Research on the Orderly Charging Regulation Capability of Electric Vehicles in Beijing

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Abstract. The carbon peaking and carbon neutrality goals accelerate the pace of energy transformation. Urban energy development faces many challenges. While electric vehicles are promoting the clean and low-carbon transformation of urban transportation sectors, their application prospects as distributed energy storage are increasingly receiving attention from all parties. By providing reasonable guidance on the charging behavior of electric vehicles, they can provide power and energy regulation services such as frequency regulation and peak shaving to the electric power system, improving the utilization level of random and fluctuating new energy. However, there is currently limited research on the quantitative evaluation of the orderly charging regulation ability of electric vehicles. Based on the outlook for energy development and the prediction for the scale of electric vehicles in Beijing, taking into account the characteristics of different vehicle types, this article quantitatively evaluates the regulation ability of orderly charging of electric vehicles in Beijing in the future. The research provides a reference for electric vehicles to participate in demand response and form friendly interaction with the power grid.

Keywords: electric vehicles; carbon peaking and carbon neutrality goals; orderly charging; regulation capability.

1. Introduction

A new round of energy revolution is brewing and rising. As the main body of the world economy and energy consumption, cities are the main battlefield for promoting energy transformation in the future. The Beijing Energy Development Plan proposes to accelerate the construction of a modern energy system that is green, low-carbon, safe, efficient, urban-rural integration, and regional coordination, providing strong and reliable energy security for building an internationally first-class harmonious and livable city. Beijing has been committed to the energy structure adjustment characterized by "coal removal, gas extraction, and electric power increase" for many years, leading the pace of energy transformation in the country. Beijing has preliminarily formed a clean and efficient energy system, which has a good foundation for building a modern energy system. Ensuring energy security is the fundamental prerequisite for achieving the carbon peaking and carbon neutrality goals. How to coordinate and solve the contradiction among low-carbon, security and economy of energy system has become the key to achieving the carbon peaking and carbon neutrality goals. Faced with the accelerating pace of energy transformation, ensuring the security of energy and electricity supply in the capital city is a problem that must be solved in the process of energy development in Beijing.

2. Overview and Prospects of Energy Development in Beijing

2.1 Current Situation

energy supply coming from external sources. The local primary energy production in Beijing mainly comes from coal, electric power and other energy sources. The proportion of output in the total energy supply has fluctuated below 10% in recent years. In 2021, the total local energy production in Beijing reached 3.856 million tons of standard coal, accounting for 5.4% of the energy supply[1]. With the gradual closure of local coal mines, the coal production in Beijing has sharply declined, with zero production in the past two years.

With the adjustment of industrial structure and the promotion of green development mode, Beijing's economic and social development has gradually weakened its dependence on energy. The total energy consumption in Beijing has maintained a slow growth rate, achieving a medium to high speed economic development supported by a relatively low energy consumption growth rate. The average growth rate of energy consumption in Beijing during the 12th and 13th Five Year Plans was 0.6%. At the end of the 13th Five Year Plan, the growth rate of energy consumption in Beijing was 2.5 percentage points lower than the national average during the same period. The optimization and adjustment of Beijing's energy consumption structure have achieved significant results. The proportion of coal consumption has decreased from 29.6% in 2010 to 1.4% in 2021, and the proportion of natural gas consumption has increased from 14.6% in 2010 to 36.1% in 2021.

2.2 Development Prospects

Considering the characteristics of Beijing's resource endowment, the carbon neutrality path in Beijing mainly includes the following two points. On the supply side, Beijing should to vigorously develop local new and renewable energy, significantly increase the proportion of foreign green electricity, and build a diversified clean energy supply system. On the demand side, Beijing should adhere to energy conservation and efficiency enhancement, control the total amount of energy consumption, and accelerate the low-carbon substitution process of terminal energy in areas such as construction and transportation. After preliminary calculations, it is expected that the total energy demand in Beijing will maintain a slow growth trend in the future, reaching a peak around 2030, and then steadily decreasing. The energy supply structure in Beijing will continue to develop towards low-carbon and clean. All new electric power installations will come from non fossil energy sources such as wind and solar power generation. External electricity remains the main source of supply, and the proportion of external electricity remains steadily increasing. Beijing's energy consumption structure will continue to be optimized and adjusted. The proportion of clean energy such as electricity and hydrogen in terminal energy consumption is constantly increasing. In general, the carbon emissions of Beijing during the "14th Five Year Plan" period have declined steadily. Beijing's carbon emissions will continue to decline before 2035, and will accelerate to decline after 2035, basically achieving the carbon neutrality goal.

2.3 Problems

The storage and development of local energy resources in Beijing are relatively small, relying heavily on external energy sources. Currently, the capacity of the Beijing's power grid and external electric power channels is still insufficient. The construction of natural gas channels and peak shaving facilities is relatively lagging behind. The peak shaving heat source and pipeline network of the central network still need to be optimized. And the facility safety guarantee ability needs to be improved. The seasonal and structural contradictions between energy supply and demand are becoming increasingly prominent, and the impact of extreme weather is more significant. With the slowdown of energy consumption growth, the contradiction between tight supply and demand balance will be alleviated. However, the supply-demand contradiction between some energy varieties, partial regions, and partial time periods remains prominent. The focus of energy security guarantee will shift from "maintaining total capacity" to "maintaining both total capacity and peak capacity", posing a challenge to the peak shaving capacity of urban energy system.

But the development of local peak shaving power sources in Beijing is severely limited. To ensure energy security, it is necessary to comprehensively consider the basic characteristics of cities, start from the terminal, and deeply implement the energy-saving priority policy through energy variety combination, technological progress, business model innovation, system integration, and other methods. It is necessary to integrate energy conservation throughout the entire process of economic and social development in various fields, in order to solve the challenges faced by Beijing's energy development.

3. The Role of Electric Vehicles in Solving Urban Energy Problems

3.1 Development of Electric Vehicles

Nowadays, the development of electric vehicles has become a major consensus among major countries around the world to address the issue of low-carbon urban development. In recent years, the global electric vehicle market has grown rapidly and the industry scale has been continuously expanding. The report “Global Electric Vehicle Outlook 2022” released by IEA points out that even in 2021, with limited supply chains, global electric vehicle sales still break records. In 2021, global electric vehicle sales doubled year-on-year to 6.6 million units, accounting for 10% of all new car sales. As of the end of 2021, the global electric vehicle ownership is 16.5 million vehicles[2]. It is three times the data at the end of 2018. The growth in quantity and scale provides conditions for electric vehicles to participate in energy storage in the electric power system. Electric vehicles are naturally connected to the power grid, serving as both energy consumption terminals and energy storage units located at the end of the grid. A large number of electric vehicles can serve as distributed energy storage to provide a considerable amount of flexible resources for the electric power system. Futhermore, it effectively enhances the electric power system’s ability to absorb volatile renewable energy. With the continuous growth of the number of vehicles, electric vehicle energy storage has gradually attracted attention from all parties. The National Development and Reform Commission has explicitly proposed to encourage electric vehicles to provide energy storage services and obtain profits through peak valley price differences[3]. Electric vehicles are increasingly interacting with the power grid through power demand response and other ways. Relevant research also shows that electric vehicles have strong demand response capability. The charging capacity of electric vehicles can be reasonably allocated during parking hours according to the demand of the power grid, helping to regulate peak load, improve the reliability of distribution network operation, and improve the economic efficiency of electric power system operation[4]-[6].

3.2 Orderly Charging

The orderly charging of electric vehicles can be optimized based on the operating status of the electric power system, with the goal of optimal economy or minimal impact on the power grid. By comprehensively considering battery performance constraints and user charging needs, the charging time and power of electric vehicles can be adjusted to promote peak shaving and valley filling in the power grid, achieving the role of “virtual energy storage”[7]. At present, the technology of orderly charging is relatively mature and suitable for promotion and application. The advantage of participating in orderly charging for vehicles with low travel intensity and long parking time, such as private cars and official cars, lies in the high flexibility of charging adjustment. Some regions in China have begun to carry out demonstration projects for orderly charging of electric vehicles in residential communities. For vehicles with high operating intensity and regular operating time, such as buses, taxis, and logistics fleets, the advantage of participating in orderly charging lies more in the large amount of vehicle charging and the relatively low difficulty of centralized control. Overall, orderly charging of electric vehicles is of great significance for improving the regulatory capacity of urban electric power systems.

4. Evaluation of Orderly Charging Regulation Capability of Electric Vehicles in Beijing

The overall number of electric vehicles, battery capacity, charging device power, travel intensity, parking time, and other factors directly constrain the actual energy storage effect of electric vehicles. Among them, quantity and scale are the primary influencing factors of electric vehicle energy storage. According to “the 14th Five Year Plan for National Economic and Social Development of Beijing and the Outline of the Long Range Goals for 2035”, the total number of new energy vehicles in the city will reach 2 million in 2025, and the electrification rate will increase to 30%.

Due to significant differences in the energy storage capacity of various vehicle types, this article adopts the prediction of vehicle type proportion and average battery capacity by the Energy Research Institute of the National Development and Reform Commission. A forecast of the number and scale of electric vehicles in Beijing in 2025 can be obtained, with electric passenger vehicles accounting for 93% of the total, as shown in Table 1.

Table 1. Prediction of quantity and scale of electric vehicles in Beijing in 2025

Vehicle type	Ownership/thousand	Average battery capacity/kWh
Passenger car	1860	100
taxi	40	100
bus	10	250
coach	50	250
Light logistics vehicle	40	150

To quantitatively estimate the energy storage capacity of electric vehicles, the flexible adjustment potential of electric vehicle charging is evaluated based on the available parking time of various vehicle types. The available parking time refers to the length of time excluding vehicle driving time and charging time. The higher the proportion of available parking time, the greater the potential for orderly charging of electric vehicles. The potential for daily orderly charging of a single electric vehicle can be expressed as follows.

$$P_d = C_d \times \frac{T - t_d - t_c}{T} \tag{1}$$

In the formula, P_d is the potential for orderly daily charging of electric vehicles, C_d is the average daily charging capacity of electric vehicles, T is the measurement period (24 hours), t_d is the average daily driving time of electric vehicles, and t_c is the average daily charging time of electric vehicles.

$$C_d = \frac{L_d \times E_0}{\eta} \tag{2}$$

$$t_d = \frac{L_d}{s_0} \tag{3}$$

$$t_c = \frac{C_d}{P_c} \tag{4}$$

L_d is the average daily mileage of the vehicle, E_0 is the average power consumption per kilometer of the vehicle, η is the charging and discharging efficiency of the vehicle battery, s_0 is the average speed of the vehicle, and P_c is the charging and discharging power of the vehicle battery.

The key parameters designed for the calculation process include battery capacity, vehicle travel intensity, charging and discharging power, etc. The parameter values are shown in the table below.

Table 2. Calculation parameter settings

Vehicle type	L_d/ km	E_0/ (kWh·km^{-1})	P_c/ kW	η/%	s_0/ (km·h^{-1})
Passenger car	40	0.16	3.3	95	40
taxi	300	0.16	3.3	95	40
bus	150	0.6	60	95	30
coach	120	0.6	60	95	50
Light logistics vehicle	80	0.3	60	95	50

It can be estimated that the daily average regulation capacity of orderly charging of electric vehicles in Beijing in 2025 is 15840MWh. In terms of vehicle types, passenger cars occupy the main adjustment scale due to factors such as a large number and relatively short daily mileage.

Passenger cars provide 69% of the energy storage capacity of electric vehicles with 93% of the total number of vehicles.

Table 3. Calculation results of regulation capacity

Vehicle type	Single vehicle adjustment capability/kWh	average regulation capacity/MWh
Passenger car	6	10971
taxi	3	96
bus	69	955
coach	64	2973
Light logistics vehicle	23	846

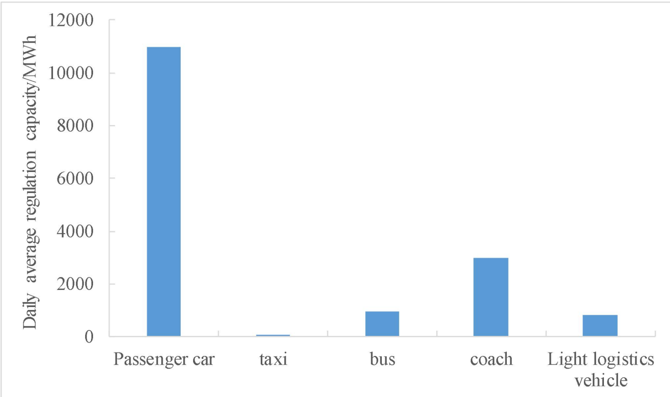

Fig. 1 Daily average regulation ability of different vehicles types

5. Conclusion

Under the carbon peaking and carbon neutrality goals, Beijing's urban energy development is facing enormous pressure from the power system regulation. Orderly Charging of electric vehicles provides an optional solution to address this challenge. Calculation shows that by the end of the 14th Five Year Plan period, the daily average regulation capacity of orderly charging of electric vehicles in Beijing can reach 15840MWh. For the development of orderly charging of electric vehicles, the specialized vehicle charging market should be taken as the entry point in the near future, and the technology and model should be further mature before expanding to the private car field. The following four aspects can be considered. Firstly, it aims to provide overall design, construction, and operation services for high-power dedicated charging stations for customers such as public transportation, environmental sanitation, and logistics, providing services including station management, energy efficiency improvement, and optimized scheduling. Secondly, it aims to launch a service product that combines dedicated charging and public charging based on the charging behavior characteristics of customers such as taxis, and customize charging strategies for customers. Thirdly, it is necessary to carry out the construction of an intelligent group charging and control demonstration project, achieve automatic power distribution, and promote the integration of the power grid and charging equipment. Fourth, it is necessary to actively explore the integration of charging facilities in the form of load aggregators to participate in grid demand response.

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