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A Review of V2G Technology Applications and Impact on the Grid

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Abstract

This paper first summarizes the development and application status of vehicle-to-grid (V2G) technology for electric vehicles, and explains the impact of V2G technology on the grid in terms of cost, carbon emission, and renewable energy utilization. The current problems of V2G technology are presented and the future outlook is given.

Keywords

Electric Vehicle; V2G; Grid; Charge and Discharge.

1. Introduction

As society, economy and technology continue to progress, human demand for energy is increasing. At the same time,the massive use of fossil energy has brought about a series of environmental problems such as global warming and declining air quality, and people urgently need a cleaner and more efficient way to travel. As one of the measures to cope with the increasing energy demand and climate change, Electric Vehicle (EV) has emerged and its market share is growing rapidly.

The industry analysis website Clean Technica has published the global EV sales ranking in 2021 [1],which shows that global EV sales reached nearly 6.5 million units last year, a 108% increase over the same period last year and a record annual increase since 2012.Among them, China ranked first with 2,939,800 new energy passenger vehicles sold, occupying 45% of the global new energy passenger vehicle market share. The market share of new energy vehicles is expanding, and the ensuing problems are becoming more significant, such as the influx of large numbers of electric vehicles into the evening charging peak, which will produce large power fluctuations and shocks, bringing serious challenges to the safe operation of the power grid.

To solve the above problems, Vehicle-to-Grid (V2G) technology has come into the vision of scientists, which refers to the establishment of bi-directional power transmission between the grid and electric vehicles, so that electric vehicles can not only passively charge, but also actively send electricity to the grid. The V2G system mainly consists of Battery Management System,Charge and discharge machine, Backend Management System and V2G Control Center. The V2G Control Center is the core of the system, which can forecast the load, make charging and discharging plans and post them to the Backend Management System for aggregation.V2G has been considered as the path to the future since the concept was introduced by Kempton and Letendre in 1997 [2].When EVs are connected to charging posts, they can provide a variety of services to the grid, such as reactive power support, active power regulation,load balancing,and current harmonic filtering, among others [3-5].In addition,V2G can reduce transmission losses by promoting local consumption in grids with high penetration of decentralized generation [6].

2. Application and Development Of V2G Technology

In practical applications,V2G is realized by connecting charging piles to electric vehicles. In the case of disorderly charging,V2G will aggravate the load and fluctuation of the grid, while in the case of

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orderly charging,V2G can achieve peak and valley reduction of the grid load, which is conducive to the optimization of the grid operation. In recent years, many scholars have conducted a lot of application research for the combination of V2G technology and various fields.

2.1 Theoretical Development of V2G Technology

Zhang et al [7] investigated a control method for using vehicle batteries as mobile energy storage devices by proposing a DC microgrid topology containing bi-directional radio energy transmission for electric vehicles. Waldron Julie et al [8] proposed a V2G control scheme combining one year of historical vehicle and energy data, aiming to increase local renewable energy consumption, offset vehicle charging demand to low carbon intensity hours,and offsetting local local building demand by storing in vehicle batteries from peak and carbon intensive hours. K.Nandha Kumar et al [9] proposed a half-hourly V2G capacity estimation algorithm based on real-time EV scheduling as part of a building energy management system (BEMS).The algorithm uses the predicted load demand of buildings without EV connections and the predicted charging profiles of EVs connected to the building to estimate the V2G capacity. To address the identity privacy leakage problem when charging and discharging vehicles with the grid,Shi et al [10] proposed a lightweight cross-domain identity authentication scheme. The scheme uses ECC and ECDSA to ensure the privacy of data and authenticity of identity between grid servers, while using blockchain to host server public key certificates. For authentication between the charging pile to the grid server,a faster symmetric encryption algorithm AES and message authentication code MAC are used to guarantee the privacy and authenticity of the data. Benedikt Tepe et al [11] propose a method based on the power and energy capacity curves of commercial electric vehicles, forming an optimized battery combination, using a genetic algorithm to determine the revenue of each possible pool of participating EVs.

2.2 Application Development of V2G Technology

In China,V2G charging pile equipment was used in the "2014 Tour of Qinghai Lake International Electric Vehicle Challenge" held in Xining City, Qinghai Province,and the problem of grid fluctuation due to sudden load changes caused by large-scale EV charging was solved by orderly charging control, which achieved good results.[12] In December 2021,the first V2G charging station in Xinjiang was completed in Urumqi Economic and Technological Development Zone, and in April 2022,the North China Division of the State Grid Corporation of China formally included V2G charging pile resources into the North China Power Peaking Auxiliary Service Market for the first time in China and formally settled the bill. Through V2G charging piles,electric vehicles expand from single charging to participate in real-time grid regulation and peaking auxiliary services in both charging and discharging forms.in January 2022,Nuvve USA announced a pilot program for the operation of V2G.The company will work with a number of power companies in the UK, Singapore and Japan to establish several demonstration sites in preparation for the commercialization of V2G technology.

3. The Impact of V2G on the Grid

V2G as a form of distributed storage offers higher scheduling flexibility than controlled EV charging, and it differs from other forms of distributed storage in its lower expected capital cost because it utilizes batteries purchased for transportation functions that are idle 96% of the time.[13] Therefore, how EVs are utilized and how they will affect the grid is a hot topic of research among scholars.

3.1 Study of the Stability of V2G on the Grid

Currently, literature has been devoted to charging modes and discharge strategies for electric vehicles. Gajduk et al [14] studied the discharge strategies for electric vehicles and showed that plug-in electric vehicle (PEV) participation in V2G systems can directly serve as a backup for renewable energy, support reactive power, regulate active power,balance loads The study shows that PEVs can directly serve as a backup for renewable energy,support reactive power,regulate active power,balance load,reduce peak load, reduce operating costs, generate social benefits,and even improve the transient

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stability of the grid under large disturbances (including bus failures,generator and branch trips) and large load changes.Zhang [15] analyzed the effects of different modes on daily load changes of the grid from three modes of disorderly charging, orderly charging, and orderly charging and discharging; at the same time, considering the effects of EV charging and discharging on battery life,an EV charging and discharging model was established, and the model was solved by using particle swarm algorithm, which improved the peak load of the grid and smoothed the load curve; Yang et al [16] used Monte Carlo method to construct an EV behavior model, a conventional charging model and a fast charging model. The impact of the number of EVs connected to the grid on the daily load curve was analyzed. The research results showed that the dynamic pricing mechanism and V2G mechanism can effectively guide EVs to participate in peaking and optimize the daily load curve.

3.2 V2G on the Grid Cost Study

The grid entry of electric vehicles increases the burden on the distribution network [17-18],and to avoid this potential negative impact, the power supply mode can be converted from centralized to decentralized, and V2G technology can achieve an incentive effect on the economic efficiency of the distribution network. Ai[19]established an optimal configuration model with the minimum annual cost of the sum of reactive power compensation device investment and network loss in order to improve the voltage level and reduce the network loss, and finally solved the model using genetic algorithm. Jiang et al [20] introduced V2G and distributed power as a coordination factor to coordinate the environmental benefits of generation in order to balance the costs between distribution companies and distributed power investors, and used a distribution network stochastic tide calculation method to solve the problem.Nworgu et al [21] evaluated the economic benefits generated by the entry of V2G into the distribution network by quantitatively analyzing the economic models of different V2G strategies.

In addition, the benign and complementary roles of V2G and renewable energy can provide new solution ideas for distribution grid reconfiguration, which,as the basis of demand-side management, has been an important factor influencing grid reconfiguration in terms of economic efficiency and stability [22]. Tabatabaee et al [23] conducted a study on the hybrid dispatch optimization problem of electric vehicles and renewable energy units by using a novel stochastic optimization method to solve the hybrid dispatch problem considering V2G and renewable energy stochasticity to reduce the total cost of grid operation.

3.3 Environmental Impact of V2G

Electric vehicles essentially shift the use of gasoline in the transportation sector to coal-fired power generation, leading to increased coal consumption and CO2 emissions in the power system. However,the impact of electric vehicles in terms of CO2 emissions depends heavily on the charging strategy. Therefore, given the factors of energy security, economic efficiency and environmental impact, it is crucial to use clean energy for power generation and establish regulations for energy efficiency and CO2 emissions for power dispatch. Li et al [24] investigated different scenarios of electric vehicle deployment in China and explored their energy mix, economic and environmental impacts. Zakari azadeh et al [25] proposed a system containing a large number of electric vehicles of smart distribution systems with multi-objective resource scheduling scheme and developed a conceptual model of EV management system. A generalized Benders decomposition is used to solve the large-scale multi-period problem addressed in the paper. zhao et al [26] investigate the potential net present revenue and GHG emissions provided by a typical fleet electric truck under V2G regulated service to analyze the relationship between the total cost of electric vehicles and their life-cycle GHG emissions and compare them with conventional diesel trucks.

In addition, as an important part of smart grid optimization, the optimal dispatching of microgrids is important for reducing environmental pollution (mainly greenhouse gas emissions such as CO2,SO2,NOx,etc.) [27-28].With the development of low-carbon transportation,V2G will become the most promising technology in new energy vehicles. With the characteristics of two-way interaction, efficient coordination,and mutual benefit,it can play a role in a series of energy-saving

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and carbon-reducing links such as promoting CO2 emission reduction, integrating renewable energy, and balancing the peak and valley of the power grid,so V2G technology can certainly lead a low-carbon revolution in the traditional automobile industry in the development process of technological innovation, end-market cultivation, and government orientation.

3.4 V2G's Use of Renewable Energy

In recent years, with the improvement of subsidy systems, there has been an increasing number of self-consumption battery installation projects supporting home PV in Germany, Australia and parts of the U.S. Fathabadi et al [29] constructed a new grid-connected solar electric vehicle charging station with V2G technology. The grid-connected solar electric vehicle charging station presented in this work converts solar energy into electrical energy and uses a fast and high-precision technique to track the photovoltaic array used in the charging station. Experimental results show that the charging station not only generates electricity to charge electric vehicles when the sun is shining, but also balances the load demand of the local grid in cloudy weather.

Based on the improved particle swarm optimization POS algorithm, Weng et al. proposed and verified the V2G operation mechanism and scheduling strategy for electric bus battery cluster based on the calculation example of wind-light-wood-storage island microgrid in Fushan Island, Dandong, Zhejiang Province,which is feasible and effective, and is conducive to reducing the investment and operation cost of the system.[30] At present, the field of electrochemical energy storage is developing relatively rapidly, and lithium battery technology is growing rapidly in the fields of frequency regulation, distributed microgrid, and user energy storage,and its application prospects are open, such as establishing V2G systems, optical storage electric vehicle charging and switching stations, and demand response charging.[31].

4. Conclusion and Prospect

This paper reviews the definition of V2G technology, the development and application of V2G technology, and the impact of V2G technology on the power grid, and introduces in detail the impact of V2G technology on the stability, cost and carbon emission of the power grid.

V2G technology can complete the two-way interaction of energy and information between the on-board battery pack and the grid, relieving the pressure on the grid and optimizing the function of the electric vehicle charging and discharging system. Countries around the world are actively introducing V2G technology to reduce the cost of electric vehicle battery packs based on V2G technology to achieve green and clean economy while mitigating fluctuations in the load of renewable energy into the grid and ensuring optimal grid operation.

However,V2G technology has problems of location privacy, identification privacy,etc.V2G technology leads to deep discharge of EVs, which is at the cost of battery degradation of EVs, which reduces the battery life.Therefore,V2G technology needs to be further developed if it is to be used on a large scale.

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