Research and Analysis on V2G Technology and Its Application

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Abstract. In recent years, with the increasing popularity of new energy vehicles and the gradual increase in the number of charging piles, V2G technology has gradually emerged. Compared with the traditional grid charging system, which mostly uses natural energy, has unstable charging, and is difficult to interact with the grid, V2G technology uses new energy electric vehicles to interact with the grid, which has a better effect of adjusting the grid balance, peak shaving and filling, adjusting power consumption, and allowing more users to participate in power generation. This article studies the definition and principles of V2G technology, as well as its development history, relevant research and innovation achievements in this field. Secondly, the article expounds on the basic working principle and practical application of V2G, including interaction control systems, grid interaction, and virtual power plants. In order to verify the basic principles of V2G technology, this article constructs and simulates a Simulink circuit to convert the direct current of electric vehicles into alternating current of the grid by step-up inverters, further verifying the basic working principles of V2G.

Keywords: V2G technology, Electric vehicles, Energy to grid.

1. Introduction

The rapid growth of energy demand in the world today has led to a sharp increase in the increase of energy of consumption, which has aggravated the global environmental pollution. In recent years, the world EV industry has developed rapidly. It is estimated that in 2030, about 36% of the world's cars will be EV[1]. By the end of June 2022, the number of new energy vehicles in China has reached to 13.1 million, in which EV accounts for 79.78%, according to the data of the Ministry of Public Security [1]. The Ownership of new energy vehicles and EVs from 2016 to 2022 is shown in TABLE I.

The numbers of charging piles in China from 2016 to 2022 is shown in Fig. 1. In terms of the construction of electric vehicle charging infrastructure, according to the data released by the China Electric Vehicle Charging Infrastructure Promotion Alliance, there is a rapid growth of charging piles from 2016 to 2022 in Fig. 1.

In 2022, charging infrastructure added 2.59 million units, of which the increase of charging piles increased by 98.9% to last year, the total scale of national charging infrastructure reached 5.21 million units [1]. Compared with the growth rate of new energy vehicles, the construction of charging infrastructure still needs to be accelerated.

Tab. 1 Ownership of new energy vehicles and EVs from 2016 to 2022[1]

Index (One hundred million)	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
National car ownership	1.94	2.17	2.4	2.6	2.81	3.07	3.19
New energy vehicle ownership	91.3	153.4	260.8	380.9	492	784	1310.1
Proportion of new energy vehicles in China	0.47%	0.71%	1.09%	1.47%	1.75%	2.60%	4.11%
Electric vehicle ownership	72.6	125.5	211.4	309.3	400.1	640	1045
Proportion of EVs in new energy vehicle	79.5%	81.8%	81.1%	81.2%	81.3%	81.6%	79.8%

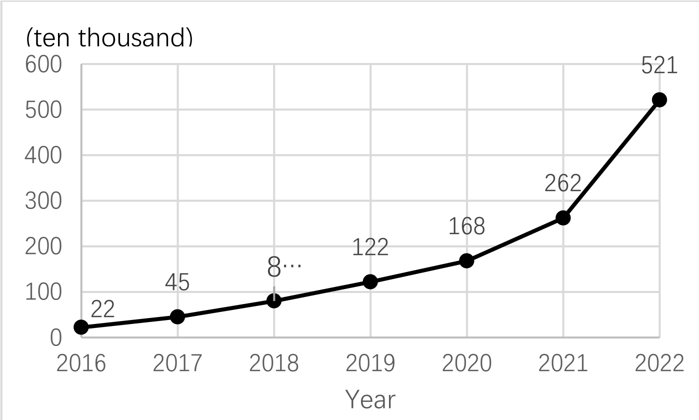

Fig. 1 Numbers of charging piles in China from 2016 to 2022[1]

This article is a study on V2G technology. Firstly, in Chapter 1, the author explains the basic definition and principles of V2G technology, as well as the meaning of scaling V2G technology. Secondly, Chapter 2 discusses the development of V2G-related technology, including pilot examples in China and related inventions and innovations based on V2G technology both domestically and internationally. Chapter 3 describes the basic principles of V2G technology, the shortcomings of traditional charging systems, the components of V2G systems, and how they work. It also discusses the practical applications of V2G technology, primarily focusing on the interactive and coordination control system, grid interaction, and virtual power plants. In Chapter 4, the author uses Simulink software to simulate the basic principles of V2G technology, including the use of step-up inverters for electric vehicles to charge the grid. Finally, Chapter 5 summarizes the entire article.

2. V2G definition and basic theory

2.1. V2G definition

Vehicle to grid refers to the interaction of energy and information between electric vehicles and the power grid through charging piles. It can be divided into charging and bidirectional charging according to the energy flow direction [2]. The nature of car network interaction is that users use electric vehicles to produce interaction values, according to their participation in the production of micro energy interaction, in which process users liberate their hands.

when the scale of new energy vehicles has developed to a certain extent, it changes to large-scale vehicle network interaction. It means that based on the external environment such as the new power system, power market, digital grid and so on [1].

V2G technology can enable the batteries of electric vehicles not only to store electricity to provide power, but also to store the remaining power to support the grid balance by connecting it to the grid [3]. This technology can regard electric vehicles as flexible loads, rather than loads that only consume electrical energy.

2.2. Development process

Since 2020, China has introduced a number of policies to promote V2G technology progress, among which the New Energy Vehicle Industry Development Plan is issued by the State Council. It clearly proposed to support local V2G pilot work and promote the development of V2G.

The number of charging piles in Shanghai exceeds 280,000, with the vehicle pile ratio close to 1:1, of which 190,000 are private charging piles, and 50,000 and 40,000 are public and 40,000 respectively. At present, there are three V2G demonstration areas in Shanghai, with more than 10 EVs participating in the discharge of about 500 kilowatt hours per month. In recent years, Shanghai has been actively exploring the use of economic incentives to encourage all types of controllable load resources to participate in demand response trials.

The large-scale commercial operation demonstration project of V2G in industrial parks has been officially launched in Hebei. Currently, Great Wall Motors has built the country's largest V2G charging and discharging station, with a total of 50 V2G charging piles. V2G vehicles participating in the pilot can participate in energy and power system transactions through a charging app. Nowadays, the company's brand's new energy vehicles have been equipped with V2G functions, and can provide at least 1,500 V2G charging and discharging cycles while guaranteeing a driving distance of 8 years.

Chongqing Public Transport Group's new energy company has established a solar storage charging demonstration station. The project is expected to generate 100,000 kWh of green electricity per year, equivalent to saving 33 tons of standard coal and achieving an annual carbon reduction of 95 tons. In the future, this new energy company will promote the innovative development of the integration of new energy vehicles and green energy through the demonstration of solar storage charging, V2G and other technology applications, and construct a "virtual power plant" in a real scene, to contribute to the development of public transportation.

2.3. Technical achievements

V2G technology is the interaction process between the power grid and EV. Daim and his team proposed a system called the smart grid, in which electric vehicles can also act as energy sources through vehicle-to-grid operations, sending electricity back to the grid to prevent or delay blackouts [4]. Charging and V2G services are optimized for grid load, while ensuring they meet the demands of property owners in terms of scheduling and scope. The latest technological advancements in distribution and load management are achieved.

Cheng Liu and Jian Qin highlight some issues that may arise when a large number of distributed sources are connected to the distribution network. The flow distribution of the distribution network inevitably changes and the protection devices of the distribution network are inevitably affected, which may seriously affect the reliability of the distribution network [5]. Additionally, the connection of distribution to the network has certain impacts on the power quality, scheduling management, and operation of the network [5].

In addition to technical requirements, it also needs to reach the needs of both the power grid and the users. Shanting Ma's team presents a V2G electric vehicle charging and discharging model with coordinated scheduling of photovoltaic output in residential communities [6]. The authors obtained the driving pattern of electric vehicles and photovoltaic generation characteristics based on their probability density distributions, and optimized the response to the discharge state of electric vehicles through this model.

Zhengwei Qu's team developed a probability model for wind power output that takes turbulence into account and uses normal distribution to describe the randomness of wind speed [7]. A probability model for vehicle-to-grid was also established, and corresponding probability distributions were used to describe the initial charging and discharging time, daily mileage, and charging status of electric vehicles [7].

2.4. Operation principle

When the power demand is high, it is allowed to transmit the energy stored in the battery to the power grid. when the power demand is low or the renewable energy Power generation is high, it reduces the dependence on fossil fuel power generation by using electric vehicle charging, so as to achieve energy conservation and carbon balance the power load.

When a large number of EVs are charged at the same time, it will cause huge pressure to the power grid operation, so it is necessary to study how to reduce the load of power grid operation.

In the traditional electric vehicle charging system, energy can only flow from the grid side to the vehicle side. With the popularization of V2G technology, the energy interaction with the power grid can be realized by controlling the charging and discharging of electric vehicles. Electric vehicles are regarded as loads when charging and as energy storage devices when discharging. At present, the power grid and electric vehicles are mostly connected by cables. In order to achieve two-way flow of energy, complex two-way converter devices are required.

V2G system consists of AC power grid, two-way AC/DC converter, BD - WPT system and electric vehicle[8]. When the electric vehicle is charged, the AC power grid gives power to the BD-WPT system through the circuit, and the electric energy flows to the electric steam in the way of wireless transmission [8]. The V2G system is shown in Fig. 2.

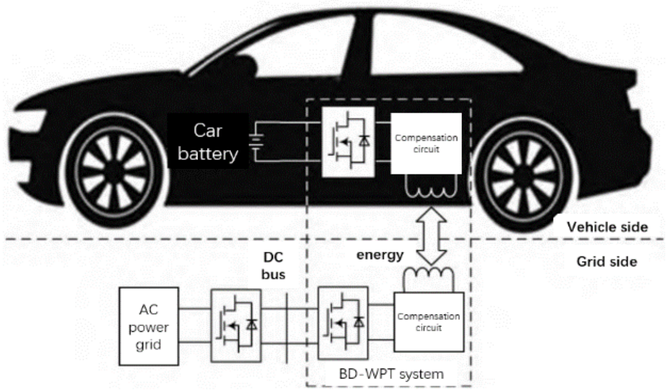

Fig. 2 V2G system [8]

The DC-AC inverter is an essential part of the V2G circuit. It converts the direct current output from the battery into the alternating current required by the grid, or converts the alternating current from the grid into direct current and outputs it to the battery for charging. The inverter also needs to be controlled and adjusted based on the battery status and grid requirements.

The inverter can use a single-phase full-bridge inverter. Due to the large amplitude of the input and output voltage, an isolation transformer needs to be added. The inverter consists of two reverse-phase parallel diodes and switch tubes. There is also an isolated transformer with a center tap on the original side. The inverter is shown in Fig. 3.

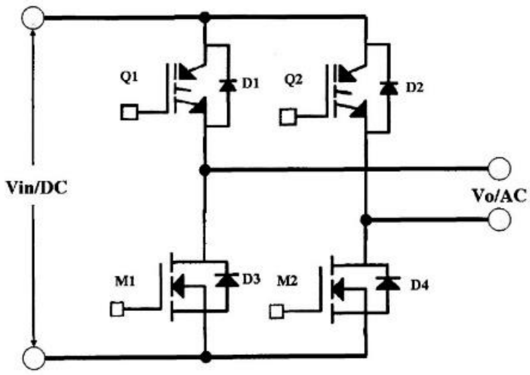

Fig. 3 Single-phase full-bridge inverter

3. Practical application

3.1. The interactive and coordination control system

State Grid Nari Technology Company and other units have developed AC charging piles, high-power DC chargers, electric vehicles and power grid interactive coordination control system [2]. The interaction and coordination control system of electric vehicle and power grid adopts V2G orderly optimization. The systems can real-time operate the status of electric vehicle and charging equipment, and simulate the reflection of large-scale electric vehicle charging and discharging on the power grid. It realizes the information interaction between the electric vehicle and power grid interaction, verifying the extensive adaptability of V2G technology.

This system is also an electricity network that combines a set of information, communication, and other advanced technologies for monitoring and managing the transmission of power from all power sources to meet the varying power needs of end-users [4]. It can better coordinate the demands and abilities of all generators, grid operators, end-users, and power market stakeholders. It can also operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts, while maximizing the system's reliability, resilience, and stability [4].

In 2018, the interactive and coordination control system of electric vehicles and power grids was put into operation in Jiangsu Province with good results [2]. The promotion and application of the system has got the coordinated development of green transportation, new energy vehicle and electric vehicles industries, and smart grid in Jiangsu Province, achieving the goal of low-carbon travel.

3.2. Electric vehicle to grid energy storage

The electric energy stored by electric energy can charge the power grid to achieve "peak shaving and valley filling", reducing the investment cost of the power system, and improving the stability of the power grid. As a resource with huge energy storage potential, electric vehicle participates in the grid structure of energy storage shown in Fig. 4.

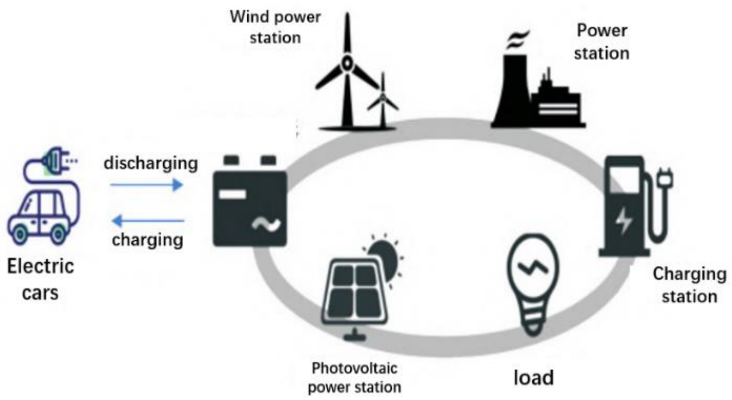

Fig. 4 Strcture of vehicle to grid energy storage [9]

From the current state of energy storage technology, a single energy storage method cannot meet the diverse needs of energy storage. Hybrid energy storage systems combine high-capacity storage with high-frequency storage to effectively improve the output capacity of the energy storage system and extend the cycle life of the energy-type energy storage. Yumei Wang and Zhaochu Song established a Hybrid energy storage system model composed of batteries and supercapacitors after building a power distribution network to study the improvement of reliability [10]. The hybrid energy storage is combined with wind turbines and photovoltaics in a certain way and connected to the distribution network [10]. In the event of equipment failure, the hybrid energy storage network is connected to the energy storage system. Due to the stable backup power source, it has a good supporting role in the reliability of the distribution network.

3.3. Virtual power plants

In addition, due to the continuous development of distributed energy, virtual power plants have gradually materialized from the conceptual stage. Electric vehicle is the most important link in virtual power as the representative of new energy storage equipment.

The virtual power plant model integrates wind turbines, photovoltaics, gas turbines, energy storage systems, charging piles, electric vehicles, and other common electrical loads [11]. It coordinates user-side loads and distributed sources with electric vehicles supplying power back to the busbar [11]. The power grid and natural gas companies are the primary energy supply sources for the grid. New energy generation units include wind power generators and photovoltaic power plants, while gas turbines consume gas to supply power to user-side loads.

The application of virtual power plant can solve the problem of the difficulty of EV and renewable energy scheduling. Virtual power plants aggregate distributed generation, store energy, control load equipment, and participate in demand response through information technology and software algorithms [9]. Compared with other types of power grids, virtual power plants have the advantages of low cost and high efficiency.

4. Simulation of V2G technology

4.1. Software used

MATLAB is a powerful scientific computing software and programming language that is widely used in various engineering, scientific, and financial fields for computational analysis, modeling, and simulation.

MATLAB provides a powerful modeling and simulation environment that can be used to model and simulate various systems, including physical systems, control systems, computer systems, communication systems, etc. The simulated systems can reproduce the behavior of actual systems, helping engineers and scientists better understand and analyze system performance.

Simulink is a model-based, multi-domain simulation and model design tool developed by MATLAB company. It is an extension toolbox of MATLAB. It can help engineers design electromechanical systems, signal processing systems, control systems and so on in a graphical way, and complete system simulation analysis and optimization design.

Simulink allows engineers to intuitively build systems by dragging and dropping icons through a graphical design interface. Users can easily create multiple modules and combine them into an overall graphical model.

In this article, the writer mainly used Simulink to build relevant circuits of simulation.

4.2. Simulation results and analysis

The circuit mainly uses a unidirectional full-bridge inverter to simulate the electric vehicle and the power grid. The DC part of the circuit consists of a DC power supply, which represents the electric vehicle. One transformer is used to increase the voltage to the specified value due to the large amplitude of the power grid voltage. The inverter part is connected to an LC filtering network to filter the output waveform. The final output of the circuit represents the power grid. The circuit adopts bipolar SPWM waveform because it is easier to implement than unipolar modulation. The circuit structure is shown in Fig. 5.

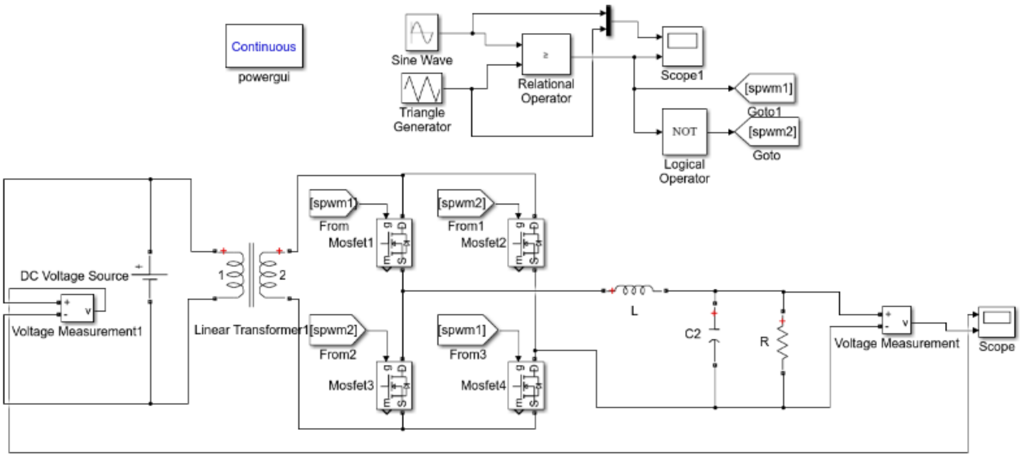

Fig. 5 Simulink circuit

A sine wave can be equivalently replaced by many stepped pulses. If there are more pulses in a period, the AC waveform displayed is smoother. The SPWM modulation circuit is shown in Fig. 6.

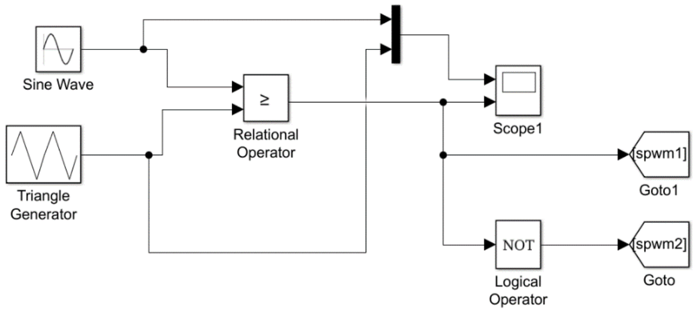

Fig. 6 SPWM modulation

To obtain the SPWM waveform, the circuit uses a sine wave and a triangular wave to output through a comparator. Its parameters are set as follows: the amplitude of the sinusoidal wave is 0.95 V, the frequency is 50 Hz, the amplitude of the triangular wave is 1 V, but the frequency is higher, which is 10 kHz. If the sine wave is greater than the triangular wave, the output is 1V, and vice versa for 0. The signal output is the SPWM1 signal, and the inverse is the SPWM2 signal. In this way, many suitable pulse waves can be obtained. Connect the SPWM1 output to switch tubes 1 and 4, and the SPWM2 signal to switch tubes 2 and 3. The output wave of SPWM modulation is shown in Fig. 7.

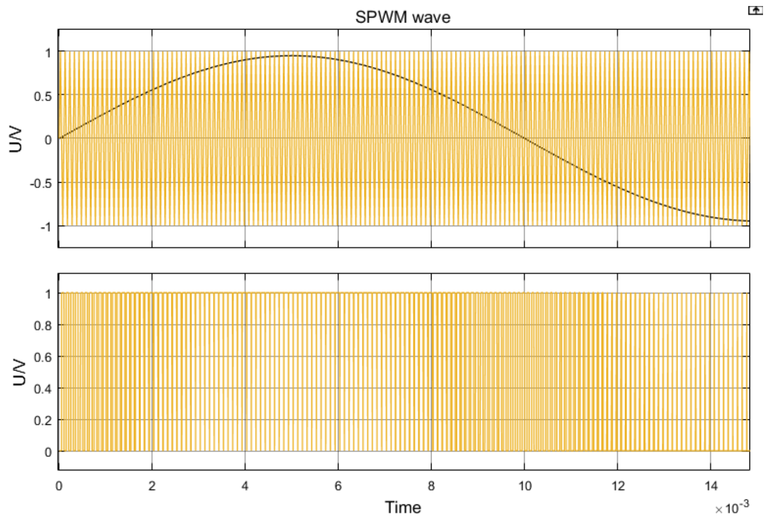

Fig. 7 SPWM modulating wave.

Other parameters of the circuit are set as follows: DC power supply 12Vpp, transformer ratio 1:19, filter inductance set to 23mH, filter capacitance set to 10uF, and load resistance set to 100ohms.

The input and output wave are shown in Fig. 8. In the oscilloscope, the input waveform is a 12V DC voltage and the output waveform is a 220V AC voltage. Due to the effect of the SPWM modulation signal, the AC voltage is relatively smooth. Therefore, under ideal conditions, this circuit can be regarded as the reverse power supply of the electric vehicle to the power grid.

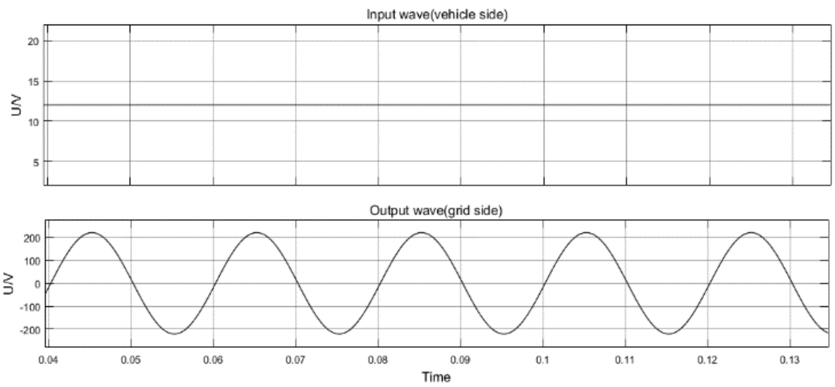

Fig. 8 Simulation results

5. Conclusion

This article first elaborates on the background of the vehicle to grid technology and the development of new energy vehicles and charging piles. The second chapter describes the definition of this technology and the specific meaning of large-scale vehicle network interaction, and then describes the development process of V2G technology, including some domestic urban charging pile pilots and regional beneficial impacts. This chapter also briefly introduces the research and achievements of this technology. Then the core principles of this technology are described, including two-way AC-DC converters, radio energy transmission systems, and power grid energy transmission. The third chapter describes the practical application of V2G technology, including the interaction and coordination control system of the vehicle network, the working principle of the grid to store the remaining energy of electric vehicles, and the principle and effect of the virtual power plant. The practical application of each technology reflects the basic principle of this technology, which has certain significance for the power adjustment of the power grid. Chapter 4 focusses on the simulation of the basic DC-AC inverter on the Simulink software. By building relevant circuits, the DC waveform successfully outputs the AC waveform, which verifies the most basic working principle of vehicle network interaction.

However, there are still many shortcomings in the current V2G technology. For example, there is an economic issue. Currently, the cost of accommodating new energy sources is mainly beard by power generation and power grid companies, and the incentive that is passed on to end-users through the power market is limited. The power market transaction price is also difficult to drive large-scale EV user participation in interactions. If reasonable mechanisms can be developed to pass on the benefits to users, it will surely attract more EV users to participate in vehicle to grid interactions. There are also safety issues. Vehicle-grid interaction technology involves battery management and interaction, which requires consideration of security, privacy protection, and communication signal safeguards. Therefore, it is necessary for resource aggregators to pay attention to user interaction and guidance issues.

The significance of this article is to understand the theoretical and practical application of the technology through various studies of the technology, and provide basic assistance for the comprehensive application of the technology in the future.

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