Proceedings of the 5th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/129/2025.20254

Recent Advances in DC-DC Converter for Vehicle-to-Grid Applications

Xizhong Wang[1,a,*]

[1]*College of Physics and Optoelectronics Engineering, Shenzhen University, Shenzhen, 518060, China*
a. 2022270277@email.szu.edu.cn
**corresponding author*

Abstract: In recent years, the global energy market is undergoing an unprecedented transition from traditional fossil fuels to clean energy. At present, China is actively promoting the optimization and upgrading of its energy structure, people will vigorously develop renewable energy sources such as wind power and solar energy. With the increasing number of new energy vehicles, the charging demand of a large number of electric vehicles has become an important issue in the construction of new power systems. In addition, as the global power grid becomes smarter, energy management becomes more diverse and interactive, with users becoming both consumers and providers of energy, the industry and academia are jointly promoting the green, efficient and intelligent development of the global energy system. In this paper, the vehicle-to-grid (V2G) function of domestic charging pile is realized by vehicle-borne bi-directional converters for V2G applications and the feasibility of this goal is analyzed, finally, the prospect and summary are put forward.

Keywords: Electric vehicles, bi-directional converter, vehicle-to-grid, energy conversion.

1. Introduction

In recent years, the global energy market is undergoing an unprecedented transition from traditional fossil fuels to clean energy. At present, China is actively promoting the optimization and upgrading of its energy structure, people will vigorously develop renewable energy sources such as wind power and solar energy. The rise and popularity of electric vehicles is a direct manifestation of this energy transition, not only by reducing dependence on oil but also by integrating advanced power management and energy recovery systems, improved overall energy efficiency. In addition, as the global power grid becomes smarter, energy management becomes more diverse and interactive, with users becoming both consumers and providers of energy, industry and academia are jointly promoting the green, efficient and intelligent development of the global energy system [1].

The traditional fossil fuel vehicles mainly have the problems of environmental pollution and low energy conversion efficiency. By contrast, electric vehicles have many advantages: they produce no emissions and can be charged with renewable energy, allowing cleaner energy use; Electric motors are energy efficiency than conventional internal combustion cars. In this kind of plug-in electric vehicle (PEV), as shown in Figure 1, direct current (DC) on-board charger (OBC) is a very important component [2]. After adding an altering current (AC) link in the DC-DC converter, the isolated DC-DC converter is obtained, which can ensure the bidirectional flow of its energy, that is, the isolated

DOI: 10.54254/2755-2721/129/2025.20254

bidirectional DC-DC converter is obtained [3]. DC-DC bi-directional converter is widely used in electric vehicle, they are used primarily for battery management and charging, motor control, kinetic energy recovery system, vehicle-to-grid (V2G) technology, inter-vehicle energy transfer, energy allocation for hybrid systems, voltage matching and conversion, and energy optimization and scheduling, electricity. By precisely controlling the energy flow, these converters not only improve the performance and efficiency of electric vehicles, but also enhance their reliability and flexibility, enabling electric vehicles to more effectively utilize and manage the energy in the system.

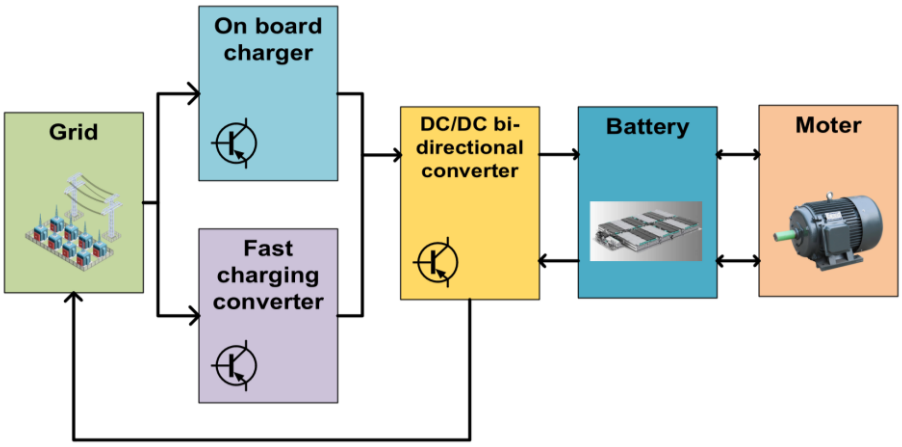

Figure 1: Diagram of V2G architecture [3].

The simple classification of DC-DC converters includes isolated and non-isolated types [4-7]. A non-isolated converter uses the same ground at the input and output terminals as its name suggests, while an isolated converter has electrical isolation between the ground at the input and output terminals. Mainstream isolation includes dual active bridge, forward, flyback, full bridge, half bridge; mainstream non-isolation includes step-down, step-up, switching capacitor, coupling inductance. The isolated type has the advantages of good security, strong anti-interference ability and suitable for high voltage conversion applications, while the non-isolated type has the advantages of low cost, high efficiency and small size. In this paper, the topology and typical modulation of bi-directional DC-DC converter are introduced in detail, and the key characteristics, advantages and disadvantages of various topologies are analyzed, finally, the application of this technology in V2G charging piles, a new form of distributed energy storage, is prospected.

2. Topology and typical modulation mode of on-board bi-directional DC/DC converter

Multi-port DC/DC converter is a device that can process multiple input sources and multiple outputs simultaneously. This converter has the unique advantages of centralized control and integrated power conversion, which is ideal for small power systems such as electric vehicles [7]. The topology of multi-port DC/DC converter can be simply divided into three types: DC-link-based converter, magnetic coupling-based converter and switched capacitor-based converter.

2.1. DC link based converter

The converter based on DC link is mainly composed of rectifier, filter, switch device, control circuit and protection circuit, the DC link is established, and then the modulation control strategy is implemented by using the switch device and control circuit to adjust the output of the inverter, so as to realize the power conversion and stable output of different voltages or power sources [8].

DOI: 10.54254/2755-2721/129/2025.20254

The main features of dc-link-based converter include energy management and distribution, that is, energy can be distributed dynamically between different inputs and outputs by control strategy, to meet system requirements and optimize the efficiency of power supply. Although DC links do not provide isolation per se, they are often used in combination with transformers or other isolation techniques to ensure electrical safety and system reliability. At the same time, without losing flexibility, the system can easily add or remove the input and output port DC link converter as needed, isolated converter provides electrical isolation, high security, suitable for the occasions that need isolation, but high cost and complexity, non-isolated converter structure is simple, low cost, small size, but because of the lack of isolation, the corresponding security is relatively low. If the vehicle-mounted bi-directional converter is used in such high power rated scenarios, obviously the isolated bi-directional converter is a better choice.

2.2. Converter based on magnetic coupling

The transformer based on magnetic coupling makes use of the magnetic coupling principle of transformer to realize energy transfer and conversion between different power sources. Magnetic coupling converter can be divided into magnetic coupling converter and electromagnetic coupling converter, electromagnetic coupling converter uses the principle of electromagnetic induction to achieve energy transfer between different circuits or power supply. Compared with the traditional magnetic coupling converter, the electromagnetic coupling converter is a device which can transfer or transmit energy by the interaction of electromagnetic fields [9].

The electromagnetic coupling converter is usually an isolated converter, which realizes the electrical isolation between the input power supply by using the isolated transformer, and has the ability to increase or decrease the input voltage, to meet the needs of different loads. The converter can manage multiple input power sources, such as batteries, charging posts, high-voltage inputs, and so on, and integrate their power input or output. It allows precise control of the output voltage by adjusting the duty cycle of the switches, and it allows two-way energy flow in a given topology, this converter is helpful to integrate different voltage levels of power supply, vehicle kinetic energy recovery, as well as the realization of external vehicle AC input and external vehicle AC output. Therefore, the electromagnetic coupling converter may be more suitable for vehicle chargers and DC-DC converters.

2.3. Converter based on switching capacitor

The switch-capacitor-based converter is a kind of high-efficiency power electronic equipment which realizes voltage conversion by using the charge-discharge principle of capacitor. The core principle of this converter is to realize the charging and discharging process of the capacitor by controlling the switch devices to turn on and off, to control the direction of energy flow and voltage conversion. In bi-directional converter, by changing the control strategy of the switch device, the charge and discharge states of the capacitor in different phases can be controlled to realize the bi-directional flow of energy [10].

Switching-capacitor-based converters have high voltage-to-voltage ratios, which can be switched capacitor in series or parallel to achieve higher voltage-to-voltage ratios than conventional converters, at the same time, because the physical dimensions of capacitors are usually smaller than those of inductors of the same rating, they are also easily integrated with semiconductor device, facilitating modularization and miniaturization, this means that switched capacitor converters can be designed to be more compact, with high voltage conversion ratios and small sizes more suitable for use in the compact spaces of electric vehicles. In addition, the switched capacitor converter can have lower input current ripple requirements, which can reduce the input power requirements of the converter,

DOI: 10.54254/2755-2721/129/2025.20254

especially in energy storage battery-powered applications. This converter is designed to connect the battery to the propulsion system through a DC link interface and has a high voltage turns ratio and low input ripple current [8] , which leads to the conclusion that it is very suitable for electric vehicle applications.

3. Future Prospectives

One of the main applications of bi-directional DC/DC converter is electric vehicle. In recent years, the new energy vehicle industry in China has developed rapidly, and the vehicle scale has gradually expanded. V2G technology is put forward with the increasing scale of electric vehicle charging. With V2G technology, electric vehicles (EVs) owners use low-cost valley power to charge their batteries while they are parked or idle, and discharge the grid during peak-price periods, because there is a price difference between peak and trough hours of the day in China, car owners can earn a price difference, at the same time, it also alleviates the stability pressure of the power grid caused by the huge difference of power load at different time [9, 10] .With the support of the policy, a part of the public V2G charging piles have been put into operation in our country, and the initial results have been achieved, but the public charging piles require the car owners to spend a lot of time and cost to go to a specific place to sell electricity, this is not conducive to the wide spread and widespread use of V2G, and compared to the need to drive to a designated location to use the public V2G charging pile, a home V2G charging pile is particularly convenient, that is to say, electric vehicles can automatically buy and sell electricity at specific times by setting up programs at home, which greatly simplifies the V2G process and reduces the time it takes, make electric car owners more willing to do V2G. Because of the AC input characteristic and the volume limitation of the household charging pile, the electric energy characteristic of the electric vehicle is AC. That is, through the vehicle directly output AC power and through the home V2G charging pile and achieve grid-connected. Of course, there are also many difficulties, such as the harmonic problem of AC power output from vehicles, and the burden of grid stability caused by a large number of V2G vehicles connected to the grid, etc., these are the issues that need to be considered for domestic V2G charging piles. In order to realize this technology, bi-directional DC/DC converter is essential, it directly related to the electric vehicle can output AC power to the grid, the power quality of the DC/DC converter is also directly related to whether it can be connected to the grid.

In the future, with the continuous development of science and technology, a high efficiency, conversion loss can be almost negligible bidirectional DC-DC converter, will greatly change the world's energy pattern and energy use. At night, the electricity generated by the power plant is electricity generated in the valley, during which time much of the electricity is wasted, but an extremely efficient two-way DC-DC converter can make use of any energy storage device such as the battery of an electric car, batteries for everyday household use can even be built with dedicated storage facilities, using DC-AC circuits to store energy that would otherwise be wasted, the use of AC-DC circuits during peak hours to release power to the grid, because there is little loss in the conversion process, the behavior is almost cost-free except for the upfront equipment input, thus saving energy, this in turn makes it possible to reduce the number of generating facilities in order to meet peak demand. In today's artificial intelligence era, these devices are connected to the smart grid by machines that learn how much electricity the region uses at different times and then model it, the ability to autonomously and precisely regulate the charging and discharging of a large number of energy storage devices directly through artificial intelligence, all of which are fully automated, could greatly accelerate the process of human carbon neutrality.

DOI: 10.54254/2755-2721/129/2025.20254

4. Conclusion

This paper discusses the importance of the role of electric vehicles in the global energy market transition to clean energy, and the role of on-board chargers and DC-DC converters in this transition. Then, the paper introduces three kinds of main topology of bi-directional DC/DC converter: DC link based converter, magnetic coupling based converter and switched capacitor based converter, their characteristics and applications are analyzed. In many applications, with the increasing number of new energy vehicles, V2G technology is very important in the new power system, there is a huge potential to achieve home V2G charging piles by vehicle-borne bi-directional DC/DC converter.

References

[1] *Wang Y, Wen H, Zhu Y, et al. Minimum-current-stress scheme of three-level dual-active-bridge dc–dc converters with the particle swarm optimization [J]. IEEE transactions on transportation electrification, 2021, 7(4): 2067-2084.*

[2] *Bu Q, Wen H, Shi H, et al. A comparative review of high-frequency transient DC bias current mitigation strategies in dual-active-bridge DC–DC converters under phase-shift modulations [J]. IEEE Transactions on Industry Applications, 2021, 58(2): 2166-2182.*

[3] *Yuan J, Dorn-Gomba L, Callegaro A D, et al. A review of bidirectional on-board chargers for electric vehicles [J]. IEEE Access, 2021, 9: 51501-51518.*

[4] *Jaga O P, Gupta R, Jena B, et al. Bi-directional dc/dc converters used in interfacing esss for ress and evs: a review [J]. IETE Technical Review, 2023, 40(3): 334-370.*

[5] *Gao H, Liu Z, Bi H, et. al. Application of three-level bi-directional converter in vehicle energy storage system [J]. Power Electronics Technology, 2023, 57(06): 112-115.*

[6] *Chen H, Tang Z,Yuen W, et. al. Development of intelligent high-power bidirectional three-level DC/DC converter [J]. Power Electronics Technology, 2024, 58(06): 72-76.*

[7] *Xu Q, Vafamand N, Chen L, et al. Review on advanced control technologies for bidirectional DC/DC converters in DC microgrids [J]. IEEE Journal of Emerging and Selected Topics in Power Electronics, 2020, 9(2): 1205-1221.*

[8] *Sethuraman R, Rudhramoorthy M. Performance of Bidirectional ON-Board Charger in Electric Vehicle: A Review [J]. e-Prime-Advances in Electrical Engineering, Electronics and Energy, 2024: 100613.*

[9] *Ojeda-Rodríguez Á, González-Vizuete P, Bernal-Méndez J, et al. A survey on bidirectional DC/DC power converter topologies for the future hybrid and all electric aircrafts [J]. Energies, 2020, 13(18): 4883.*

[10] *Panchanathan S, Vishnuram P, Rajamanickam N, et al. A comprehensive review of the bidirectional converter topologies for the vehicle-to-grid system [J]. Energies, 2023, 16(5): 2503.*