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Research Advances in Multiport DC Converter of Distributed Generation Systems

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Abstract:

DC microgrids combine ports in various forms, such as power supply, energy storage, and load, and can operate in isolated islands and grid-connected ways in a variety of situations. Multiple converters in parallel on the DC bus will lead to system redundancy, complex control, and low efficiency. By integrating many different forms of ports, a multi-port DC converter has emerged. This paper first introduces the topology of multiport converters, summarizes the existing derivative products of multiport converters, and then briefly introduces their structures, and analyzes their functions and advantages and disadvantages. Because they provide electrical isolation between all ports, effectively preventing the risk of shock and fault propagation, isolated converters perform best in terms of safety, resistance to electromagnetic interference, and system reliability. Non-isolated converters have advantages in terms of cost and efficiency. Partially isolated converters offer a compromise that provides isolation for specific ports, improving security while controlling cost and complexity.

Keywords: Multi-port converter; DC microgrid; distribution network; energy storage system

1. Introduction

With the continuous advancement of modernization, climate issues and energy transition issues have gradually risen to the height of national strategy and international security. With the shortage of global market energy and the consumption of traditional fossil energy, the rise of the renewable energy industry has become an important supplement to the energy supply system. Renewable energy sources such as wind, solar, water, and tidal energy have attracted much attention because of their abundant resources. Free access and pollution-free characteristics, especially solar and wind energy, are widely regarded as the most potential new forms of energy in the future energy system [1]. Although the development of distributed power generation has promoted the development and application of new energy, it is often significantly affected by environmental conditions, and its power generation is difficult to maintain continuity and stability. In order to solve the above problems, DC microgrids play an important intermediate link, which is used to connect large power grids and distribute power sources. DC microgrid structure integrates an AC power grid, power generation unit, energy storage unit, AC and DC load, and uses converters to connect a common DC bus for energy distribution and transmission. In practical applications, the combination of renewable energy and energy storage technology can flexibly dispatch the output of multiple renewable energy sources according to changing environmental conditions. The energy storage system, depending on its characteristics, stores excess energy or releases energy during peak demand to meet the system demand. This integrated application requires the converter to be able to adapt to the needs of multiple ports for efficient energy conversion and management between different energy forms and energy storage systems [2].

In early renewable energy integration scenarios, the system generally relied on the use of multiple bidirectional DC-DC converters that connected the generation unit, the energy storage unit, and the AC-DC load to each other via a common DC bus [3]. Although these converters have reached a high level of theoretical research and practical application in unidirectional and bidirectional power conversion, there are some significant limitations in this system design. Specifically, the need to use multiple converters in the system leads to insufficient power density, and it needs to go through multiple stages of power conversion during the energy transmission process, which not only reduces the overall energy efficiency but also increases the complexity of the system. In addition, the control of the individual converters is carried out independently, which requires a communication network to coordinate the various renewable energy access points for information exchange. This decentralized control mechanism slows down the response speed of the system, thus adversely affecting the stability and reliability of the whole system [4].

In order to improve the comprehensive performance of the system to solve the above problems, the multi-port converter is introduced as a new integration scheme. The multi-port converter has the advantages of simple structure, high power density, and high efficiency, and it can realize arbitrary transmission of power flow between multiple ports [5]. In this paper, the topology convergence schemes of multi-port DC transformers are reviewed, and the multi-port converters are divided into three types: non-isolated type, partially isolated type, and fully isolated type, which can provide a reference for the study or selection of multi-port converter topology.

2. Non-isolated Multiport Converters

Non-isolated multiport converters are power conversion devices that do not rely on transformers to achieve electrical isolation between input and output. They convert voltage directly through power electronic switches and passive components. Since the transformer is omitted, the non-isolated converter usually has a higher conversion efficiency. Through rational topology design, they can achieve high voltage gains to meet the needs of specific applications.

Lei Xi et al. proposed a new non-isolated three-port converter, the structure of which is shown in Figure 1. On the basis of the non-isolated bidirectional high-lift buck converter, a bidirectional three-port converter is formed by adding an extra port to the low-voltage bus capacitor. The three-port converter is connected to the battery, the low-voltage bus and the high-voltage bus respectively. The equivalent circuit of the battery port and the low-voltage bus port is a bidirectional boost circuit, and the power adjustment can be carried out by using the duty cycle [6]. A boost half-bridge converter is the equivalent circuit for the battery port and the high-voltage bus port, and a half-bridge converter is the equivalent circuit for the low-voltage bus and the high-voltage bus port.In both circuits, phase shifting control can be used to achieve power balance. The new non-isolated three-port converter has a simple structure and high integration and can effectively transmit power bidirectionally between each port. The experimental results show that the converter can operate stably in different working modes, and it has good voltage output quality and a low total harmonic distortion rate. Although the control strategy using phase shift and pulse width modulation can achieve a wide range of voltage regulation, this control strategy is relatively complex and requires high control accuracy and fast dynamic response.

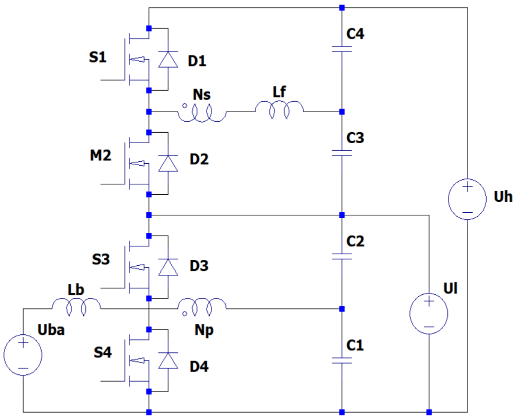

Fig. 1 Non-isolated bi-directional three-port converter [6]

Although the non-isolated converter has the advantages of simple design and high efficiency, due to voltage constraints between ports, the energy characteristics of

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renewable energy cannot be fully matched, and the operation mode is relatively simple. In future studies, energy storage systems should be more closely integrated into the converter design to achieve more efficient energy management and optimize the operation of the power system. New non-isolated converter topologies can also be explored and implemented to improve voltage conversion efficiency and overall system performance.

3. Isolated Multiport Converters

A high-frequency transformer in a fully isolated multiport converter is a core component with multiple windings, each connected to a different port of the converter. In this way, the transformer not only provides electrical isolation but also allows energy to flow bidirectionally between the different ports. By designing the winding turns ratio of the transformer, the converter can provide different voltage levels for each port, so as to meet different voltage requirements, and each port can adapt to a wide operating voltage range.

Tahsin Koroglu et al. proposed a five-port isolated bidirectional DC-DC converter (FPIBDC) for connecting photovoltaic (PV), solid oxide fuel cell (SOFC), and battery energy storage systems[7]. The FPIBDC topology consists of two full-bridge converters, a resonant loop, and a voltage-balancing circuit. The converter consists of five ports connecting PV, SOFC, battery, load, and grid. Through the multi-loop control strategy, energy can be effectively distributed under different energy supply and demand conditions, and the stable operation of the system under different operation modes can be ensured.

HEXIAN MAHFOUZ IBRAHIM SALEEB et al. proposed a novel fully isolated multiport bidirectional DC/DC converter, as shown in Figure 2[8]. The converter combines a soft switch and a resistance-capacitor-diode buffer circuit for charging and discharging in photovoltaic systems. The fully isolated design allows energy to flow bidirectionally between the battery and the photovoltaic system, both charging the battery and discharging it from the battery to meet load requirements. It also helps to reduce noise and interference that may be caused by direct connections between circuits, improving the stability and reliability of the system.

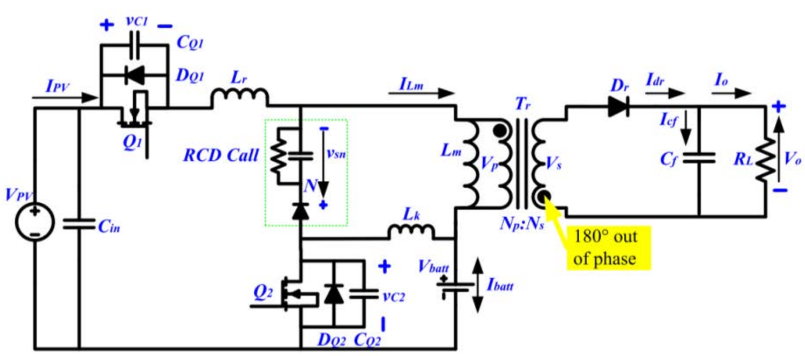

Fig. 2 Fully isolated multi-port bidirectional DC/DC converter [8]

The fully isolated converter can provide electrical isolation between various ports, greatly reducing the risk of shock and the spread of electrical faults. It can connect different voltage levels and different characteristics of power supplies and loads, improving the flexibility and compatibility of the system. However, compared with the non-isolated converter, the dynamic response speed of the fully isolated converter may be reduced, because the isolated components may affect the transmission speed of the signal. Besides, the design of the fully isolated converter needs to consider more factors, higher complexity and higher cost. High-frequency transformers play an important role in fully isolated multiport converters. Future research can focus on improving the efficiency and power density of high-frequency transformers, reducing leakage induction and stray capacitance, thereby reducing losses and improving system reliability.

4. Partially-isolated Multiport Converters

In order to simplify the design of the control system, the parts of the converter are integrated, and the power parts and the storage units are combined. Electrical isolation is realized through the transformer and the other port, so the partial isolation type multiterminal converter is developed, also known as the semi-isolated multiterminal converter. This converter combines the advantages of non-isolation and fully isolated multiterminal converter, which maintains both cost efficiency and necessary electrical isolation to ensure the safety and reliability of specific application scenarios.

Maoqing Liu et al. proposed a partial isolation type two-way four-port dc converter, which is composed of two two-way buck-boost circuits and two all-bridge switches [9]. The converter can achieve two-way energy transmission to reduce the number of converters in the home dc microgrid, and realize the energy management of photovoltaic power generation, energy storage equipment, low voltage and high pressure load. The control strategy of the converter is the original edge controller and the secondary side controller, the original edge controller is responsible for the pv voltage control and the storage voltage control, and the vice side controller is responsible for the voltage control of the high voltage output. Through experimental verification, the converter can realize the energy decoupling and efficient management of different ports in the domestic dc microgrid, and improve the overall efficiency and reliability of the system.

As can be seen from Figure 3, Zhe Wang et al. have proposed a novel zero-voltage switch (ZVS) partially isolated three-port converter (TPC) that integrates the two filter inductors and isolation transformers of the Boost converter and replaces them with coupled inductors. The partially isolated TPC reduces the number of magnetic elements while maintaining the low current ripple and high voltage gain of the traditional current source TPC, so the converter is suitable for fuel cell vehicles. In addition, zero voltage switching (ZVS) between all MOSFETs is achieved over a wide voltage and load range, while low current stress is ensured due to multi-degree-of-freedom modulation [10].

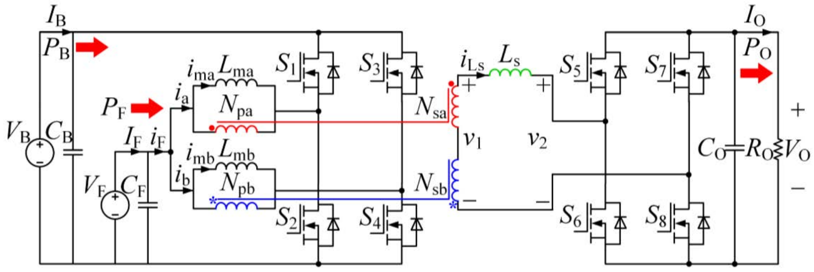

Fig. 3 ZVS partially isolated three-port converter [10]

While partially isolated multiport converters combine the characteristics of fully isolated and unisolated converters, they provide a degree of electrical isolation while maintaining the benefits of cost-effectiveness and simplified design. However, the combination of isolated and non-isolated parts may cause the power electronic device to be subjected to uneven voltage and current stress, affecting the reliability and life of the device. With the development of power electronic device technology, the use of new semiconductor materials, such as silicon carbide SiC and gallium nitride GaN, can achieve higher efficiency and power density, reducing losses during energy conversion. These materials can operate at higher frequencies and temperatures, reducing the volume and weight of the converter. In addition, more complex control algorithms can be developed to achieve efficient coordination and dynamic responses between ports, such as using artificial intelligence and machine learning techniques to optimize control strategies and improve the stability and response speed of the system.

5. Conclusion

This paper mainly reviews the existing technologies of multiport converters and gives the types of multiport converters and various derived topologies. Compare and analyze various multiport converters, and analyze the structure and function advantages and disadvantages of various topologies. Isolated, non-isolated, and partially isolated multiport converters each have unique advantages and limitations and are suitable for different application scenarios. Isolated converters perform best in terms of safety, resistance to electromagnetic interference, and system reliability because they provide electrical isolation between all ports, effectively preventing the risk of electric shock and fault propagation. However, this also leads to higher cost, volume, weight, and thermal management requirements, as well as possible reduced efficiency. Non-isolated converters have advantages in terms of cost and efficiency, because of the lack of isolation components, their structure is simpler, smaller, and lighter weight, but less safe. And electromagnetic interference problems are more prominent, and there are common ground problems and cross-regulation problems. Partially isolated converters offer a compromise that provides isolation for specific ports, improving security while controlling cost and complexity. However, partially isolated converters may not fully address electromagnetic interference issues and may be more complex to design and control than non-isolated converters. In general, the type of multiport converter chosen depends on the needs of the specific application, including considerations of safety, cost, efficiency, volume, thermal management, and control complexity.

With the continuous advancement of power electronics

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technology, especially the application of wide band gap devices such as SiC and GaN, the design of multi-port converters will be more efficient and compact. Innovations in control strategies, such as the integration of digital control and artificial intelligence algorithms, will further improve the dynamic response and stability of the system. In addition, with the growing demand for renewable energy and microgrid technologies, it is expected that fully isolated and partially isolated converters will be more widely used to meet the need for high security and flexibility. At the same time, non-isolated converters will continue to take their place in the cost-sensitive market. Future research is likely to focus on improving the power density, efficiency, and reliability of converters, as well as developing more advanced integrated solutions to adapt to growing power system demands.

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