A Review of the Progress of Electricity Price and Market Mechanism for Vehicle-grid Integration in China

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Abstract. Electric vehicles (EVs) are characterized by flexibility, which could be exploited by electricity prices and market. In recent years, demonstration pilots for vehicle-grid integration (VGI) have been launched in some provinces and cities in China, which shows the technical potential of VGI. In this article, the charging time-of-use (ToU) tariff is examined in various provinces and cities in China firstly. Then, the participation of EVs in the electricity market in typical regions in China is researched. Finally, based on the analysis, outlook and suggestions are put forward to help address the growing need for VGI in China.

Keywords. vehicle-grid integration (VGI); time-of-use (ToU) tariff; electricity market; demand response; ancillary services**.**

1 Introduction

EVs have been characterized as a "movable energy storage" with shiftable charging time and various charging locations, which can provide the power system with large-scale time-space flexibility [1]. It is estimated that in 2040, the capacity of EVs will reach 2.9 billion to 3.5 billion kW, which is approximately half of the non-fossil installed capacity in that year [2]. However, the large-scale integration of EV charging systems with power grid poses challenges for grid management due to the demand for electrical energy [3].A large number of simultaneous events related to battery charging can increase demand peaks and lead to overload, thus affecting the quality and reliability levels of the grid [4][5].

VGI is a key driver to adapt to the large-scale development of EVs and enhance the stability of high-penetration renewable generation. It is expected to play an important role in the low-carbon transition of global transportation and electricity, which attracts the attention from both the international pioneering regions and the Chinese government. In October 2020, the State Council officially released the "New Energy Vehicle Industry Development Plan (2021-2035)" [6], which explicitly proposed to integrate transportation and energy, and subsequently issued a carbon peak action plan and a number of related industry policies. They all proposed to encourage applications of VGI.

MSIEID 2023, December 08-10, Guangzhou, People's Republic of China

DOI 10.4108/eai.8-12-2023.2344689

In this article, the VGI-related electricity price and market mechanism in China are scrutinized, and the income of each entity participating in market transactions is analyzed. Based on the analysis of the electricity market, suggestions for the development of VGI-related electricity price and market mechanism are put forward to incentivize EVs' participation in VGI and load aggregation. Meanwhile, it can also provide more abundant, economical and efficient control resources for power grid regulation and operation, improve reserve capacity and emergency response capabilities, accelerating the building of a new power industry.

2 Price mechanism for VGI in China

The official release of the "Several Opinions on Further Deepening the Reform of the Electric Power System (Zhongfa [2015] No. 9)" issued by the Central Committee and the State Council in 2015 marked that Chinese power system reform has entered an accelerated stage. However, the development of the power industry still faces some problems that urgently need to be solved through reform. One of them is that the price relationship has not been straightened out, and a market-oriented pricing mechanism has not yet been fully formed. Current electricity price management is still dominated by government pricing. Electricity price adjustments often lag behind cost changes, making it difficult to timely and reasonably reflect electricity costs, market supply and demand, resource scarcity, and environmental protection expenditures. With the vigorous development of the EV industry, EV electricity price pricing models and strategies have become the focus of industry research [7].

2.1 Electricity tariffs in China

The current charging tariff are mainly categorized into fixed tariff and ToU tariff .

The fixed charging tariff refers to the EV charging operation management agency purchases electricity from the wholesale power market and provides electric energy to EV users at a fixed charging price and basic charging service fee based on its operating costs and expected reasonable profits. Under this electricity price mechanism, EV users only need to consider their own driving mileage, start charging the EV immediately when they arrive at the charging stations, and stop charging when the battery energy reaches the required level. This large-scale, unguided and disorderly integration of EVs into the grid may have adverse effects on the regional grid load [8].

After the large-scale development of EVs, disorderly bidirectional charging will cause violent fluctuations in the load of the power grid, making it difficult for the power grid to operate economically and stably. At this stage, the tariff in most countries is ToU tariff. The implementation of this tariff has enabled EVs to bidirectional smart charge [9]. At the same time, as a key component of the EV market, charging stations' income and user charging fees play an important role in the promotion and application of EVs [10]. By adopting the ToU tariff and designing ToU charging tariffs, it can significantly reduce the power purchase cost and the average charging cost of users, effectively guiding residents, public and bus users to smart charge, and reduce the negative impact of large-scale EVs on the grid .

2.2 Policies for Charging ToU tariffs in China

The tariff makes full use of the spatial and temporal flexibility of EV loads and the initiative of users. Through in-depth study of the behavioral characteristics of EVs' independent response to the dynamic ToU tariffs of charging stations, users' charging costs can be reduced, thereby guiding users to smart charge and smoothing the load fluctuations of the power grid [11][12]. Since 2014, government agencies such as the National Development and Reform Commission have successively promulgated a series of policy documents related to ToU tariff for EV charging, as shown in Table 1. At present, for commercial centralized charging and swapping infrastructure such as public and dedicated charging and swapping stations, preferential electricity price policies are implemented, and large industrial electricity prices are exempted from basic electricity charges. Except for some users of power transfer, the ToU tariff is basically covered [13].

Table 1. Policies for charging ToU tariffs in China.

Title	Document number	Release date	Publishing department	Abstract
Notice on issues related to the electricity price policy for electric vehicles	Development Reform Price [2014] No. 1668	July 22, 2014	National Development and Reform Commission	A supportive electricity price policy will be implemented for the electricity used by EV charging and swapping facilities. Centralized charging and swapping infrastructure that are directly installed and connected by power grid companies will be subject to large industrial power prices. Basic electricity charges will be temporarily exempted before 2020. Other charging infrastructure will implement classified catalogue tariffs according to its location; EV charging and swapping infrastructure implements ToU tariffs [14].
Opinions on innovating and improving the price mechanism for promoting green development	National Development and Reform Price Regulations [2018] No. 943	June 21, 2018	National Development and Reform Commission	Demand (capacity) electricity charges will be exempted for centralized charging and swapping infrastructure with a two-part tariff by the end of 2025 [15].
Notice on further improving the ToU tariffs mechanism	Development Reform Price [2021] No. 1093	July 26, 2021	National Development and Reform Commission	Reasonably determine the peak-to-valley difference. If the maximum peak-to-valley ratio exceeds 40%, the peak-to-valley difference should not be less than 4:1 in principle, while in other place the difference should not be less than 3:1. A peak electricity price mechanism should be established and peak electricity price is more than 20% [16].
Guidance on further building a high-quality charging	State Council issued [2023] No. 19	June 8, 2023	Office of the State Council	The ToU tariffs should be implemented, guiding users to widely participate in smart charging and VGI. Demand (capacity) electricity fees for centralized charging and swapping infrastructure with two-part tariffs are exempted before 2030 [17].

infrastructure system				
Several measures to promote automobile consumption	Development and Reform Employment [2023] No. 1017	July 20, 2023	National Development and Reform Commission	Promote the implementation of residential tariffs for the energy consumption by public charging and swapping infrastructure in residential areas, and promote the implementation of ToU tariffs for the electricity used by charging and swapping infrastructure that implement industrial and commercial tariffs [18].

2.3 The impact of ToU tariff for residential charging on charging demand

As of the end of September 2023, 26 provinces (cities) have released ToU tariff for residential charging, as shown in Table 2 and Table 3. Residential charging tariff in 9 provinces (cities) are independent from ordinary residential tariffs, and 17 provinces (The charging tariffs of cities) follow the residential electricity prices, and 7 provinces (cities) have not issued ToU tariffs. The maximum peak-to-valley electricity price ratio for residents is 4.47:1 (Shenzhen). Seven regions have introduced refined electricity pricing schemes such as deep valley electricity prices and sharp peak electricity prices. Users who choose to implement the ToU tariffs can apply to the local power grid company, which will install the smart meter for free. The implementation time is mostly annual, and it must be implemented for one year before withdrawal [19].

Table 2. Three different types of ToU tariffs for residential charging.

Type of charging ToU tariffs	Regions
independent charging ToU tariffs (different from ordinary residential tariffs)	Hunan, Jiangxi, Heilongjiang, Jilin, Shaanxi, Sichuan, Shandong, Zhejiang, Hainan
ToU tariffs for residential charging (the same as ordinary residential tariffs)	Gansu, Anhui, Chongqing, Fujian, Jiangsu, Hebei, Hubei, Henan, Northern Hebei, Inner Mongolia, Liaoning, Shanghai, Ningxia, Shanxi, Xinjiang, Guangdong, Shenzhen
fixed tariffs	Beijing, Tianjin, Qinghai, Tibet, Guangxi, Guizhou, Yunnan

Table 3. Residential charging ToU tariffs in September 2023.

Province/City	Critical Peak pricing (Yuan/kWh)	Peak pricing (Yuan/kWh)	Flat pricing (Yuan/kWh)	Valley pricing (Yuan/kWh)	Deep-valley pricing(Yuan/kWh)
Gansu		0.759	0.51	0.261	
Anhui		0.6153	/	0.3353	
Chongqing		0.64	0.54	0.36	
Fujian		0.5283	/	0.2983	
Hunan		0.704	0.604	0.504	
Jiangsu		0.5583	/	0.3583	
Hebei		0.57	0.5362	0.31	
Hubei	0.73	0.68	0.58	0.43	
Jiangxi		0.65	0.62	0.5	

Heilongjiang	0.9234	0.7695	0.513	0.2565	
Jilin		0.6924	/	0.3924	
Henan		0.598	/	0.448	
Northern Hebei		0.57	0.5362	0.31	
Inner Mongolia		0.695288	0.465	0.234713	
Shaanxi		0.5609	/	0.3109	
Liaoning	0.9375	0.75	0.5	0.25	
Shanghai		0.641	0.617	0.331	
Sichuan	1.049088	0.87424	0.5464	0.21856	
Shandong	0.888	0.585	0.555	0.385	0.222
Ningxia		0.4986	/	0.2486	
Shanxi		0.507	0.487	0.2862	
Zhejiang		0.588	0.558	0.308	
Xinjiang	0.95	0.83125	0.475	0.11875	0.0475
Guangdong	1.24375	0.995	0.589	0.229	
Shenzhen		1.11	0.65	0.25	
Hainan		1.0643	0.6295	0.2568	

Regarding residential charging energy, scholars have confirmed through typical case study that ToU tariffs have a significant guiding effect on residential charging energy. Literature [20] proposed a pre-evaluation method for the policy benefits of ToU electricity tariffs for residential EV charging based on large-scale actual data, and conducted a case study based on the measured data in Tianjin, verifying the impact of ToU electricity tariffs on the system in reducing maximum charging energy and increasing power consumption during off-peak hours of the power grid. Literature [13] compares fixed tariffs (Tianjin) and ToU tariffs (Shanghai and Guangzhou) in different cities. According to statistics of car insurances, the total number of private EVs promoted in these three cities has reached 220,000, 530,000, and 230,000 respectively by July 2022. The penetration rate of private EVs reached 32.3%, 40.4%, and 26.5% respectively from January to July 2022, which is at the top of ownership and penetration rates in major cities.

Based on the comparative analysis of the residential charging characteristics in Tianjin, Shanghai and Guangzhou, it can be found that compared with the fixed tariffs, the impact of ToU tariffs on residential charging energy can be concluded as below.

- ToU tariffs can significantly reduce the impact of residential EV charging energy on the peak load of the grid. Comparing measured data from three cities, ToU tariffs can reduce the charging load overlap of the system during peak hours from more than 80% to less than 20%.
- ToU tariffs can significantly increase the proportion of off-peak electricity for residential charging. Comparing the measured data in three cities, ToU tariffs can increase the proportion of off-peak electricity for residential charging from about 40% to more than 75%.
- ToU tariffs will increase the simultaneous charging load rate of residents. Comparing the load change trends in the three cities, ToU tariffs can "shift" the maximum value of

charging energy to the off-peak hours, but more charging energy will be aggregated at the beginning of the off-peak hours, increasing the maximum charging energy and causing a new peak in the stations.

- With ToU tariffs, the charging energy will climb steeply at the beginning of the off-peak hours. The climbing rate of the charging energy can reach about 70% of the maximum charging energy within 15 minutes.

2.4 The impact of ToU tariff for public charging stations on charging demand

Regarding ToU tariffs for public charging, literature [13] investigated the charging energy of public charging stations in Tianjin, Shandong, Shenzhen and other places, and then analyzed the impact of charging ToU tariffs on public stations from the aspects of charging price and charging hours. The survey found that public charging users are also sensitive to prices and have strong guidance potential. Meanwhile, the peak and valley time division is also very significant in guiding public users, especially during the daytime off-peak hours, which highly overlapping the photovoltaic generation hours.

2.4.1Peak and off-peak charging prices

In February 2022, Shenzhen adjusted the peak and off-peak allocations. The charging load changes of public charging stations and P+R charging stations in general communities in Shenzhen in March 2021 are compared with those in March 2022, reflecting the changes in user charging behavior before and after the price change.

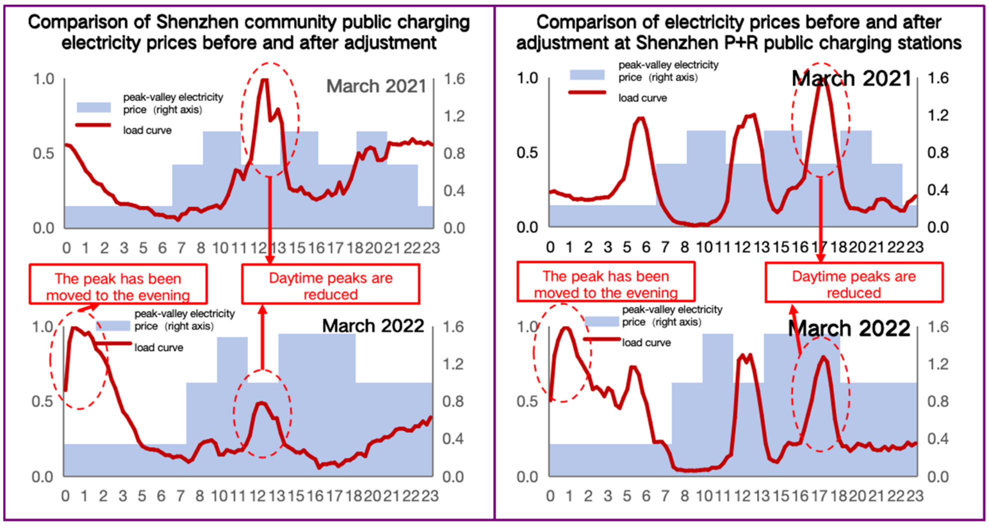

Figure 1. Comparison of charging load profiles before and after the adjustment of public charging tariffs in Shenzhen.

Figure 1. presents the comparison of charging load profiles before and after the adjustment at the same station. Energy consumption during off-peak periods was greatly increased after the adjustment. The ratio of off-peak energy consumption to the total daily energy consumption has increased from about 30% before the adjustment to more than 50%, reducing the peak

charge during the day. The peak load has been moved from the flat period during the day to the beginning of the off-peak period at night, indicating that there is great potential for price guidance for public charging users.

2.4.2Peak-valley hours division

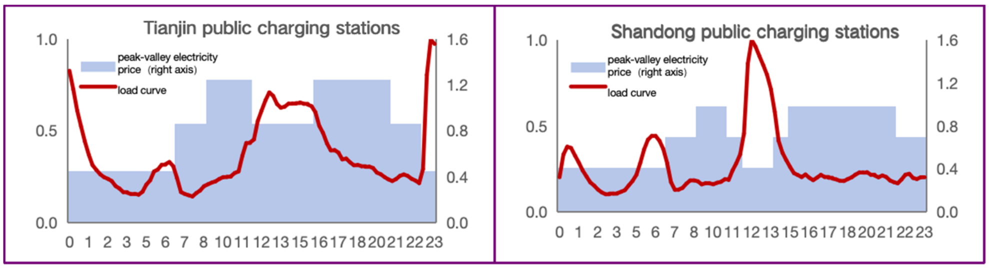

Figure 2. Comparison of charging load profiles in public charging stations in Tianjin and Shandong.

Shandong is one of the few provinces that has off-peak periods during the day. Comparing the charging loads of public stations in Shandong and Tianjin as shown in Figure 2., we can find that the peak charge occurs during the off-peak periods in both cities, However, the peak load in Shandong appears during the off-peak periods during the day. Energy consumption during daytime off-peak periods accounted for about 25% of the total daily energy consumption. It can be seen that the electricity price in the off-peak period during the day has a greater guiding effect on users compared to that at night. The daytime charging hours coincide with the maximum photovoltaic generation hours, which shows a good potential for photovoltaic consumption.

2.5 Problems with the current ToU tariffs in China

The current ToU tariffs have played a positive role in guiding users to charge during off-peak periods, but it has not fully exerted its guiding effect. The reason is that the peak-to-valley difference in some provinces is so low,that the users lack proper incentives. In addition, due to insufficient relevant publicity and vehicles that do not have a delayed start, the proportion of users who choose valley charging has not yet reached an ideal level. Most provinces that have introduced ToU tariffs simply follow the ToU tariffs for ordinary residents. Only a few provinces have introduced residential charging electricity prices that are independent of ordinary residential electricity prices. There is insufficient consideration of the difference between residential charging load and conventional residential electricity load. There is still room for optimization in the electricity price mechanism.

Due to the lack of a discharging on-grid electricity price, the application scenarios for VGI are limited. Currently, the vehicle to everything is limited to pilot projects in Vehicle-to-building (V2B) scenarios such as parks and units. "Charging during off-peak hours and discharging during peak hours" is used to reduce electricity cost during peak hours. The scenario limitations are large, and the scale of participation of EVs is limited. The largest V2G scenario in residential areas lacks discharging electricity price mechanism and cannot directly discharge electricity to the power grid, making it difficult to expand the application.

3 Market mechanism in China

Since the issuance of Zhongfa Document No. 9 in 2015, Chinese electricity market reform has continued to deepen, and now it has covered inter-provincial and intra-provincial in space, medium and long-term and spot in time, and electric energy and ancillary services in variety. Medium- and long-term electric energy market transactions have continued to operate, the spot market has made significant progress, the ancillary service market system has been continuously improved, the capacity price mechanism has been actively explored, and green power and green certificate transactions have achieved breakthroughs[21].Trading varieties of China's electricity market is shown in Table 4. [22].

Table 4. Trading varieties of China's electricity market.

Electrical energy	Medium and long-term electricity transactions	Electric energy trading from multi-day to multi-year scale, mainly annual and monthly transactions.
	Electricity spot trading	Including day-ahead and intra-day electric energy trading, there are 14 provincial pilot projects in two batches and are being promoted nationwide.
Ancillary services	Peak shaving ancillary service market	For intra-day peak shaving design, gradually shift to spot market and adjustable capacity market.
	Ancillary services market (except peak shaving)	For auxiliary services such as frequency regulation, backup, reactive power compensation, flexible climbing, and inertia.
Capacity	Capacity compensation mechanism/capacity market	Maintain system adequacy, stimulate available generation capacity, and improve power supply resilience.
Green power procurement	Green electricity/green certificate market	Initial realization of green premium for new energy and effective guidance of green electricity consumption.

With the advancement of the construction of new power systems, load-side power generation, energy storage and load-type distributed renewable energy have been connected to the grid on a large scale, and new business formats such as comprehensive energy services, power aggregators, green power trading, and carbon trading have emerged one after another. The difficulty of direct control of the power grid and the cost of power balancing have increased dramatically. Introducing demand response into power market, increasing the role of the demand side in the market through incentive-based price, and guiding multiple stakeholders to conduct comprehensive resource planning are inevitable to adapt to the development of the power market.

EVs have the resource characteristics of both "load" and "energy storage", and can widely participate in power market transactions through VGI. Given the different construction and access conditions in various provinces, the current VGI mainly participates in three types of markets: demand response, peak shaving ancillary services and green power trading.

3.1 Demand response

On May 19, 2023, the National Development and Reform Commission issued the "Measures for Electricity Demand Side Management (Draft for Comments)" and "Measures for Electricity Load Management (Draft for Comments)" for public consultation. The measures mentioned that it encourages demand-side resources such as adjustable loads and new energy storage, distributed power supplies, EVs, air-conditioning loads and , etc., to participate in demand response in the form of load aggregators or virtual power plants to support local power grids, incremental distribution electricity grid, and microgrids. By 2025, the demand response capacity of each province reaches 3%-5% of annual peak load, and provinces with over 40% of peak-to-valley ratios in annual peak load should reach 5% or more.

More than 20 provinces or cities have issued demand response policies. Shanghai, Tianjin, Shandong and other places have launched pilot projects for EVs to participate in demand-side response. In 2021, State Grid Corporation of China has participated in 12 demand-side responses (including 4 peak-shaving responses and 8 valley-filling responses) in 7 provinces or cities including Tianjin, Shanxi, Shandong, Shanghai, Jiangsu, Zhejiang, and Hunan. The response power is 460,000 kWh.

The demand response of the pilot is mainly day-ahead invitation-based demand response. The transaction unit that wins the bid for demand response and provides effective response capacity within demand per time period will calculate the response cost on an hourly basis and settle it monthly. The day-ahead invitation-based demand response revenue can be calculated as follows [23].

$$R = \sum_{i=1}^{n} \Delta P_i * K * C \quad (1)$$

$$\Delta P = P_B - P_R \quad (2)$$

Where:R is the response revenue, P_B is the baseline electric load, P_R is the average load during the user response period, n is the frequency of published demand responses, ΔP_i is the i-th actual response power of the user, K is the subsidy coefficient, and the subsidy coefficient is set according to the actual load response rate, C is the subsidy price.

From practical experience, demand response has a good guiding effect on EV owners. From Shanghai's 159 private charging infrastructure participating in the valley-filling demand response, the average charging load (1068 kW) on the response day was 7.8 times that of at the same period on weekdays (140 kW). And the average charging capacity (64.5 kWh) was 6.9 times that of the average daily charging capacity (9.35 kWh) [24].

Based on practical experience, demand response has a good guiding effect on electric vehicle owners, but invitation-based demand response also has problems such as limited market space and low transaction frequency. By introducing interruptible load (IL) transactions and direct-controlled adjustable load competitive bidding transactions, transaction frequency can be increased and varieties expanded.

Interruptible load transactions are weekly transactions and are settled based on spare capacity and response power. Providing a stable revenue stream through long-term response capacity trading incentivizes long-term investment in demand response resources, and also incentivizes demand response resources to fully function through short-term response power trading.The interruptible load transactions demand response revenue can be calculated as follows[25].

$$R = \sum C * L_1 * P_i + \sum P_j * C \quad (3)$$

Where:R is the response revenue, P_i is the reserve capacity of the virtual power plant in the interruptible load call list for the day. If the virtual power plant is called on the same day, $P_i = 0$; P_j is the effective response capacity, C is the clearing price, L_1 is the reserve price ratio.

The transaction organization for direct-controlled adjustable load competitive allocation transactions is half a year or a year, and settlement is based on capacity. The compensation costs for peak shaving (peak shaving) involving direct-controlled adjustable loads are all shared by market-oriented power users, guiding market-oriented users to increase their own adjustment capabilities to achieve the purpose of saving investment in the power system and ensuring the safety of power grid supply.The direct-controlled adjustable load competitive allocation transactions demand response revenue can be calculated as follows.

$$R = \sum C * [P_b - \sum P_{d,m} / D - M * \sum P_{d,u} / D] * (1 - \Delta_m) \quad (4)$$

Where:R is the response revenue, P_b is the competitive allocation winning bid capacity of the virtual power plant, C is the clearing price of competitive allocation, d is the day, D is the total number of days in the month, $P_{d,m}$ is the planned maintenance capacity of virtual power plant, $P_{d,u}$ is the unplanned outage capacity, Δ_m is the monthly average dispatch plan execution deviation of the virtual power plant, and M is the unplanned outage assessment coefficient.

By collecting the number of residential, public, and bus charging infrastructures in Tianjin, as well as the frequency of demand response transactions in Tianjin in the three years from 2021 to 2023, modeling based on power demand response transaction rules, comparative analysis of the current aggregation transaction model, interruptible load type, and competitive allocation transaction types for electric vehicles.Compared with the current model, after adding interruptible load-type and competitive configuration demonstrations, users' expected income is expected to increase significantly. Among them, Table 5. and Figure 3.show the residential charging infrastructures participation in the market income is expected to increase by 410%, public charging infrastructures are expected to increase by 650%, and bus charging infrastructures are expected to increase by 650%. Charging infrastructures are expected to increase by 560%.

Table 5. Aggregated trading market annual revenue and proportion(unit: yuan).

Type	Total revenue(yuan)	Day-ahead solicitation demand response transactions		Interruptible load transactions		Direct controlled adjustable load competitive allocation transaction	
		Single pile income	Proportion	Single pile income	Proportion	Single pile income	Proportion
residential charging infrastructure	492	96	19%	116	24%	280	57%
public charging infrastructure	762	101	13%	662	87%	0	0%
bus charging infrastructure	7217	1094	15%	1323	18%	4800	67%

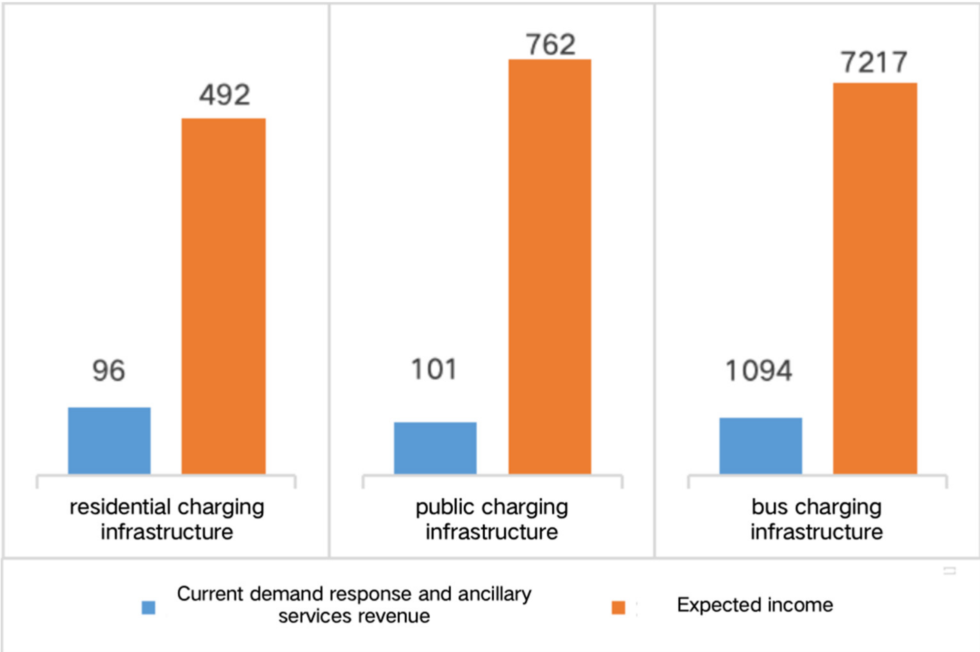

Figure 3. Transaction aggregation income of various charging infrastructures before and after the demonstration.

3.2 Auxiliary services market

VGI participation in the ancillary service market is represented by the peak-shaving ancillary service market in North China. Many places have introduced relevant policies and launched promotion pilots, giving full play to the aggregation and adjustment capabilities of EVs. In November 2019, the North China Energy Regulatory Bureau released the "Pilot Plan for Third-Party Independent Entities to Participate in the North China Electric Power Peaking Auxiliary Service Market (Draft for Comments)", which creates a brand new market for independent auxiliary service providers including distributed and power generation side energy storage devices, EVs (charging infrastructure), heating and independent third-party entities such as virtual power plants. In addition, in May 2021, the Zhejiang Provincial Energy Supervision Office issued the "Zhejiang Provincial Third-Party Independent Entities Participation in Electric Power Ancillary Services Market Transaction Rules (Trial) (Draft for Comments)". And in August 2021, the Central China Energy Regulatory Bureau issued the "New Entities Participation" "Central China Electric Power Peaking Ancillary Service Market Rules (Draft for Comment)" allows EVs (charging infrastructure) to participate in the power ancillary service market through independent third-party entities. From the actual operation of North China's auxiliary services, the aggregated regulation potential of VGI has been initially released. In 2021, State Grid Co., Ltd. organized 68,000 charging infrastructure to participate in the North China peak-shaving market, with an aggregated capacity of 1934.55MW and 199 million kWh of peak-shaving electricity, reducing wind and solar power abandonment by 0.54 billion kWh, and generating dividends of 1.2693 million yuan, and implementing5.18 million VGI.

Take the peak shaving ancillary service market in North China as an example. This is currently the largest and most mature ancillary service market. As a independent third-party entity, EV aggregators are allowed to participate in power grid peak shaving auxiliary services. State Grid Electric vehicle and Teld served more than 27,000 charging infrastructure to participate in the market as agencies.

The peak shaving service fee received by market entities participating in North China peak shaving auxiliary services every 15 minutes is equal to the product of market coefficient, peak shaving contribution rate, charging capacity, and market clearing price.The peak shaving service fee can be calculated as follows[26].

$$F^{i,t} = K^t * min\{\frac{P^{i,t}}{P_b^{i,t}}, \ 1\} * min\{P^{i,t}, P_b^{i,t}\} * t_{m,\ g} * A_{m,\ g}^t \tag{5}$$

Where: $F^{i,t}$ is the total peaking service fee obtained by market entity i during t period; K^t is the market coefficient during t period, $P^{i,t}$ is the actual charging power or aggregate charging power (MW) of market entity i in period t; $P_b^{i,t}$ is the benchmark charging power or aggregate charging power (MW) of market entity i in period t; $\min\{\frac{P^{i,t}}{P_b^{i,t}}, \ 1\}$ is the peak regulation contribution rate, which is smaller of the sum 1 Value; $\min\{P^{i,t}, P_b^{i,t}\}$ is the charging power, which represents the small value of the sum, if it is the same day, the peak shaving contribution rate is recorded as 1, and the charging power is recorded as $P_b^{i,t}$;$t_{m,\ g}$ is the provincial grid market clearing period, in hours; $A_{m,\ g}^t$ is the provincial grid market peak shaving service marginal clearing price (yuan/MWh) during t period.

Literature [27] use the Formula(5) to analyzed the changes in the power curve of a bus charging station in Beijing before and after participating in the peak shaving ancillary service market adjustment in North China, compared with a typical day before participating in the market, the station changed the charging power and time after participating in the market, providing peak power of 60 to 240kW to the grid, showing that the ancillary service market has a good peak-shaving effect.

3.3 Green electricity trading market

In recent years, based on the aggregation function of the State Grid Smart Internet of Vehicles platform, the State Grid has carried out many explorations and demonstrations of VGI to participate in cross-provincial green electricity trading in the Beijing Electricity Trading Center. At present, State Grid electric vehicle's participation in green electricity trading has been carried out in 16 provinces or cities, consuming 1.344 billion kWh of green electricity and generating dividends of 89.27 million yuan [28]. In 2021, Hunan Province took the lead to introduce a policy for EVs to participate in green electricity trading within the province. The Hunan Provincial Development and Reform Commission issued the "2021 Hunan Electric Vehicle Green Power Trading Trial Plan" [29], which for the first time proposed targeting EVs as an adjustable resource. The relationship between the various entities, the registration and transaction process, the allocation of each party, etc., are clarified to guide for green electricity trading policy innovation. Figure 4.shows the relationship between the various entities and the distribution of each party.

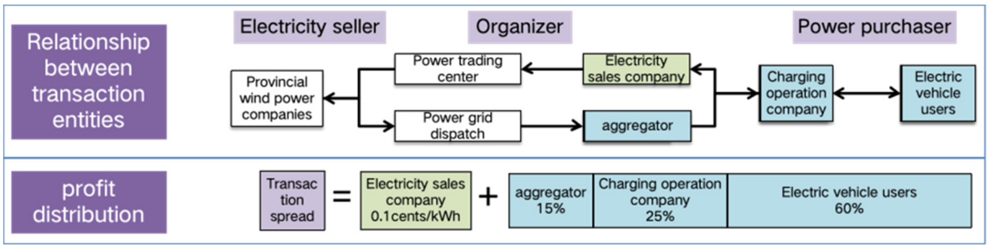

Figure 4. Relationship diagram between various entities in the Hunan Province Electric Vehicle Green Power Trading Pilot Plan.

3.4 Problems with the market mechanism

First, transfer power users fail to participate in the power market due to the lack of the measurement data. At present, a large number of EVs are behind-the-meter and cannot be independently measured by meters. Measurement and standards for behind-the-meter resources have not yet been clarified. Therefore, the participation of behind-the-meter EVs in the electricity market lacks an officially recognized measurement.

Second, there is little demand response, and a lack of sustainability for VGI. The current demand response implemented in most areas is seasonal, holiday and total response planning. It has not yet formed a normalized and market-oriented adjustment system. Some regions lack stable funding, so that demand response is not sustainable, with fluctuating revenue of EVs participating in VGI, making it impossible to fully incentivize EV users and aggregators to participate in response in the long term.

Third, the scale of EVs participation in the electricity market can be greatly improved. At present, residential users in China are unable to participate in the electric market, while non-residential users such as charging and swapping stations must enter the market through electricity sales companies. The relationship between power sales companies and load aggregators is still unclear. In some markets, the identification of aggregator entities is unclear and does not support direct clearing and settlement by aggregators. There are also obstacles for EVs and charging and swapping infrastructure to enter the mid to long-term market through aggregation and green electricity trading.

Fourth, the capacity value of EV as mobile energy storage has not yet been fully utilized. At present, China's capacity market has not yet been fully established, and the shared capacity leasing market for independent energy storage power stations has not been opened to EVs. In the field of participating in energy storage advantageous market such as frequency regulation, backup, and ramping. The market rule and stable earnings are still not clear for V2X.

4 Conclusion and outlook

With increasing large-scale EVs and penetration of renewable energy, VGI has received widespread attention due to its huge flexibility and value potential, and is regarded as an important component in improving the regulation capability and flexibility of the power system. Many regions in China have actively employed VGI-related electricity prices and market mechanisms, creating a good environment for VGI. In terms of electricity price mechanism, ToU tariffs have a significant peak-shaving effect on both residential and public charging. However, there are still shortcomings in peak-to-valley differences, peak-valley hours division, innovation of tariff mechanisms, and publicity efforts. In terms of market mechanisms, multiple domestic pilot projects have verified aggregating EVs to participate in demand response, ancillary services, and green electricity trading. However, there is still room for improvement in behind-the-meter metering, market types, number of transaction, and aggregation.

With reference to the experience of international pioneering regions,it is recommended to improve the electricity price and market mechanisms in the following two aspects to support high-quality development for VGI.

A scientific and flexible ToU tariffs should be built. In terms of policy, the ToU tariffs for residential charging should be fully covered nationwide. In terms of mechanism, based on the charging characteristics of residents, public and bus users, reasonable peak-to-valley differences and hours division should be designed. Encourage price mechanism innovations such as peak electricity prices and deep valley pricing to further stimulate the flexibility of various charging and swapping infrastructure.

A widely participated aggregation and trading system for VGI should be established. Optimize and improve mechanisms such as demand response, ancillary services and spot trading, enriching trading varieties, expanding the scope of participation. Feasible options for behind-the-meter charging and swapping infrastructure to participate in aggregate transactions should be studied. Demonstration pilots of bidirectional charging to participate in energy storage capacity leasing, spot markets, and ancillary services to verify the equivalent energy storage potential of EVs.

Funding: This work was supported by State Grid Smart Internet of Vehicles Co., LTD. for Technology Project"Research on the theoretical framework and key technology of electric vehicle load regulation for power system based on renewable energy"(8100/2022-71008B).

References

[1] Guo,Q.L. (2023) A preliminary study on power network-transportation network coordination issues from the perspective of information-physics-society integration.https://mp.weixin.qq.com/s/pyqrGuk0v9xdvBVY-BMxpg.

[2] Ouyang,M.G. (2021) Vehicle-grid integration (V2G) technology potential and implementation feasibility.https://mp.weixin.qq.com/s/0gcwN7vuwxqQriSYvoCDtQ.

[3] P. Mallet et al. (2014) Power to the People!: European Perspectives on the Future of Electric Distribution. IEEE Power and Energy Magazine,12: 51–64.

[4] H. Shareef, M. M. Islam, A. Mohamed. (2016) A review of the stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles. Renewable and Sustainable Energy Reviews,64:403–420.

[5] D. Bozic, M. Pantos. (2015) Impact of electric-drive vehicles on power system reliability. Energy,83:511-20.

[6] Office of the State Council. (2020) New energy vehicle industry development plan (2021-2035).https://www.miit.gov.cn/jgsj/ghs/zlygh/art/2022/art_158cc63ebe76470cbff2458c4328ea22.html.
[7] CPC Central Committee and State Council. (2015) Several opinions on further deepening the reform of the electric power system (Zhongfa [2015] No. 9). http://fjb.nea.gov.cn/pufa_view.aspx?id=31434.
[8] Cui,J.D.,Luo,W.D.,Zhou,N.C. (2018) Research on Pricing Model and Strategy of Electric Vehicle Charging and Discharging Based on Multi View.Proceedings of the CSEE,38:4438-4450.
[9] Ge,S.Y.,Huang,L.,Liu,H. (2012) Optimization of peak-valley TOU power price time-period in ordered charging mode of electric vehicle.Power System Protection and Control,40(10):1-5.
[10] Zhou,F.Q. (2010) Discussion on operation mode to the electric vehicle charging station.Power System Protection and Control,38:63-71.
[11] Xu,Z.W.,Hu,Z.C.,Song,Y.H. (2014) Coordinated Charging Strategy for PEV Charging Stations Based on Dynamic Time-of-use Tariffs.Proceedings of the CSEE,34:3638-3646.
[12] Tong,J.J.,Wen,J.Q.,Wang,D. (2016) Multi-objective optimization charging strategy for plug-in electric vehicles based on time-of-use price.Power System Protection and Control,44:17-23.
[13] China Society of Automotive Engineers.,Sichuan Energy Internet Research Institute Tsinghua University. (2022) Research on the targets and approaches of vehicle and grid integration (VGI) development in China considering China's carbon peak and neutrality goals.https://www.efchina.org/Reports-zh.
[14] National Development and Reform Commission. (2014) Notice on issues related to the electricity price policy for electric vehicles.https://zfxxgk.ndrc.gov.cn/web/iteminfo.jsp?id=19564.
[15] National Development and Reform Commission. (2018) Opinions on innovating and improving the price mechanism for promoting green development.https://zfxxgk.ndrc.gov.cn/web/iteminfo.jsp?id=20016.
[16] National Development and Reform Commission. (2021) Notice on further improving the time-of-use electricity price mechanism. https://www.ndrc.gov.cn/xwdt/tzgg/202107/t20210729_1292068.html.
[17] Office of the State Council. (2023) Guidance on further building a high-quality charging infrastructure system.https://www.gov.cn/gongbao/2023/issue_10566/202307/content_6890792.html.
[18] National Development and Reform Commission. (2023) Several measures to promote automobile consumption.https://www.ndrc.gov.cn/xwdt/tzgg/202307/t20230721_1358540.html.
[19] State Grid Corporation of China. (2023) Electricity price standard. https://www.95598.cn/osgweb/ipElectrovalenceStandard.China Southern Power Grid Company Limited.(2023)Electricity price inquiry. https://95598.csg.cn/#/gd/serviceInquire/LRLayer/elePriceInquire
[20] Li,S.J.,Zhang,J.,Zhang,Z.D.,Li,L.L. (2023) Method to Pre-evaluate the benefits of Time-of-use Tariff on Residential Electric Vehicle Charging Loads.In:2023 IEEE 6th International Electrical and Energy Conference (CIEEC).Hefei.1304.
[21] Shi,L.J. (2023) Recent electricity market operations and thoughts on the development of the electricity market under energy transformation. https://mp.weixin.qq.com/s/hvo3xzRtjDMDczwIdiDPlQ.

[22] RMI Innovation Center. (2023) Insights into the transformation of electricity marketization:20 major trends for market participants.https://rmi.org.cn/insights/2023powermarketreviewandoutlook/.
[23] Tianjin Municipal Bureau of Industry and Information Technology. (2021) Tianjin’s 2021 Summer Electricity Demand Response Implementation Rules.https://gyxxh.tj.gov.cn/ZWGK4147/ZCWJ6355/wjwj/202107/t20210705_5495772.html.
[24] NRDC. (2020) The business prospects of electric vehicles interacting with the power grid—Shanghai demand response pilot case.http://www.nrdc.cn/information/informationinfo?id=250&cook=2.
[25] Guangdong Electricity Trading Center. (2022) Guangdong Province Market-Based Demand Response Implementation Rules (Trial Draft). https://pm.gd.csg.cn/views/page/tzggCont-10998.html.
[26] National Energy Administration North China Regulatory Bureau. (2019) Pilot plan for third-party independent entities to participate in the North China electric power peaking ancillary service market (draft for comments). https://hbj.nea.gov.cn/adminContent/initViewContent.do?pk=000000006e69cbf9016e6e4b59700059.
[27] Shi,P.R.,Li,Y.B.,Jiang,C.M. (2021) Rule Design and Practice for Third-party Independent Entities Participating in Electric Power Peak Regulation Auxiliary Service Market of North China.Automation of Electric Power Systems,45:168-174.
[28] Wang,W. (2021) VGI makes electric vehicles a new energy source. https://chejiahao.autohome.com.cn/info/9986411/
[29] Hunan Provincial Development and Reform Commission. (2021) Hunan Electric Vehicle Green Power Trading Trial Plan in 2021.http://fgw.hunan.gov.cn.