

# Simulation of on-board charging and discharging power supply for electric vehicles with V2G technology

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**Abstract.** With the increasing number of electric vehicles (EVs), the demand for charging facilities and power networks also gradually increases. The concurrent charging of a considerable number of EVs might result in an escalation of the load on the power grid and the pressure on energy supply. This paper first introduces the principle of Vehicle-to-Grid (V2G) technology, its performance status, and domestic market mechanism and policy support. It discusses the application of Sinusoidal Pulse Width Modulation (SPWM) technology in rectifier and inverter circuits, which provides the foundation for building simulation models. The charge and discharge strategy of EVs was simulated by Simulink, the correctness and feasibility of the proposed control strategy were verified, and the influence of V2G technology on the stability of the power grid, power quality, and frequency regulation was evaluated. These assessments help to understand the real-world effects of V2G technology and support its commercialization and deployment on a wider scale.

**Keywords:** V2G; EVs; Energy storage; Simulink simulation.

## 1. Introduction

With the rise in the number of electric vehicles, there is also a gradual increase in the demand for charging facilities and power networks. The concurrent charging of a significant number of EVs could lead to a heightened load on the power grid and increased pressure on energy supply. This paper starts by introducing the principle of V2G technology, along with its performance status and the support from domestic market mechanisms and policies. It further discusses the use of SPWM technology in rectifier and inverter circuits, which serves as a foundation for constructing simulation models. The charge and discharge strategy for EVs was simulated using Simulink, confirming the correctness and feasibility of the proposed control strategy, while also assessing the impact of V2G technology on the stability of the power grid, power quality, and frequency regulation. These assessments aid in understanding the real-world implications of V2G technology and support its commercialization and broader deployment [1].

This paper explores the potential of V2G technology in grid load regulation, energy efficiency, user preference, and environmental impact reduction by modeling the V2G technology in electric vehicle on-board charger/discharger based on enabling Simulink simulation platform. The simulated waveforms in the model are analyzed by building a Simulink simulation model and controlling the circuit with SPWM as the IGBT trigger signal. This paper aims to explore the potential of V2G technology for grid "peak shaving and valley filling", energy results, user benefits, and environmental impact reduction, and to provide theoretical support for the design and construction of future smart grid technology and smart EV charging systems.

## **2. Basic theory of EVs and V2G technology**

### **2.1. Background and current status of EVs**

In recent years, sales of electric vehicles (EVs), which are a key component of clean energy transport, have rapidly increased due to rising concerns about environmental protection and energy sustainability. The development of electric vehicles began with concerns about environmental pollution and climate change associated with traditional fuel vehicles. In recent years, advances in battery technology and declining costs have also been important factors in driving the popularity of electric vehicles. With the development of advanced battery technologies, such as lithium-ion batteries, the range of electric vehicles has continued to increase, and their costs are gradually approaching or even falling below those of traditional internal combustion engine vehicles.

### **2.2. The significance and advantages of adopting V2G technology**

The adoption of V2G technology for electric vehicles enables them to be more than just energy consumers, but also dispatchable loads for the power system. Through intelligent control, EVs can be discharged or recharged when they are needed by the grid, thus helping to balance the load on the grid and reduce the pressure on power demand during peak hours, to improve the stability and efficiency of the grid. At the same time, large-scale access to EVs can improve the flexibility and resilience of the grid. With V2G technology, the power system can respond more flexibly to energy fluctuations and demand changes, reducing energy waste and optimizing power system operation.

From the perspective of economic, the adoption of V2G technology not only enhances the economy and user benefits of electric vehicles but also contributes to social and environmental benefits. The participation of EVs in grid services through V2G technology can provide an additional source of revenue for vehicle owners. For example, EVs can participate in energy scheduling in the electricity market, perform charging and discharging operations according to electricity demand, and gain revenue through the market mechanism, thus enhancing the economy of EVs. The vigorous development of V2G technology is more conducive to reducing carbon emissions and air pollution, promoting urban air quality improvement, and contributing to environmental protection and sustainable development goals. In addition, the promotion of V2G technology also provides opportunities for development and innovation in emerging technology areas.

### **2.3. Performance and status of V2G technology**

The principle of V2G technology is vehicle-to-grid energy flow, which realizes the flow of energy from the grid to the electric vehicle during the traditional charging process while allowing the electric vehicle to reverse charge the grid. Through the centralized control of the EV vehicle charging and discharging process, the impact of EVs on the grid in the traditional mode can be effectively mitigated [2].

Currently, there is a large number of research on the technical aspects of V2G by scholars at home and abroad. The team of Chunjie Li et al. analyzed the integrated power converter topology under different charging/discharging modes and gave the control strategy undercharging/discharging modes [3]. The experiment finally gives the simulation and experimental results. The simulation and experimental results are given at the end of the experiment to verify the feasibility of the multi-port integrated on-board power converter. Zhou Jingwen et al. team researched the EV charging and discharging system topology and control strategy based on the V2G technology, and put forward a strategy of dual closed-loop control of voltage and current and finite-set-model predictive current control for charging and discharging, respectively, which can better inhibit the harmonics of the grid-side currents and reduce the harmonic distortion rate. distortion rate [4].

Based on the above study, this paper proposes and designs a simulation scheme to build a system model of V2G technology in Simulink for on-board charging and discharging power supply of electric vehicles.

### 3. Analysis of SPWM technology and the fundamentals of rectifier and inverter circuits

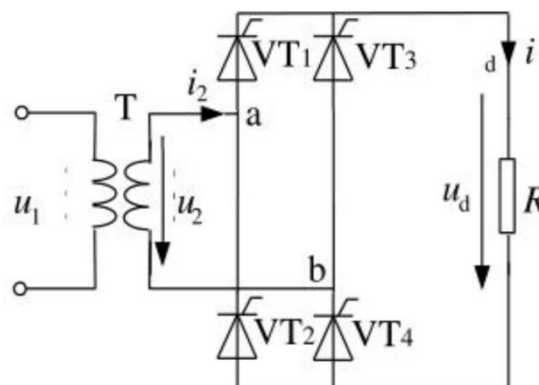
The SPWM technology-based rectifier inverter circuit can effectively transform DC power into controllable AC power, offering the necessary power quality and power regulation capabilities for various applications. This paper constructs a simulation of the V2G technology system model for electric vehicle on-board charging and discharging power supply in Simulink, utilizing the rectifier and inverter circuits based on SPWM technology [5].

#### 3.1. Theoretical basis of SPWM techniques in power electronics

SPWM technology is based on PWM to change the modulation of the pulse, pulse width time duty cycle according to the sinusoidal law arrangement, after driving the isolation circuit, in order to give the signal to improve the driving ability of the basis of isolation of the output and control circuits, to effectively ensure the safety of the control circuit [6]. The control circuit can be effectively secured.

#### 3.2. Basic analysis to rectifier and inverter circuits

Rectifier circuits are circuits that convert alternating current (AC) into direct current (DC). Since the voltage and direction of the alternating current is variable, it is not used directly in real life. Commonly used components are diodes, thyristors, transformers and so on. The single-phase bridge controllable rectifier featuring a resistive load is depicted in Fig.1.



**Fig. 1** Single-phase bridge controllable rectifier with resistive inductive loads

$$U_0 = \frac{1}{\pi} \int_{\alpha}^{\alpha+\pi} \sqrt{2} + U_2 \sin wtd(wt) = \frac{2\sqrt{2}}{\pi} U_2 \cos \alpha = 0.9U_2 \cos \alpha \quad (1)$$

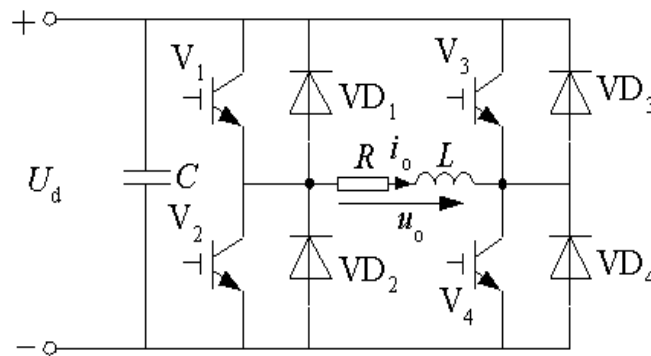
During the positive half of  $u_2$ ,  $w t = \alpha$  moment, gate trigger pulses are simultaneously applied to VT<sub>1</sub> and VT<sub>4</sub>, VT<sub>1</sub> and VT<sub>4</sub> conduct, and the output voltage  $u_0 = u_2$ ; during the negative half-cycle of  $u_2$   $w t = \pi + \alpha$  At the negative half-cycle of  $u_3$ ,  $= +$  moment, apply gate pulse to VT<sub>2</sub> and VT<sub>3</sub> at the same time, because VT<sub>2</sub> and VT<sub>3</sub> have been subjected to the positive anode voltage, so the two tubes conduct, at this time, the output voltage  $u_0 = -u_2$ .

The average value of the rectified output voltage is:

$$U_0 = \frac{4U_d}{\pi} (\sin wt + \frac{1}{3} \sin 3wt + \frac{1}{5} \sin 5wt + \dots) \quad (2)$$

When  $\alpha = 0$  when  $U_{0 \max} = 0.9U_2$ ;  $\alpha = \pi = 0$ . Therefore, the single-phase bridge controllable rectifier with resistive inductance load has the following characteristics  $U_0 = 0$ . Therefore, the single-phase bridge controllable rectifier with resistive inductive loads has  $\alpha$  has a moving range of  $0$  to  $\pi/2$ .

An inverter circuit is a circuit that converts DC power into AC power. The inverter circuit is actually a frequency converter that converts DC power into AC power which is shown in Fig.2. Commonly used components are thyristors, IGBTs, and so on.



**Fig. 2** Full bridge inverter circuit

$U_d$  The expansion of the rectangular wave  $u_o$  into Fourier series yields

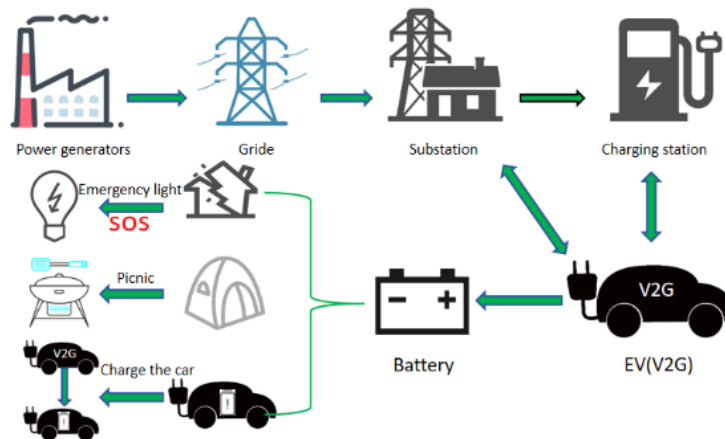
$$U_{o1m} = \frac{4U_d}{\pi} = 1.27U_d \tag{3}$$

where the amplitude of the fundamental wave  $U_{o1m}$  and the RMS value of the fundamental wave  $U_{o1}$  respectively:

$$U_{o1} = \frac{2\sqrt{2}U_d}{\pi} = 0.9U_d \tag{4}$$

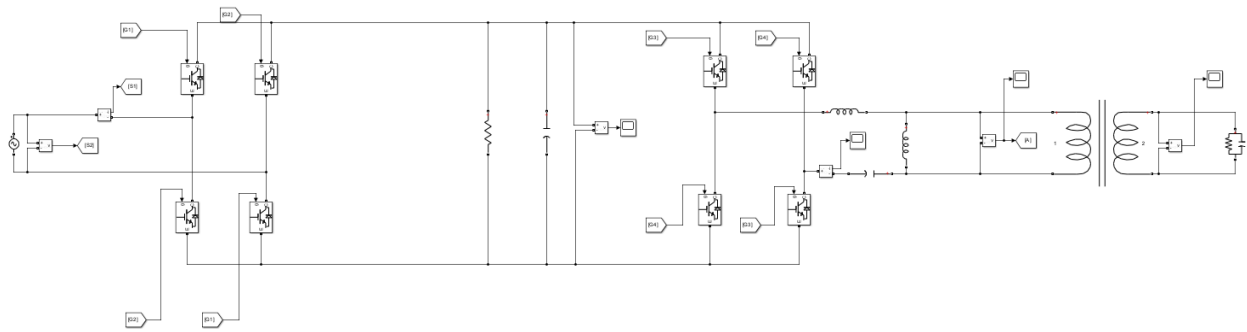
#### 4. Simulink simulation and result analysis

The basic principle of the EV on-board battery charging and discharging model based on V2G technology is that the current from the grid is inversely rectified and converted to AC power at the on-board power supply side, and the power stored in the EV is converted to alternating AC power through the rectifier circuit. Considering the difference in voltage level between the AC power obtained directly from the EV and the power used at the user's end, the processed current is rectified through a transformer to meet the power demand at the load side. The actual application flowchart is depicted in Fig.3.



**Fig. 3** Flow chart of EV on-board battery charging/discharging model

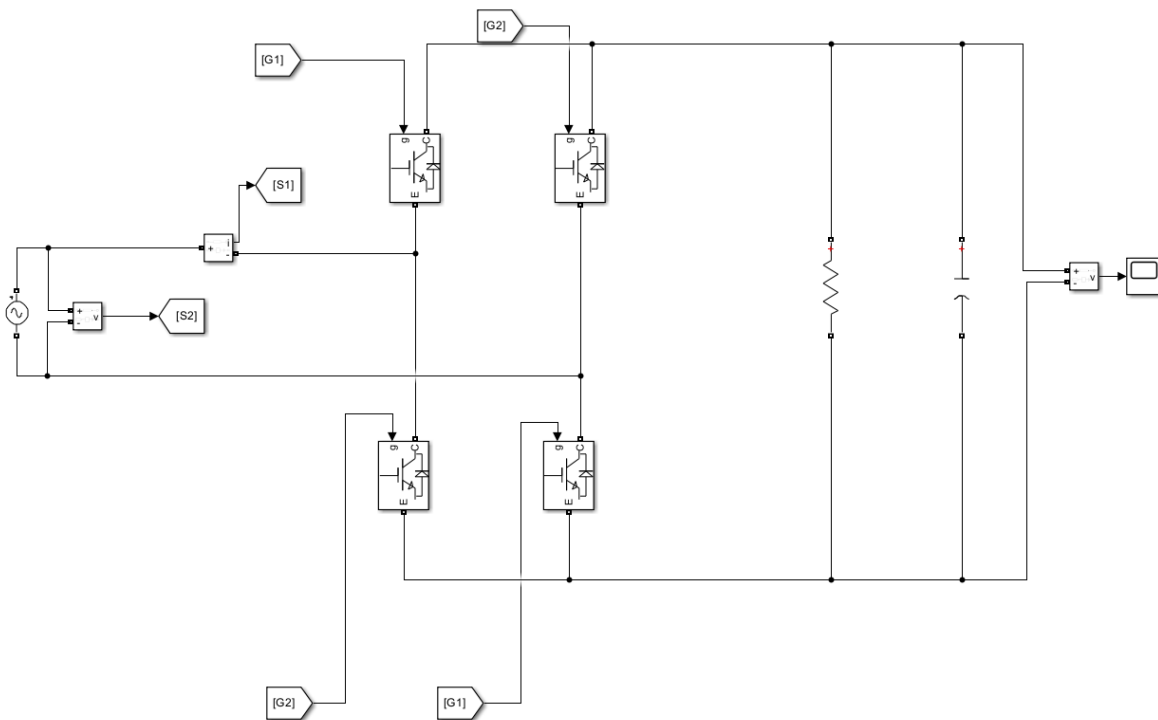
In this paper, the Simulink module is used to build the EV on-board battery charging and discharging model, and the EV on-board battery charging and discharging is processed in modules, and the output waveforms of each part are analyzed step by step. The overall simulation model diagram is shown in Fig.4.



**Fig. 4** Circuit diagram of EV on-board battery charging/discharging model

#### 4.1. AC-DC Rectifier Circuit

The simulation circuit simulates the flow of power from the grid system to the on-board power supply of the EV, i.e., the rectifier circuit where the current is converted from AC to DC. The built circuit diagram model is depicted in Fig.5.



**Fig. 5** Model diagram of AC-DC rectifier circuit

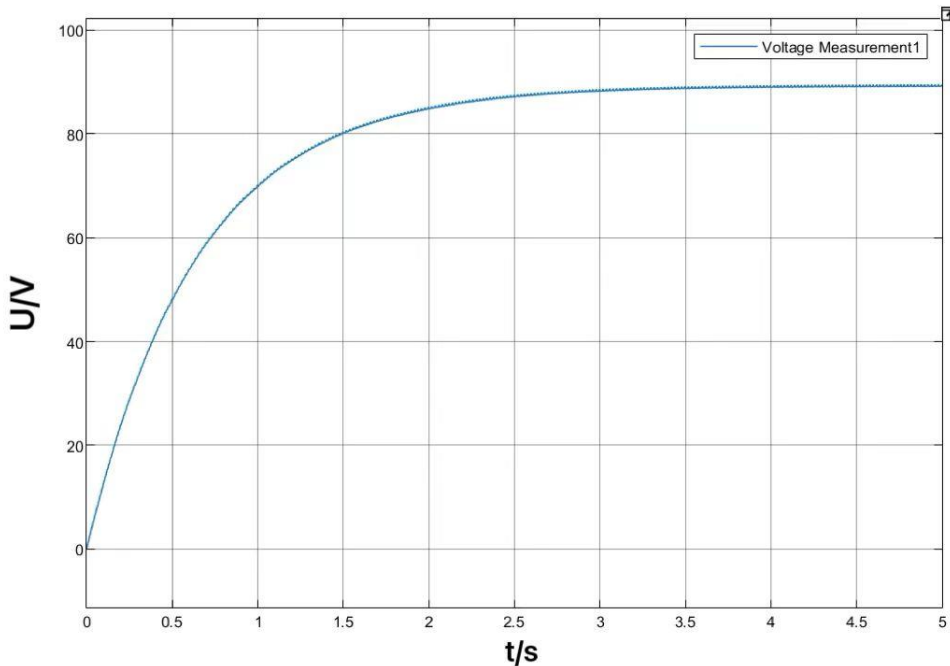
##### 4.1.1 Parameter setting

The simulation circuit consists of a control circuit and a main circuit. An AC voltage source with a frequency of 50Hz and voltage amplitude of 220V is used at the input. Among them, the four bridge arms of the main circuit are built by IGBTs and the inductive load is built by Series RLC Branch, while the load R is set to 10Ω, capacitor C is 100F.

Bridge arm 1 (upper left) and bridge arm 4 (lower right), bridge arm 2 (upper right) and bridge arm 3 (lower left) use trigger pulses in a uniform manner, with the trigger signals generated by the Pulse Generator module. Bridge arm 1 and bridge arm 4 use pulse signals without delay, while bridge arm 2 and bridge arm 3 use phase-lagged 180° trigger pulses, and the pulse width is 5%.

##### 4.1.2 Simulation analysis

At the end of the simulation, the output voltage waveform is obtained at the output of the rectifier circuit as depicted in Fig. 6.

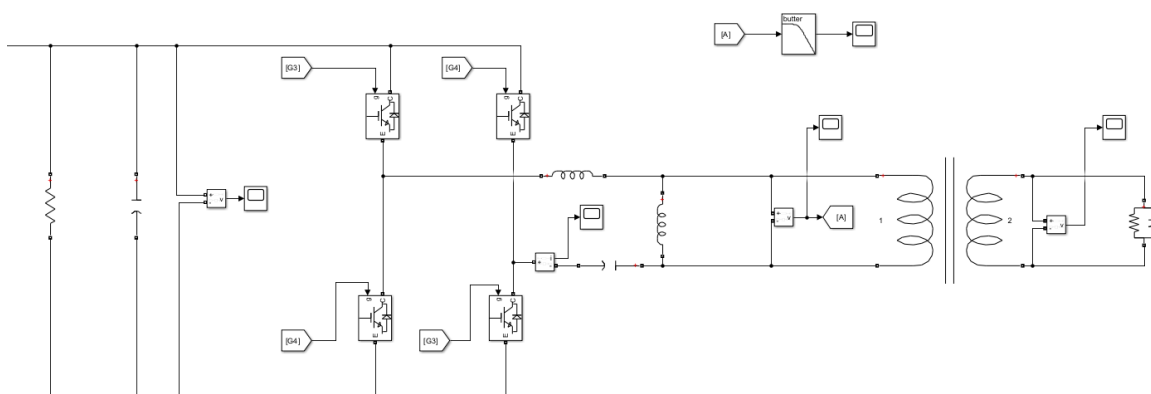


**Fig. 6** Output voltage waveform of rectifier circuit

The theoretical value of the output voltage waveform after passing through the rectifier circuit should be DC voltage. It can be intuitively seen from the image that after a certain period of time, the waveform tends to be stable. The image proves that the AC-DC rectifier circuit realizes the function of voltage changing from AC to DC, which accords with the experimental expectation.

#### 4.2. DC-AC Inverter Circuit

The simulation circuit simulates the power from the electric vehicle energy storage power supply through the inverter from DC to AC conversion process, that is, the current from DC to AC conversion of the inverter circuit. The rectified load end is used as the power supply for the inverter circuit to obtain Fig. 7.



**Fig. 7** Model diagram of DC-AC inverter circuit

The inverter circuit also consists of the main circuit and the control circuit, and the main circuit consists of four bridge arms, each of which is triggered by SPWM. The IGBTs of the bridge arms are all triggered by SPWM pulses, and the trigger pulses of bridge arm 1 (upper left) and bridge arm 4 (lower right), bridge arm 2 (upper right) and bridge arm 3 (lower left) are used in a uniform way, in

which the above-generated SPWM pulses are used for bridge arm 1 and bridge arm 4, and the SPWM waveforms of a sinusoidal waveform with a phase lag of  $30^\circ$  are used for bridge arm 2 and bridge arm 3.

#### 4.2.1 Parameter setting

According to the intersection of sine wave and sawtooth waveforms in the image, to determine the output pulse width, and then output a section of equal amplitude pulse series, equivalent to the original sinusoidal wave, which is the basic principle of the SPWM natural sampling method. The control circuit uses bipolar voltage SPWM as the pulse, sine wave using Sine Wave module, parameter selection amplitude of 0.8, frequency of 50Hz; sawtooth wave selection Triangle Generator module, parameter selection amplitude of 1, frequency of 750Hz, the phase angle of  $90^\circ$ . The generated waveform is shown in Fig. 8.

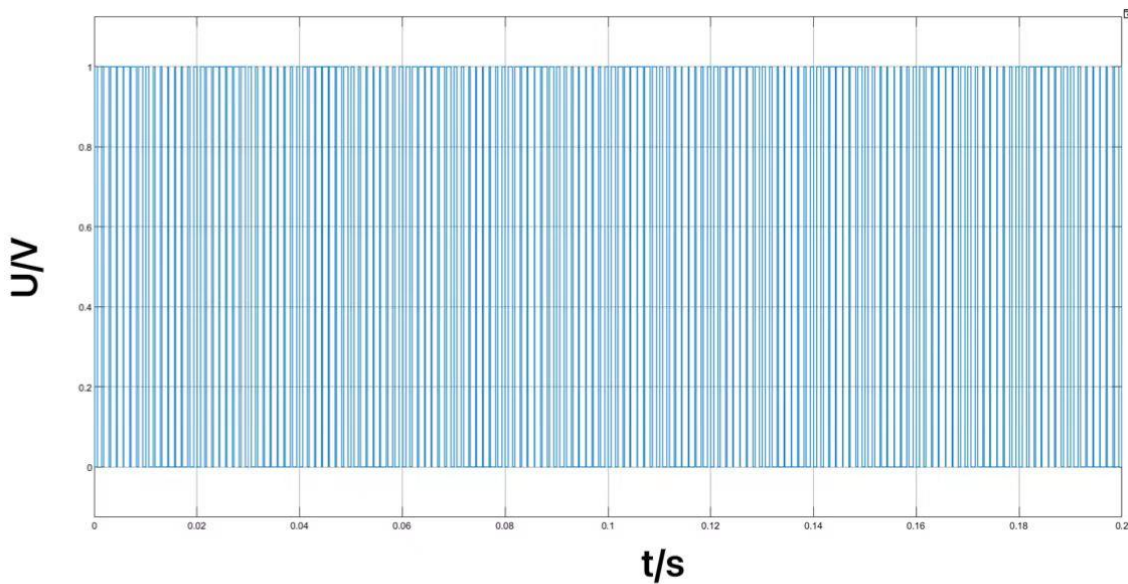


Fig. 8 Waveform of SPWM trigger pulse

The LLC resonant converters in the inverter circuits are all built by Series RLC Branch, setting the load-side top inductance L to 750mH; the right inductance L to 7.5mH, and the capacitance to 15uf. The inductor L on the load side is 750mH; the inductor L on the right side is 7.5mH and the capacitor is 15uF. Add a filter to the output, as shown in Fig.9.

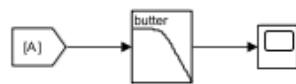
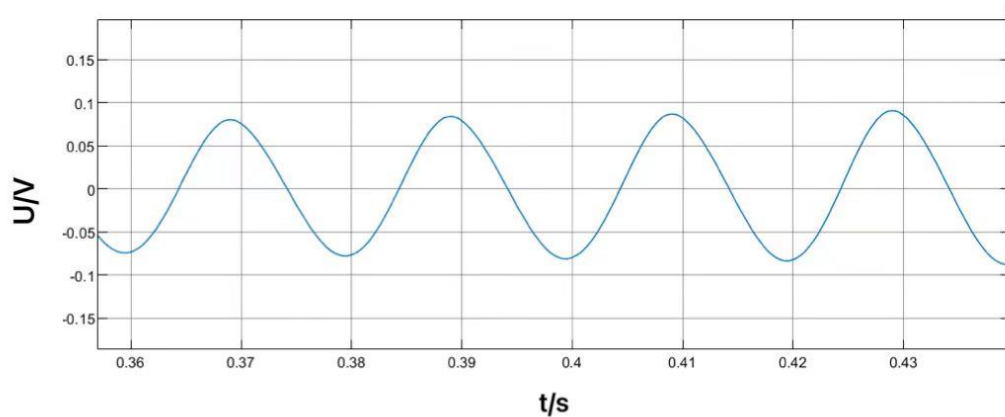


Fig. 9 Inverter circuit load side filter module

#### 4.2.2 Simulation analysis

The current-voltage waveforms obtained after simulation are shown in Fig.10.

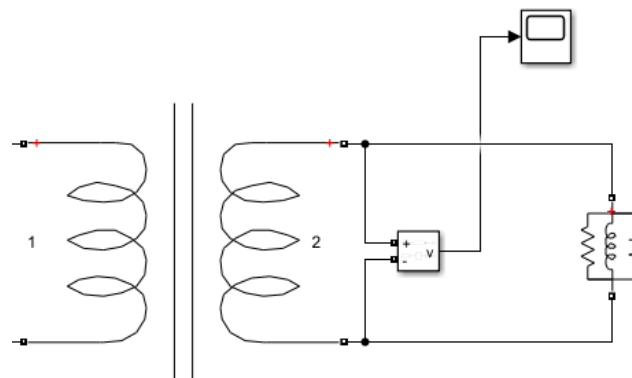


**Fig. 10** Voltage waveform of load side of inverter circuit

The theoretical value of the output waveform after passing through the inverter circuit should be AC sine wave. The voltage waveform of output of the inverter circuit is observed, which accords with the law of sine wave transformation. It is confirmed that the DC-AC inverter circuit can realize the function of converting DC to AC.

### 4.3. Practical applications on the load side

In practice, the voltage level obtained from the inverter on the on-board side of the EV often does not fully comply with the grid voltage level specification, and needs to be transformed by the transformer to the power ratio conversion before it can be planned to be put into use. In this paper, Parallel RLC Branch module is chosen to build the circuit to simplify the circuit at the grid. The model diagram of the built circuit is shown in Fig.11.



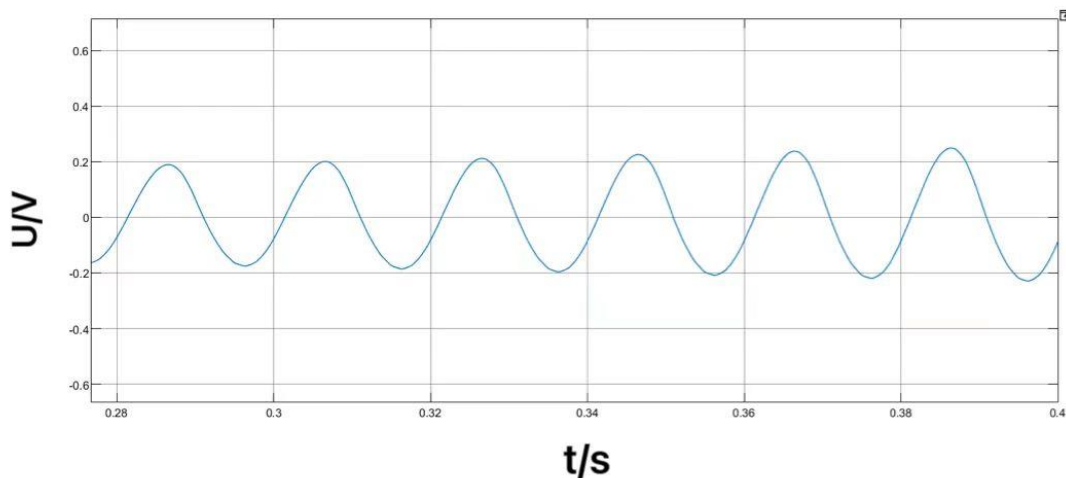
**Fig. 11** User load side model diagram

#### 4.3.1 Parameter setting

Set the load resistance to  $2\Omega$ ; the inductor L to 500mH; the inductor L to 10mH and the capacitor to 1000uF.

#### 4.3.2 Simulation analysis

At the end of the simulation, the voltage waveform obtained at the user side is shown in Fig.12.



**Fig. 12** User load side voltage waveform

The inverted AC power passes through the transformer ratio and outputs a new sine wave at the output. As seen from the simulated waveform, the output result conforms to the AC sinusoidal waveform.

#### 4.4. Practical Scenario Application

The basic idea of EV on-board power supply under V2G technology is to re-direct the current in the on-board power supply back to the grid after inversion to achieve a purpose of charging the grid in reverse. In fact, the flow direction of the on-board current can be selected to include but not limited to the grid system.

According to the official report of Azalea, on 23rd August 2023, the V2G charging and discharging system demand response experiment between the new energy vehicle brand "Azalea" and Wuxi Power Grid was officially opened [7]. The V2G charging and discharging system is a demand response experiment. EVs are like giant power sponges, and with the addition of V2G technology, EVs can be fully utilized as distributed mobile energy storage units, and through the efficient localized deployment and application of source-network-storage-load, not only can they make effective use of dispersed clean energy such as wind or solar energy, and realize self-generation and self-sale of green energy, but they can also provide EV owners with a certain amount of economic returns [8]. The deployment and application of EVs can not only achieve self-production of green energy, but also provide some economic returns for EV owners. For example, in the peak period from 8:00 to 22:00, electricity consumption is 0.568 yuan/degree, and in the valley period from 22:00 to 8:00, electricity consumption is 0.288 yuan/degree, with a difference of about 197 per cent. EVs are positioned mainly as inner-city commuting tools, and their usage time is concentrated at 6:00 to 9:00 and 16:00 to 20:00. If every EV owner can charge the car after 22:00, and charge the car after 8:00, and then charge the car after 22:00, and then charge the car after 8:00, then each of them can charge the car after 22:00, and then charge the car after 8:00. If every electric vehicle owner can charge the vehicle after 22:00 and transfer part of the power back to the grid after 8:00 by connecting the V2G charging piles at the parking place, based on the current electric vehicle ownership of more than 7 million in China, this peak-shaving and valley-filling scheme will greatly reduce the burden on the urban power grid and create a large amount of direct and indirect value [9]. This paper will greatly reduce the burden on the urban power grid, creating a great deal of direct and indirect value.

Besides, V2G vehicle charging and discharging power supply can provide many convenient services for people. When an earthquake, typhoon, flood and other force majeure natural disasters that can easily destroy transmission frames and cause regional blackouts occur in the region, the collection of saved new energy vehicles can easily form temporary hospitals or temporary camps to provide warmth, lighting and external distress services for the affected people, which will greatly

increase the rate of rescue and treatment of the affected people; in terms of life, but people go to the wild to have picnics and other nature-oriented recreational projects, no power guarantee is a dilemma that people often face. In life, when people go to the wilderness for picnic and other nature-oriented recreational projects, no power guarantee is a dilemma that people often face, V2G vehicle charging and discharging power supply can easily provide people with electric power support, and has been lifted; in traffic, once the vehicle breaks down on the road because of energy depletion, the traditional automobile can be quickly solved by borrowing the fuel from other people's vehicles, but at this stage of the system of energy vehicles can only be returned to the charging station through the high price of the towing service. However, at this stage, energy-saving vehicles can only be towed back to the charging station by expensive towing services. Once the vehicles are equipped with V2G on-board charging and discharging power supply, a fast and high-speed rescue solution can be realized by charging each other, avoiding the risk of accidents or traffic congestion due to the forced stopping of the vehicles.

## **5. V2G Current Applications**

### **5.1. Market Mechanisms and Policy Support for V2G Technology**

Electricity market participation can be profitable for EV owners, while consumer preference for cleaner energy and new technologies has fueled growth in market demand for EVs. In the electricity market, EVs can provide energy dispatch services, such as providing energy storage capacity to balance the load on the power system and supporting frequency regulation and voltage stabilization of the grid.

Many countries and regions have introduced policies to encourage the sale of electric vehicles, such as subsidies, tax exemptions and access to low-emission zones, which have promoted the development of the electric vehicle market. The formulation of the Technical Specification for Orderly Charging and V2G Two-Way Energy Interaction in Electric Vehicle Charging and Switching Facilities provides the technical basis and normative guidelines for the large-scale development of electric vehicle participation in grid interaction. In order to encourage the scale mass production of key equipment for virtual power plants, Shenzhen has put forward Several Measures to Support the Accelerated Development of Virtual Power Plants, which encourages new energy vehicle enterprises to carry out technological innovation and open up the V2G function at the vehicle end. For V2G charging piles, distributed resources intelligent control terminals, distributed resources co-operation operation management software, metering communication chip module, computing chips and other key core equipment industrialization projects of virtual power plants, after evaluation, a single project will be given a maximum of no more than 15 million yuan of support.

### **5.2. Current shortcomings of V2G technology**

Despite the significant potential and advantages of the current V2G technology, there are still difficulties and challenges in practical applications. Further scenario constraints can be incorporated in future research, such as considering the impact of battery charging and discharging on its lifetime, and taking into account real-time changes in electricity price [10]. The high-frequency V2G two-way charging method will inevitably accelerate battery aging [11]. Therefore, it is necessary to consider how to maximize the life of the battery to reduce costs and improve the sustainability of the battery; secondly, it is also necessary to consider the cost-effectiveness of the V2G technology and the economic incentives of the market, through the research found that the V2G charging pile, as the key "bridge" and link between the vehicle and network interaction, is still facing the constraints of high costs. V2G charging piles need to have two-way charging function, coupled with today's low penetration rate, equipment vendors need to invest more money, but it is difficult to reap obvious benefits in the short term [11]. At the same time, the current economic incentives in the power market is not mature enough, may not be able to attract enough users to participate, affecting the commercialization process of the technology. High cost is also a major constraint to the promotion

of V2G technology. V2G charging piles, as the key "bridge" and link for vehicle-grid interaction, are still facing high-cost constraints [11].

With advances in battery technology, such as higher energy density, longer lifespan, and faster charging speeds, the impact of V2G systems on batteries can be reduced, and the reliability and economics of the systems can be improved. Policy makers and power market participants can promote the adoption and development of V2G technology through various incentives, such as subsidies and preferential tariffs, while formulating relevant regulations and standards to ensure system safety and reliability. V2G technology has a huge potential for application, and through years of upgrading it is no longer limited to energy storage buffers, but can also assist in grid load shifting and participate in frequency regulation [12].

## 6. Conclusion

In this paper, the electric vehicle on-board battery charging and discharging model under V2G technology is built based on Simulink, and the electric vehicle on-board battery charging and discharging is processed in modules, the output waveforms of each part are comprehensively analyzed and compared with the theoretical values, to verify the correctness of the built model and to prove that the model has the features of convenience, intuition and so on. Then, through the experimental results obtained, it is argued that the application of vehicle power current in other fields has high practical possibilities except for back-charging to the grid. The article fully exploits the advantages and potentials of V2G technology in practical applications, and provides theoretical support for the design and construction of future smart grid technology and smart electric vehicle charging system.

## Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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