Proceedings of the 8th International Conference on Economic Management and Green Development
DOI: 10.54254/2754-1169/122/20242336

The Application and Challenges of Vehicle-to-Grid (V2G) Technology in the Development of New Energy Vehicles

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Abstract: The global automotive industry has entered a phase of energy-saving and low-carbon development, with the advancement of new energy vehicles becoming the strategic direction for automotive industries worldwide. However, the large-scale integration of electric vehicles into the power grid has imposed significant challenges on the operation of the electrical grid. This article analyzes Vehicle-to-Grid (V2G) technology, introducing its main functions, key technologies, and advantages, and outlines the current state of its application both domestically and internationally. Additionally, the obstacles hindering the development of V2G technology in China are examined, and several strategies to accelerate the development of V2G technology in China are proposed. It is hoped that these measures will encourage both the government and enterprises to take active steps towards promoting the rapid development of V2G technology.

Keywords: New Energy Vehicle Industry, V2G Technology, Electric Vehicles

1. Introduction

The rapid increase in global energy demand has led to a sharp rise in the consumption of non-renewable energy sources, exacerbating global environmental pollution. Compared to traditional vehicles, electric vehicles (EV) offer several advantages, such as zero emissions of harmful substances, potential improvement of the energy structure, and the ability to regulate the load curve of the electric grid. In recent years, the global EV industry has developed swiftly, with projections indicating that approximately 36% of all vehicles worldwide will be EVs by 2030[1]. As of the end of 2023, according to data from the Ministry of Public Security, the stock of new energy vehicles in China reached 20.41 million, of which EVs accounted for 15.52 million, representing 76.04% of the total[2]. The simultaneous charging of a large number of EVs can impose significant stress on the operation of the electrical grid, making it imperative to explore ways to alleviate this burden. In 1997, Vehicle-to-Grid (V2G) technology was proposed as a novel energy storage solution. Its core concept involves the interaction between EVs and the grid, where the energy stored in EVs serves as a buffer for the grid and renewable resources[3].

Currently, V2G technology is still in the research stage both domestically and internationally. China has introduced several policies to develop V2G technology. For example, on January 4, 2024, various departments jointly issued the "Implementation Opinions on Strengthening the Integration and Interaction between New Energy Vehicles and the Power Grid" by the National Development

DOI: 10.54254/2754-1169/122/20242336

and Reform Commission, among others. This document indicates that new energy vehicles, through charging and swapping facilities connected to the power supply network, can construct a bidirectional interaction system of information and energy flows between new energy vehicles and the power supply network. This can effectively utilize the flexibility of power batteries as controllable loads or mobile storage, providing important support for the efficient and economic operation of the new power system.

As a novel energy storage solution, V2G technology, through the bidirectional interaction between electric vehicles and the grid, can alleviate grid load pressure and support the power system. Although China has mentioned the development of V2G technology in policy documents, it still faces a series of challenges. Therefore, accelerating the development of V2G technology is of great significance.

2. Overview of V2G technology and its application status at home and abroad

2.1. Overview of V2G Technology

V2G, or Vehicle-to-Grid, refers to the bidirectional interaction between electric vehicles (EVs) and the power grid, utilizing the unique energy storage capabilities of EVs. In V2G applications, electric vehicles act as mobile energy storage units or large-scale mobile power banks, absorbing energy from the grid during low load periods and returning energy to the grid during high load periods, maximizing the efficient utilization of electricity.

The principle of V2G technology relies on bidirectional communication and energy transfer between EVs and the grid. When grid electricity demand is low and prices are cheap, EVs can charge from the grid; conversely, when grid demand is high and prices are high, EVs can feed back energy stored in their batteries to the grid. This process is facilitated by intelligent charging equipment and management systems, optimizing grid loads and providing economic benefits to EV owners, thus supporting the broader application of renewable energy sources.

V2G technology involves three key components: intelligent charging equipment, the battery management system (BMS) of electric vehicles, and grid management systems. Intelligent charging equipment allows energy to flow bidirectionally between the grid and electric vehicles, the BMS monitors battery status to ensure safe and effective charging and discharging, and the grid management system adjusts energy flow based on real-time power demand and supply. Through this interaction, V2G technology can supply energy from electric vehicles to the grid during peak electricity demand, assist in grid load management, and charge electric vehicles during off-peak hours, optimizing the use of electricity resources and driving energy transition.

2.2. Current Applications of V2G Technology Internationally and Domestically

In Europe and the United States, pilot applications of V2G began relatively early and have made significant progress. In 2014, with support from the U.S. Department of Defense and the California Energy Commission, the Los Angeles Air Force Base initiated the first V2G demonstration project globally. This project involved 32 electric and plug-in hybrid vehicles from various companies and models, including the Nissan Leaf, Ford F-Series pickups, and VIA Motors' VTRUX trucks. In 2016, Denmark launched the world's first fully commercialized V2G project, providing grid services such as frequency and voltage control through V2G technology. Subsequently, countries such as the United Kingdom and Japan have also conducted large-scale V2G trials.

One noteworthy aspect among many pilot projects and startups is the application of "regulatory sandboxes" in V2G pilot projects in the UK. The UK government removed price controls and energy allocation restrictions in the "regulatory sandbox," encouraging companies like EDF to build peer-to-peer energy trading platforms using block chain technology. This innovation laid a preliminary foundation for an ideal market mechanism for V2G.

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In China, several provinces and cities have implemented peak-valley electricity pricing policies[4]. With the support of two major power grids, the possibility of aggregating orderly charging load resources to participate in ancillary services and demand response has been verified. The participation frequency and peak shaving capacity have gradually increased, and the feasibility of bidirectional charging and discharging technology has been tested. Various applications such as peak shaving for general industrial and commercial purposes and interactive distribution network have gradually been initiated. Overall, V2G technology in China is at a stage where the technology is relatively mature, application scenarios have been validated, and supporting policies continue to improve.

From the perspective of automotive manufacturers, domestic companies such as Dong feng Motor, GAC Aion, Geely, BYD, Great Wall Motors, FAW, X Peng, NIO, Saic-Iveco-Hong yan, and Ne zha are actively researching and promoting V2G technology. For example, Dong feng Motor's V2G zero-carbon super station integrates solar energy storage and charging, advanced charging technology, and intelligent energy control. This station has been put into use in the Wuhan Economic Development Zone and is connected to the Hubei Provincial Grid. During peak electricity demand, owners of new energy vehicles can earn subsidies by discharging at the station. GAC Aion has also launched two major action plans, "fast charging + V2G," and is promoting V2G technology to private charging piles. Users participating in Aion's V2G vehicle-to-grid power transmission plan can not only enjoy free charging but also profit from the price difference between daytime and nighttime electricity prices. The Hyper GT under Aion was released in July 2023 and features reverse power transmission functionality to the grid.

At the regional level, V2G practices are widespread in regions such as the Yangtze River Delta, Pearl River Delta, and Beijing-Tianjin-Hebei. For example, in August 2022, Jia xing completed the first V2G public bus charging pile project in Zhejiang Province, supporting 24 V2G-enabled buses to charge and discharge simultaneously. In March 2023, Changzhou, Jiangsu, completed the country's first new-type power system station network interaction demonstration center, installing four V2G DC charging piles in the V2G area. In August 2023, Wuxi, Jiangsu, conducted reverse charging experiments for V2G, with 50 new energy vehicles participating. In just 30 minutes, the reverse power transmission reached nearly 2000 kW, and the transmitted electricity could meet the daily electricity needs of 133 households when integrated into the municipal-level virtual power plant platform.

3. Advantages and Challenges of V2G Technology

3.1. Advantages of V2G

V2G technology can mitigate the impact of electric vehicles on the power grid, achieving load management, improving power quality, integrating renewable energy sources, and providing new dispatching resources for power system regulation. This avoids excessive investment in grid and energy resources[5][6]. Furthermore, the application of V2G technology enables electric vehicle users to gain certain benefits from energy interaction with the grid, enhancing the overall competitiveness of electric vehicles.

From a long-term development perspective, V2G technology is a crucial component of the future power grid transformation and upgrade. From a business standpoint, V2G technology creates a win-win-win scenario for the grid, new energy vehicle owners, and automotive companies: V2G not only alleviates the pressure on the power grid caused by the mass development of electric vehicles but also utilizes EVs as storage devices for load regulation, improving grid operation efficiency and reliability, and reducing investment in energy storage construction. Through interaction between electric vehicles and the grid, owners can absorb energy during low load and low electricity price periods; and release energy during high load and high price periods, selling electricity back to the grid to achieve a profit margin. For instance, considering an electric vehicle with a 100kWh battery, if the

DOI: 10.54254/2754-1169/122/20242336

owner sells 50kWh of electricity to the grid at a peak price of 1 yuan/kWh and a valley price of 0.3 yuan/kWh, the owner could profit 35 yuan per transaction. For automotive companies, V2G technology reduces the cost of using electric vehicles for consumers and, in emergencies, allows EVs with power output capabilities to be used as emergency power sources, enhancing the practicality of electric vehicles and thereby promoting their production and sales. Hence, it can be said that V2G technology is beneficial for electric vehicle owners, the grid, and automotive companies, creating a triple-win scenario.

3.2. Challenges for V2G

The ideal Vehicle-to-Grid (V2G) model envisions a symbiotic and profitable ecosystem formed through effective interaction among multiple parties, including power generation stations, grid operators, charging station infrastructure providers, automotive companies, and electric vehicle users. However, under current technological conditions and market mechanisms, there are still numerous issues that need to be addressed to achieve this goal.

3.2.1. Standard System Awaits Improvement

The current standards for new energy vehicles and charging facilities in our country do not effectively regulate the V2G functionality. Existing standards for power grid interconnection and metering also have not yet considered the application requirements of vehicles and equipment with V2G capabilities. The standard system for data exchange related to V2G aggregation participation in electricity trading, operational control, and information security remains to be established and perfected. The V2G pilot demonstrations that have been conducted are mostly implemented by companies using proprietary protocols, which cannot support commercial applications.

3.2.2. Technological Immaturity

The applicability of various technologies on the grid side is relatively high, yet there are two hidden dangers worth noting. Firstly, the large-scale integration of users into the grid poses challenges to grid stability. Indiscriminately releasing the dispersed electric vehicle power sources to the large grid could create certain impacts. Such impacts are not only a matter of efficiency but could also affect grid safety.

Secondly, there are technical pain points on the user side of V2G as well. The total number of charging and discharging cycles and the depth of discharge per cycle are the main determinants of V2G battery degradation and lifespan[7][8]. Under normal circumstances, the lifespan of a power battery is typically 8 to 10 years, which is not long. Inevitably, V2G will increase the frequency of charging and discharging cycles and the depth of cycle discharge, accelerating the aging and degradation of power batteries, thus affecting the performance of electric vehicles. Moreover, a study by the Hawaii Natural Energy Institute in the United States stated that under constant power, V2G could significantly reduce battery life to 5 years or even less.

3.2.3. Need for Business Model Innovation

V2G technology faces two major commercial application challenges: high initial investments and uncertain returns on investment. Firstly, the high cost of V2G charging stations, due to the lack of mass production, results in their price being two to three times that of conventional DC charging stations, coupled with the need to extensively update the existing charging infrastructure, requiring substantial initial capital. Secondly, the revenue model of V2G is singular, mainly relying on arbitrage

DOI: 10.54254/2754-1169/122/20242336

between peak and valley prices. However, unclear market participation mechanisms and battery performance degradation over time make long-term operational costs high and revenues insecure.

3.2.4. Lack of Participation Enthusiasm from All Parties

From the perspective of new energy vehicle owners, the main concern is whether V2G revenues can effectively cover the losses due to reduced battery life and safety[9]-[10]. For automotive companies, the current lack of consumer demand for models with V2G functionality means there is little motivation to develop V2G models or design corresponding marketing and warranty plans. As for the grid side, considering the low discharge power and small discharge volume of a single new energy vehicle, along with the issues of being distributed and difficult to manage, compared to pumped storage energy and large-scale electrochemical storage, new energy vehicles as storage units are less efficient.

4. Recommendations for the Development of V2G Technology

4.1. Strengthen Top-level Design and Improve Standardization

Develop a V2G technology development roadmap oriented toward achieving carbon peak and carbon neutrality goals, and clearly define battery technology research, major scientific research projects, and commercial pilot application projects. Promote the construction of V2G technology agreement systems, systematically promote vehicle-pile agreements, pile-charging operation platform agreements, and charging operation platform-grid agreements, connect the technology chain, and establish a V2G technology agreement framework. Introduce documents regulating electric vehicle participation in power market ancillary services, price mechanisms, etc., standardize grid connection technology standards, engineering standards, charging and discharging standards, and "vehicle-pile-grid" information exchange standards. Clarify communication protocols between grid dispatching and charging pile systems, battery management systems; formulate systems and norms around power generation purchase, grid-connected power, etc., and promote the industrialized development of V2G technology through standardized and regulated management.

4.2. Strengthen Business Model Innovation

Support energy storage operators and grid companies to absorb the discharge of new energy vehicle power, encourage the exploration of the "vehicle-battery separation" model, and further research and develop battery health monitoring technology and battery life extension technology. Through real-time monitoring and management of battery status, finely control the charging and discharging behavior of batteries, extend battery life, and reduce costs for users and operators. Vehicle manufacturers, virtual power plant operators, and battery banks hold battery assets and commit to replacing batteries for users for free when batteries reach the decay limit, promote power batteries from personal valuable consumer goods to enterprise energy storage equipment assets, and avoid excessive user concerns about battery life.

4.3. Establish a Reasonable Incentive Mechanism to Effectively Stimulate V2G Market Vitality

To encourage participation in the V2G system by all parties, it is recommended to establish a profit-sharing mechanism covering vehicle manufacturers, battery manufacturers, grid companies, energy storage operators, and end-users. Such a mechanism can provide benefits to all parties through electricity services, frequency regulation, demand response, etc., encouraging them to promote the application and development of V2G technology. Governments and relevant enterprises can

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incentivize more users to participate in the V2G system by providing policies such as tax breaks, subsidies, preferential electricity prices, etc. Furthermore, increasing public awareness of the value of V2G through popularization education and publicity activities can increase user participation willingness. Automotive companies can develop financial products and services specifically for V2G businesses, such as battery leasing, electricity trading insurance, green credit, etc., provide financial support for V2G projects, reduce investment risks, and attract more investors to participate.

5. Conclusion

Although China has made some progress in V2G technology, it is still in the development stage, and achieving widespread popularity poses considerable challenges. In recent years, several policy documents have mentioned the development of V2G technology, but systematic strategic support is still lacking. Progress in key technology research and development has been relatively slow, and consumer awareness of fully utilizing the residual value of electricity has not been established. Therefore, China needs to accelerate its strategic layout in the V2G field, systematically carry out top-level design, improve standardization, focus on breaking through the key difficulties of V2G technology, innovate in business models, actively create an environment conducive to the development of V2G technology, and rely on the foundation of China's development of new energy vehicles to accelerate research and development and industrialization of V2G technology.

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