owners and charging stations. Therefore, this paper investigates power tariff policies in selected countries and the current implementation status of charging prices. The relationship between differences in charging price and the popularity of electric vehicles is also examined, and price-setting methods and research related to power tariffs are summarized. Finally, the paper investigates future possibilities for the profit patterns of charging station operators and topics of particular interest to researchers.

Keywords: Charging price; Electric vehicles; Power tariff; Service fee; Time-of-use price (TOU) price; Peak–valley price

* Corresponding authors.
Kai Zhang E-mail address: zhangkai@sz.tsinghua.edu.cn; Tel.: 0755-26036078
Present address: Graduate School at Shenzhen, Tsinghua University, Shenzhen 518055, China
Hongbin Sun E-mail address: shb@tsinghua.edu.cn; Tel.: +86-10-6278-3086 (ext. 803); Fax: +86-10-6278-3086 (ext. 800)
Present address: Department of Electrical Engineering, Tsinghua University, Beijing 100084, China

1. Introduction

With the conflicts between environmental protection and economic development growing increasingly acute, the development of methods for energy conservation and decreasing human reliability on fossil fuel are urgent tasks. Electric vehicles (EVs) are partially or entirely propelled by electricity, which can achieve zero-emission status, thus being an efficient method for solving environmental, energy, and transportation problems[1][2].

In 2015, a record high of nearly 1.26 million EVs were in use worldwide. This extraordinary milestone was the result of joint efforts by governments and industry over the past decade. Electric car production doubled between 2014 and 2015; in 2005, electric cars numbered only in the hundreds[3].

An efficient interest-generating mechanism is the key to the marketization of EVs. In addition to government subsidies, charging price is a principal means of regulation, linking the interests of car owners, charging stations, and load serving entities[4]. Charging price plays a key role in guiding consumption trends, regulating the balance of supply and demand, optimizing resource allocation, and improving social and economic benefits.

This paper focuses on current power tariff policies and their implementation statuses. Differences in charging price and the resulting popularity of EVs are also compared. Price-setting methods and research work related to power tariffs are summarized. Finally, this paper examines future possibilities for the profit patterns of the operators and topics of interest to researchers.

2. Power Tariff Policy

The power tariff is the core indicator of operation status and the efficiency of market competition, and is also the basis for decision-making in the power market. At the early stage, the social benefits of developing EVs outweigh the economic benefits. Therefore, government plays a decisive role in promoting the early development of EVs. Setting charging prices and determining supporting policies is a complex process. Multiple factors should be considered when balancing the profit distribution between charging station operators and car users[5][6].

The development of EVs typically begins earlier in developed countries, and can be measured in three main dimensions: financial support, policy incentives, and administrative regulations. British EV usage, for example, has a history of over 50 years. The British government has invested more than £20 million in the development of EVs. Preferential treatment is provided to EV users, including half-price electricity at night and exemption from the license tax and road maintenance fees. Other countries such as the United States, France, and Japan have instituted similar measures.

2.1. *Power Tariff Policies in China*

In the 13th Five-Year Plan, the Chinese government included an ambitious strategy to promote the production of 5 million EVs by 2020. In 2015, China became the main market for EVs, surpassing the United States. China is also the largest market for electric two-wheelers and electric buses. Over 170,000 electric buses have already been produced[3].

In China, the administrative authority for power tariffs belongs to the National Development and Reform Commission (NDRC). The price standard is set by the government according to uniform policies and gradation administration. According to NDRC regulations, charging stations can require customers to pay electricity and service fees, using them for price leverage. The goal of this policy is to ensure that the cost of using EVs is much lower than that of gasoline-powered vehicles, thus strengthening the competitiveness of EVs.

Charging-related power tariffs in the current Chinese electricity pricing system include a one-part tariff, two-part tariff, and time-of-use price. The two-part tariff is divided into the basic tariff (fixed cost) and one-part tariff (variable costs proportional to power consumption), and adopts the standards of the large industrial tariff.

The commercial, centralized charging and swapping infrastructures that directly report installation to the load serving entities implement the large industrial tariff. The basic tariff will not be charged before 2020. Additionally, the time-of-use (TOU) price is applicable to these facilities.

Numerous provinces and cities have determined their own tariff standards on the basis of state regulations. The electricity component of the tariff follows national standards. A service fee with an upper limit set by the central government is charged to offset the operational costs of this form of infrastructure.

The following Table 1 summarizes the upper limits of the service fees set by the provincial or municipal administrations in selected provinces and cities.

Table 1

Upper Limits of Service Fees in Selected Provinces and Cities

Regions	Upper limit of the service fee		Release/
	Passenger Vehicle	Bus	execution date
Jiangxi	2.36RMB/kWh (Including electricity fee)	1.36RMB/kWh (Including electricity fee)	2014-12-05
Cangzhou	1.6 RMB/kWh	0.6 RMB/kWh	2015-05-21
Wuxi	1.47 RMB/kWh	1.19 RMB/kWh	2016-03-08
Nanjing	1.44 RMB/kWh	1.23 RMB/kWh	2015-06-29
Suzhou		1.21 RMB/kWh	2016-01-10
Guangdong	1.2 RMB/kWh no parking charge	0.8 RMB/kWh	2016-01-04
Foshan	1.2 RMB/kWh	0.7 RMB/kWh	2015-01-01
Tianjin	1.0 RMB/kWh	0.60 RMB/kWh	2015-06-15
Hefei	DC 0.75 RMB/kWh AC 0.53 RMB/kWh	0.53 RMB/kWh	2015-11-19
Huizhou	0.75 RMB/kWh	Proper discount	2015-01-22
Qingdao	0.65 RMB/kWh	0.60 RMB/kWh	2014-06-01
Dalian	0.65 RMB/kWh	0.4 RMB/kWh	2015-08-01
Taiyuan	0.45 RMB/kWh	Announced later	2016-02-06
Dezhou	0.55 RMB/kWh	0.50 RMB/kWh	2016-02-04
Xi’an	0.40 RMB/kWh	0.35 RMB/kWh	2016-04-10
Beijing	Not exceed 15% of 92 petrol retail price per liter/kWh		2015-06-01
Chongqing	Not exceed 50% of the electricity tariff/kWh		2016-01-05
Suzhou	1.66 RMB/kWh		2016-07-01
Shanghai	1.6 RMB/kWh		2015-07-01
Jinan	1.45 RMB/kWh		2015-02-05
Xiamen	1.2 RMB/kWh		2015-11-18
Shenzhen	1.00 RMB/kWh		2016-01-01
Zhuhai	1.00 RMB/kWh		2015-12-15

Wuhan	0.95 RMB/kWh	2015-06-29

Standards are shown to vary in different regions. The lowest service fee standard is currently maintained by Xi'an City.

2.2. *Power Tariff Policies in the United States*

U.S. power tariffs are currently divided according to residential, commercial, industrial, and transportation sectors. Each sector has different price standards that are set by each state and vary with time (usually monthly). Generally, the industrial sector has the lowest tariffs and the residential sector has the highest. The following Fig. 1 displays the average prices of all sectors in July 2016[7].

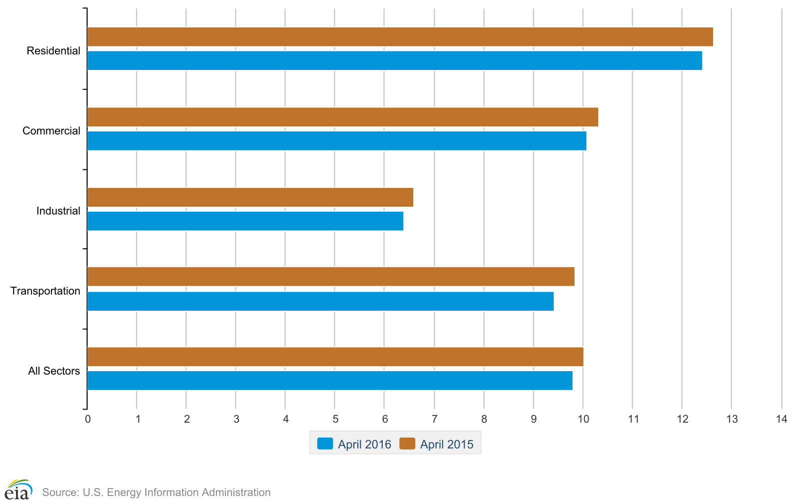

Fig. 1. Average U.S. Electricity Price for Ultimate Customers by End-Use Sector, (Cents per kWh)

Usually, home charging is covered by the standards of the residential sector, and public charging operators have the right to choose the prices they charge.

3. Charging Price

3.1. *Charging Prices of Chinese Operators*

National regulations enable charging operators to benefit from electricity and service fees. Customers are often required to pay parking fees to operators as well.

For example, charging operators in Shenzhen publish prices through a smart phone app called Charging Post. Various operators charge slightly different electricity, service, and parking fees. For example, parking fees can be categorized into three types: free of charge, fixed price per hour, and variable price per hour. The concrete charging standards are summarized as follows in Table 2.

Table 2

Charging Prices Of Different Operators in Shenzhen

Categories	Price		
Parking Fee	Free	Fixed price/hour	Variable price/hour
Service Fee	Free	Fixed price/kWh	
Electricity Fee	Free	Fixed price/kWh	Peak-valley Price/kWh

The following Table 3 lists the specific charging rates of selected operators in Shenzhen in January 2016.

Table 3

Specific Charging Rates of Selected Operators in Shenzhen

Charging Stations	Parking Fee	Service Fee	Electricity Fee
Yiwei Energy Station	5 RMB for the first hour, later 1RMB/h	0.45 RMB/kWh	1.1 RMB/kWh
Zhuoyue City Station	15 RMB/h	0.45 RMB/kWh	1 RMB/kWh
Denza DC station	15 RMB/h	0.45 RMB/kWh	50 RMB once
Haisong Mansion Station	5-15 RMB/h	0.45 RMB/kWh	1.1 RMB/kWh
Denza Shuibei Jewelry Station	10 RMB/h	Free	Free
Xili Gym Center Ancillary Building Station	5 RMB/h	0.45 RMB/kWh	1.1 RMB/kWh
Keyuan South Bus terminus Station	5 RMB/h	1 RMB/kWh	1 RMB/kWh
Keyuan Community Parking Station	5 RMB/h		Peak-Valley price
Yujin Residence Station	5 RMB/h	0.45 RMB/kWh	1 RMB/kWh
Shenzhen Civic Center Station	5 RMB/h	Free	Free
EV Huilong Garden Station	5 RMB/h		1.55 RMB/kWh
Longhua Power Supply Station	\		1.1 RMB/kWh
Minle Traffic Facility Public Parking Station	Free	Free	Free

Shenzhen Vehicle Administration Station	Free	Free	Free
BYD Baolong Station	\		BYD Free

3.2. *Charging Prices of U.S. Operators*

In the United States, differences in electricity prices are much greater than those of gasoline prices. For example, driving a 2013 Nissan Leaf in Washington costs $25 for 1,000 miles, whereas in Hawaii, the same distance costs $107[8][9].

Among the 50 states and Washington, DC, Hawaii charges the highest retail price for electricity, 27.35 cents/kWh. Connecticut is second, charging 20.84 cents/kWh. The state with the lowest retail residential price is Louisiana, at 9.14 cents/kWh, approximately one-third of that in Hawaii.

The following Fig. 2 geographical image represents electricity prices for ultimate customers in the residential sector in February 2016[10].

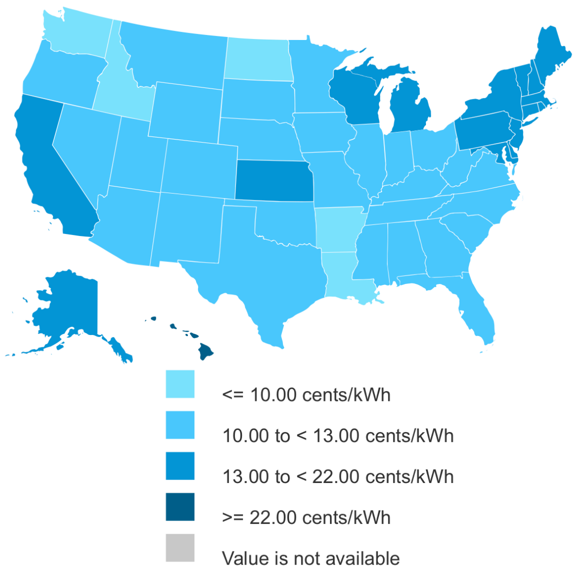

Fig. 2. Geographical Distribution of Residential Electricity Prices in February 2016

The following Table 4 lists electricity prices in the residential sector in selected states in February 2016, ranked in descending order[10].

Table 4

Average Residential Electricity Prices, February 2016 (cents/kWh)

Rank of Electricity Price	States	Average Retail Price of Electricity to Residential Sector (cents/kWh)

1	Hawaii	27.35
2	Connecticut	20.84
3	Alaska	20.06
4	Massachusetts	19.84
10	New York	16.89
15	Pennsylvania	14.06
20	Illinois	12.56
30	Texas	11.25
40	Utah	10.67
50	Washington	9.22
51	Louisiana	9.14

3.3. *Charging Prices of Worldwide Operators*

ChargePoint, established in the United States in 2007, is the largest and most open EV charging network worldwide. It has established more than 70% of the public charging posts in America, of which 60% provide free charging services. At present its business has expanded to Canada, Australia, and countries in Europe, the Middle East, and Africa. ChargePoint creates profits by selling charging posts to businesses, usually shopping malls, supermarkets, and hotels. They attract customers by offering free charging services, thus forming a profit-sharing mechanism[11].

ChargePoint has also launched the "Net+" plan for purchasing charging posts. Buyers are only required to pay a small fee at first usage, and the remaining cost is covered by operating revenue. Purchasers have the right to operate on their own terms, choosing whom to serve and what charging price to set. Currently, the average charging fee is $2/hour, much higher than the price of home charging, which is less than $1/hour[12][13].

In Japan, electric charging stations already outnumber gasoline filling stations. These charging stations are run by Nippon Charge Service, and can be used by all EVs in the Japanese market. Charging prices differ for members and nonmembers. For the membership, the higher the level, the lower the costs for EV owners. Nonmember fees are structured hierarchically. A fixed cost applies to the first 15 minutes, with a cost of 2.5 yen/minute thereafter. To fully charge a Volkswagen e-up! costs approximately 1013 yen(67 RMB). Though this price is relatively high, the system includes advantages such as convenient payment and wide network coverage[14][15].

In Europe and Britain, the energy provider Ecotricity, which provides the most widespread highway charging network, cancelled its free fast charging service in 2016. Customers will be charged £5 for each use, which is still much lower than the cost of filling the tank of a gasoline-powered car. This network is still provided free of charge to households[16].

Norway is the friendliest country for plug-in cars; Oslo is sometimes referred to as the "capital of EVs." Norway is almost fully reliant on hydropower to generate its electricity, which costs only €0.05 per kWh. Norwegians who drive EVs enjoy preferential measures such as free charging stations and exemption from road maintenance fees. These policies have caused the scale of EVs to exceed the desired volume, resulting in traffic jams and queuing at charging stations[17][18].

3.4. *Economic Comparisons in the United States*

On average, driving an EV costs approximately half as much as driving a gasoline-powered vehicle in the United States. According to data from the U.S. Energy Information Administration, the average cost of 1 gallon of gasoline is $2.70, and the average price of residential electricity is $0.11. For example, fully charging a Nissan Leaf costs $2.75 and will cover 100 miles. The same distance using a gasoline-powered vehicle is $9.00, assuming that 1 gallon will cover 30 miles. Charging is therefore the more economical option. In addition, because the charging period can be chosen with flexibility, customers can choose to charge during valley periods to cut expenses[19][20].

Table 5 provides data on the varying costs of fueling a vehicle with electricity compared to a similar vehicle that runs on gasoline[21]. States are listed according to their rank in Table 4.

Table 5

Fuel Cost Comparison for Gasoline-Powered Vehicles and EVs in the United States (July 2016)

Area	Regular Gasoline	Electric eGallon
US Average	2.25	1.13
Hawaii	2.50	2.45

Connecticut	2.28	1.92
Alaska	2.50	1.88
Massachusetts	2.25	1.88
New York	2.35	1.58
Pennsylvania	2.27	1.30
Illinois	2.15	1.16
Texas	2.06	1.03
Utah	2.29	0.97
Washington	2.64	0.85
Louisiana	2.04	0.83

*eGallon: An eGallon represents the cost of driving an electric vehicle the same distance a gasoline-powered vehicle could travel on 1 gallon of gasoline.

Although the actual costs of electricity and gasoline vary in different states, the cost of driving EVs is shown to be consistently cheaper than driving gasoline-powered vehicles.

4. Charging Price Research

Charging price is directly related to the benefits allocated to charging stations and EV owners, and is thus crucial to the development of the EV industry [22]. To date, a large body of research has been conducted on charging price. These studies can be roughly divided into the three types: price setting, TOU and peak–valley prices, and the application of game theory and interaction mechanisms.

4.1. *Price-setting Methods*

One of the main challenges encountered by charging providers is the establishment of a suitable price for supporting long-term survival and development. This concern is crucial to the marketization of EVs and the interests of customers, charging stations, and load serving entities.

Price setting mainly involves forward and backward pricing. Forward pricing uses the cost of gasoline as a benchmark and obtains a discount on conventional costs. This method is usually applied in electric buses. By contrast, backward pricing calculates the construction and operation costs, adds them to the basic tariff, and multiplies the result by the rate of return. Compared with forward pricing, backward pricing is more effective for the development of EVs and infrastructure planning, and is a commercialized pricing method applicable to private operators.

Most customers are realistic and rational, and consider cost effectiveness when comparing the costs of using EVs and gasoline cars, thus forming individual expectations toward EVs. The following formula evaluates consumer expectations of price in RMB[23].

$$K(X_1 \cdot Y_1) \geq (X_2 \cdot Y_2)$$

$X_1(L)$:fuel consumption per hundred kilometers;	$Y_1(RMB/L)$:price of fuel;
$X_2(kWh)$: electricity consumption per hundred kilometers□	$Y_2(RMB/kWh)$:service fee;
K:within 0～1 , consumer expectation coefficient;	

This formula indicates that consumers will only choose EVs when the cost of EV is less than or equal to the product of the consumer expectation coefficient and the total fuel cost of gasoline-powered cars.

The values of X_1 for passenger vehicles and conventional buses are often approximately 7 L and 45 L, respectively. Typical values of X_2, Y_1 for passenger vehicles and conventional buses are approximately 14 kWh and 120 kWh and 7–8 RMB/L and 6–7 RMB/L, respectively. The following Table 6 was obtained using different values of consumer expectations.

Table 6

Service Fees Under Different Values of the Consumer Expectation Coefficient

Value of K	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Passenger vehicle	2.8-3.84	2.45-3.36	2.1-2.88	1.75-2.4	1.4-1.92	1.05-1.44	0.7-0.96	0.35-0.48
Bus	1.44-2.24	1.26-1.96	1.08-1.68	0.9-1.4	0.72-1.12	0.54-0.84	0.36-0.56	0.18-0.28

The expected service fees for buses are clearly much lower than those for passenger vehicles. However, the carrying capability of electric buses is usually less than that of traditional buses, leading to increased costs for bus companies and contributing to corporate losses.

4.2. *Time-of-Use Price and Peak–Valley Price Difference*

High market penetration of EVs can cause considerable damage to the power grid, such as increasing power losses and peak–valley differences and decreasing equipment life span[24]. By studying TOU and peak–valley prices, some researchers have determined the response of charging loads to prices and have used these findings to structure vehicles on the volume and time for charging. These procedures can alleviate the negative effects of large-scale random charging of EVs.

Researchers have also found that increasing numbers of EVs increase the potential of electricity prices to guide customer decisions. Optimal charging decisions made by price-sensitive consumers can help flatten the load curve and effectively guide EV use[24].

The stochastic movement of EVs also influences the effects of price control. Zhong W et al. used neurodynamic programming to manage this problem and obtain the optimal price policy[25]. Neurodynamic programming solves the problem of a limited energy supply available for charging by applying adaptive price controls.

Price controls can also be applied in both unidirectional and bidirectional charging. Stoeckl G et al. introduced a charging simulation model, in which EVs can be charged with low-price electricity (unidirectional price control) and feed back the energy when the price is high (bidirectional price control) [26].

4.3. *Game Theory and Interaction Mechanisms*

Numerous studies have focused on quantitative analysis of charging prices using sensitivity analysis and game theory, with the goal of determining the main factors related to charging price and establishing a sensitivity analysis model. The acceptable price intervals for stakeholders are then provided according to game analysis. This method has enabled the maximization of profit and utility, providing a reference for EV promotion[27].

Additional methods used for charging and pricing are described as follows. In [27], hierarchical game frameworks were applied; at the lower level, charging stations were chosen according to price and delay time, whereas at the upper level, optimal charging price was obtained to maximize station revenue. In [28], which involved the multi-leader multi-follower Stackelberg game model, the charging stations (leaders) announced their charging prices in Stage I, and the Plug-in EVs (followers) selected charging stations in Stage II. A low-complexity algorithm was used to compute the pricing equilibrium and the subgame perfect equilibrium with no information exchange. In [29], the bidding pricing strategy was used to broadcast a charging price list to EV users through a mobile app. EV drivers could submit their price preferences and travel schedules to simultaneously estimate their energy consumption and minimize charging costs.

4.4. *Conclusion*

Research related to charging prices has been increasing in recent years, because the optimal setting of charging prices is of great importance to EV development and popularization. Optimal charging prices can structure charging schedules and flatten the load curve to achieve maximization of profit and utility. Therefore, related research will be critical as the market penetration of EVs increases and the electricity market continues to develop.

5. Prospects for Future Profit Patterns

5.1. *Key Problems for Charging Price Development*

To popularize EVs, the cost of electric vehicles must be considerably lower than that of gasoline-powered vehicles. High service fees will certainly reduce willingness to purchase EVs, which will in turn discourage charging operators from expanding their services. Therefore, charging fees cannot be the main source of revenue and other methods should be explored[30]. In China, for example, service fees will be opened to the market when EVs have gained a certain market share and remain relatively competitive in the transportation market, according to NDRC regulations. Currently, the cost of one charging post is approximately RMB 40–50,000. If the number of EVs reaches 5 million by 2020, the annual consumption of electricity will be 16 billion kWh[31]. Under these circumstances, cost recovery will require 3–5 years if solely dependent on service fees, which is an exceptionally low level of revenue for investors.

Therefore, new opportunities must be explored for future profit patterns. New technology could enable more interesting mechanisms to be explored for the achievement of long-term interest.

5.1.1. The Extension of Charging Services

The unavoidable waiting time involved in charging EVs creates a wide range of business possibilities. Services using charging apps can provide relevant advertisements such as those for auto sales, auto products, and insurance. Apps can even provide social functions, pay for charging their cars, and also function as a portal to online shopping sites to promote online shopping sites.

In addition, a charging ecosphere around charging stations can be established to provide a full service network. Convenience stores, motels, cafeterias, and amusement parks are all potential sites for widening the industry chain through factories, consumers, and charging stations.

5.1.2. Big Data and Internet Concepts

Charging operators can begin by establishing charging networks and combine online auto sales, auto repair data services, and payment and industrial big data to create charging ecosphere companies.

Online apps, charging networks, selling power, and offline charging facilities can connect people, vehicles, and charging stations to provide high-quality, targeted, and specialized services and improve competitiveness[30].

6. Conclusion

This paper summarizes power tariff policies for charging electric vehicles and their current implementation status, as well as comparing market- and policy-influenced differences in charging price and the resulting popularity of EVs. This paper also discusses the methods used for price setting in this context. The limited profitability of service fees indicates that other value-added services should be explored. The expansion of EV marketization, competitive mechanisms, and diversified services will play increasingly crucial roles in the automobile industry.

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