Structures, Submodule Topologies and Control Strategies for Modular Multilevel Converter

Jinrong Chen [1, *], Wangyang Lin [2], and Lihao Yang [3]

[1] School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China

[2] Maynooth University International Engineering College, Fuzhou University, Fuzhou, China

[3] School of Mechanical and Electrical Engineering, Suqian University, Suqian, China

* Corresponding Author Email: Jinrong.Chen20@student.xjtlu.edu.cn

Abstract. Global energy demand is rapidly increasing, and the limitations and disadvantages of traditional energy sources are becoming more evident. Traditional energy sources are finite, and their sustainability is facing significant challenges. Compared to traditional multi-level converters, modular multi-level converters (MMC) adopt a modular design that divides the entire converter system into several independent sub-modules, each responsible for converting specific voltage levels. This article provides an overview of the theoretical aspects, topology structures, basic operation principles, and output characteristics of multi-level converters. This paper reviews the characteristics and application ranges of different topology structures, highlighting the differences in response speed, output quality, and control complexity. This paper also discusses the advantages and limitations of multi-level converters in various application scenarios. Explored the application of multi-level converters in wind power grid integration and electric vehicle charging systems, emphasizing their energy-saving and environmentally friendly features. In conclusion, this paper emphasizes the critical role of multi-level converters in power systems and future energy applications, stressing the importance of their reliability and promising future developments.

Keywords: Modular multilevel converter, topology, structures, control.

1. Introduction

Global energy demand is rapidly increasing, and the limitations and disadvantages of traditional energy sources are becoming more evident. Traditional energy sources are finite, and their sustainability is facing significant challenges. Additionally, the extraction, processing, and utilization of energy contribute to environmental pollution, ecological degradation, greenhouse gas emissions such as carbon dioxide, climate change, and air pollution [1]. Moreover, the prices of traditional energy sources are influenced by factors like supply and demand, geopolitical issues, and market fluctuations, making them unstable and contributing to uncertainties in the socio-economic aspects. Therefore, the development and utilization of new energy sources have become a central theme of our time.

To promote the development of new energy sources, various wind power stations have been established in western regions of China. However, integrating wind power into the grid presents challenges. Wind turbines have already reached the level of megawatts in power output, necessitating large-scale wind energy conversion systems to control reactive power. Even during voltage sags or drops, it is crucial to maintain proper grid operation. Compared to traditional multi-level converters, modular multi-level converters (MMC) adopt a modular design that divides the entire converter system into several independent sub-modules, each responsible for converting specific voltage levels. This design enhances the system's flexibility and scalability, allowing for the addition or removal of sub-modules according to specific requirements. It facilitates energy conversion between different levels and simplifies fault diagnosis and maintenance. Modular multi-level converters employ higher frequencies, advanced switching devices such as silicon carbide or gallium nitride devices, and optimized control strategies to improve converter efficiency and reduce power losses, thereby achieving energy savings. They also provide more precise output control and response capabilities.

By utilizing advanced control algorithms and fast-responsive switching devices, modular multi-level converters can accurately track input variations and adjust outputs within short time frames.

Therefore, modular multi-level converters effectively address the challenges associated with wind power grid integration. MMC can independently regulate active and reactive power, reduce harmonic levels, improve power quality, and efficiently handle the instability of wind power generation based on grid requirements and environmental conditions. It mitigates the dangers of current surges and voltage drops that could harm the grid [2]. Currently, large-scale renewable energy power plants are mostly concentrated in western regions, where the electricity demand is relatively low, making complete consumption challenging. Consequently, large-scale transmission projects are becoming more common. However, long-distance transmission with large-scale systems presents issues such as power losses and equipment maintenance. Modular multi-level converters can generate composite output voltages close to sine waves by adjusting internal modules, reducing voltage waveform distortion and minimizing losses on transmission equipment. Furthermore, precise control of the output voltage's amplitude and phase can achieve more efficient energy transmission, maximize energy utilization, reduce wastage and losses, and improve the energy utilization efficiency of power transmission systems. Modular multi-level converters are also highly suitable for power applications, such as electric vehicle (EV) charging stations. With the increasing installation of EV charging stations in China, there is a growing demand for them, and their applications have broad prospects and market demands. As a core component of DC charging stations, modular multi-level converters play a crucial role in improving the efficiency and performance of DC chargers. During the charging process, multi-level converters can reduce energy losses, enhance energy utilization efficiency, and minimize waste. Moreover, they possess flexible control and scheduling capabilities that allow real-time adjustment of output voltage, current, and power according to the requirements of different EV models and battery capacities. This enables fast and precise charging control and management and meets the rapid charging needs of different electric vehicles.

In summary, compared to traditional multi-level converters, modular multi-level converters offer enhanced controllability. They allow flexible adjustments using built-in modules in various scenarios to adapt to real-world environments, effectively improving conversion efficiency and voltage quality. They also provide exceptional flexibility, allowing the replacement and substitution of individual modules based on external conditions, significantly reducing inconvenience associated with maintenance and repairs. The diverse flexibility of modular multi-level converters contributes to the existence of many different structural variants.

Different structural variants of modular multi-level converters have unique advantages. This article divides them into two sections for introduction. Firstly, this paper discusses the advantages and disadvantages based on the overall and sub-module topology structures of modular multi-level converters. Secondly, this paper provides detailed explanations on the different control strategies for multi-level converters and compare and analyze them to derive meaningful conclusions.

2. Topology Structures

2.1. Overview of Overall Structure

2.1.1 Star-Connected Modular Multilevel Converter

The star connected MMC, as shown in Fig. 1, is a special type of MMC structure that improves the reliability and efficiency of the system by modifying and optimizing the traditional MMC structure. Its characteristic is the connection of the capacitors of each MMC module to other modules of the same voltage level, forming a star-shaped structure [3]. This connection reduces the voltage stress on the capacitors and improves the reliability and lifespan of the system. Each MMC module is composed of multiple sub-modules connected in series. By precisely controlling the conduction time and switching frequency of the semiconductor switches, it achieves precise control and regulation of the output voltage. The advantages of the Star-Connected MMC structure include

reduced voltage stress on the capacitors, voltage balancing, and higher power density. However, achieving voltage balancing between capacitors requires complex control strategies, and the capacitors may need larger capacities to meet the balancing requirements. The Star-Connected MMC has broad application prospects in high-voltage DC transmission and AC transmission systems.

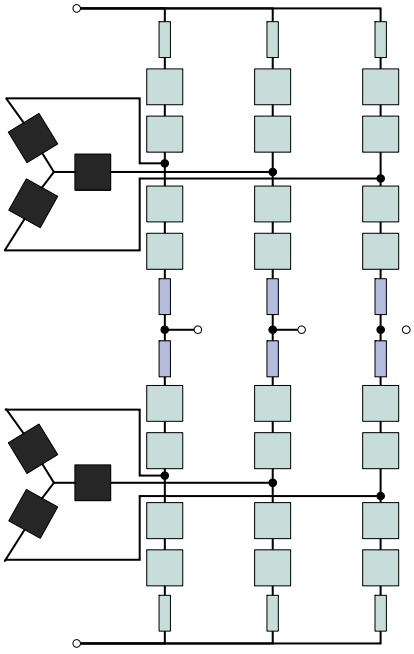


Fig. 1 Star-connected modular multilevel converter [3]

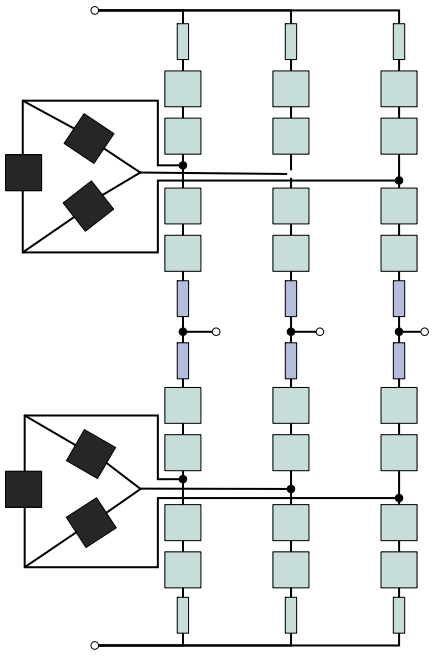


Fig. 2 Triangle-connected modular multilevel converter [3]

2.1.2 Triangle-Connected MMC

Triangle-Connected MMC, as shown in Fig. 2, is a microfabrication channel structure used for fluid control and microfluidic applications. It consists of microfabrication channels, fluid interfaces, and control systems. The microfabrication channel is the core component manufactured using microfabrication techniques, which can be microchannels or micropores. The fluid interface includes micro-pumps, micro-valves, micro-nozzles, etc., used for controlling fluid flow and pressure. The control system can be a conventional electrical control system or a MEMS-based integrated circuit,

including sensors, actuators, control algorithms, and interface circuits. The Triangle-Connected MMC achieves precise control and regulation of microfluidics through the synergistic effect of these three parts and finds wide applications in biomedical, chemical analysis, and fluid dynamics research.

2.1.3 Backup Arm Converter

The backup arm converter, as shown in Fig. 3, is used for backup power source switching in power systems. Its overall structure includes a backup arm, control system, and input/output interfaces [4]. The backup arm consists of backup power sources, switches, and connecting circuits, which provide backup power supply and switch the main power source. The control system includes sensors, actuators, control algorithms, and interface circuits, which monitor the real-time status of the power system and the availability of backup power sources, and control the backup power source switching based on feedback signals. The input/output interfaces are used to receive power system input and connect backup power source power outputs. Through the synergistic effect of these components, the backup arm converter ensures reliable power supply in power systems.

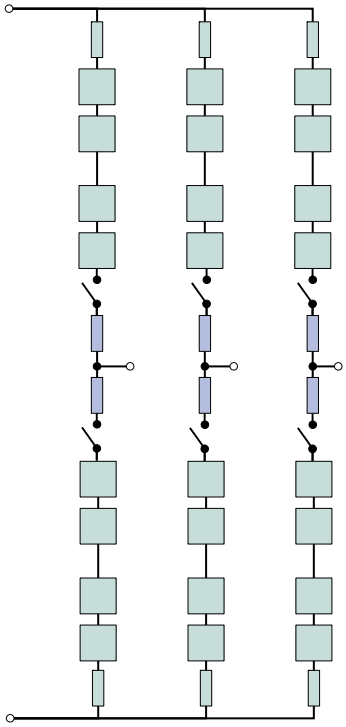


Fig. 3 Backup Arm Converter [3]

2.1.4 DC Module with Output Sub-modules

DC modules with output sub-modules are used to convert DC power sources into usable power outputs, as shown in Fig. 4. The overall structure includes an input terminal, output terminal, and control circuit [5]. The input terminal consists of power connectors and filtering circuits, used to connect DC power sources and ensure stable power input. The output terminal consists of output connectors and output filtering circuits, used to connect load devices and provide stable power outputs. The control circuit includes power converters, controllers, and protection circuits, used for converting DC power sources, monitoring current and voltage, and protecting circuits and load devices. Through the synergistic effect of these components, the DC module can meet the power system's demand for stable and reliable power outputs.

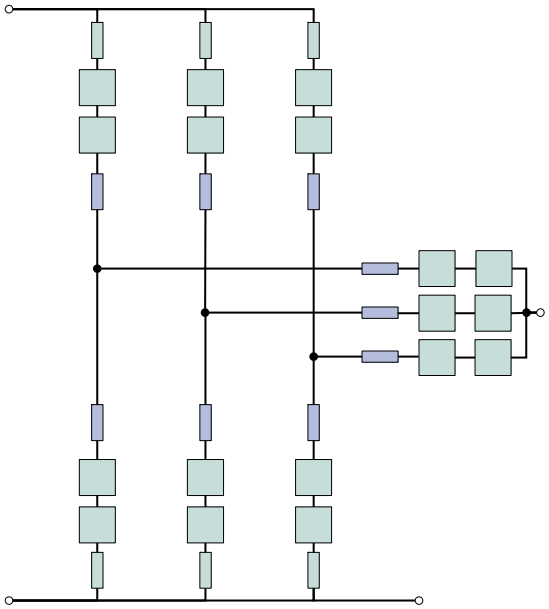


Fig. 4 DC Module with Output Sub-modules [3]

2.1.5 Single-Arm MMC

Single-Arm MMC, as shown in Fig. 5, is a converter topology structure used in high-voltage DC transmission systems, including capacitor voltage distribution units, H-bridge sub-modules, current balancing inductors, and control circuits [6]. The capacitor voltage distribution unit achieves multi-level voltage output, improving the system's stability. H-bridge sub-modules achieve precise voltage output and consist of multiple H-bridge topology structures. The current balancing inductor adjusts current distribution to improve system efficiency and stability. The control circuit monitors and controls capacitor voltage distribution, H-bridge sub-module switch states, and current balancing to ensure system stability and reliability. Single-Arm MMC achieves efficient conversion and control in high-voltage DC transmission systems.

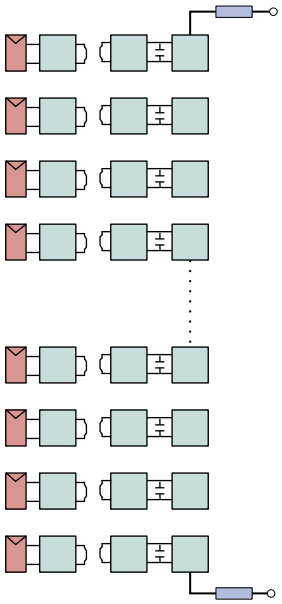


Fig. 5 Single-Arm MMC [3]

2.2. Sub-modules of MMC

2.2.1 Half-Bridge MMC

Half-Bridge MMC, as shown in Fig. 6, is a commonly used topology structure in power electronic converters, used to convert input voltage into multiple different output levels. It consists of a half-bridge topology and multiple output capacitors. During operation, by timely switching the conduction states of the two switches, multiple different output voltage levels can be achieved. The Half-Bridge MMC structure has the following advantages: multi-level output to adapt to different power requirements, improved conversion efficiency, and reduced switch losses, as well as reduced filter capacitor capacity and cost. However, the Half-Bridge MMC structure also has some disadvantages: it requires precise control of switch conduction time and switching frequency, increasing control complexity, and the output capacitors need to have higher capacitance to ensure output voltage stability and minimal ripple. In summary, the Half-Bridge MMC structure has certain advantages in power electronic converters but also faces some challenges.

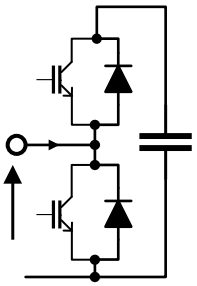


Fig. 6 Half-Bridge MMC [3]

2.2.2 Full-Bridge MMC

Full-Bridge MMC, as shown in Fig. 7, is a commonly used topology structure in power electronic converters, used to convert input voltage into multiple different output levels [7]. It consists of a full-bridge topology and multiple output capacitors. The working principle involves timely switching the conduction states of the four switches to achieve multiple different output voltage levels. This structure has the advantages of achieving multi-level outputs, improving conversion efficiency, and reducing the capacity of output filters. However, it requires precise control of switch conduction time and switching frequency, increasing control complexity, and placing higher demands on the output capacitors. Despite some drawbacks, the Full-Bridge MMC structure is still a widely used and reliable topology structure in power electronic converters.

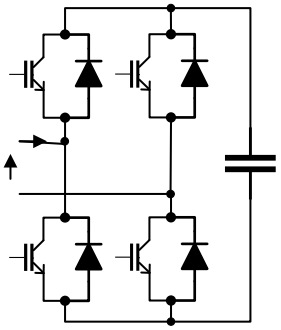


Fig. 7 Full-Bridge MMC [3]

2.2.3 Active Neutral-Point-Clamped Topology Structure

The active neutral-point-clamped (ANPC) topology structure of the Multilevel Converter consists of multiple six-degrees-of-freedom inverters, with each inverter comprising two switches and one capacitor [8]. It can achieve multiple different output levels, enhance conversion efficiency, and reduce the capacity of output filters. The operating principle of the ANPC topology structure involves controlling the conduction and turn-off states of the inverter switches, dividing the input voltage into

positive and negative parts, and connecting them to a shared neutral point. When the switches are conducting, the capacitors charge to generate output voltage, and when turned off, the voltage balances between the capacitors and between the capacitors and the neutral point to maintain output voltage stability. The ANPC topology structure has the characteristics of multi-level outputs, high conversion efficiency, reduced harmonics, and improved reliability. However, it also faces challenges of high control complexity and the requirement for higher voltage levels. Nevertheless, the ANPC topology structure is still a reliable and widely applied structure, especially suitable for high-power power electronic converters.

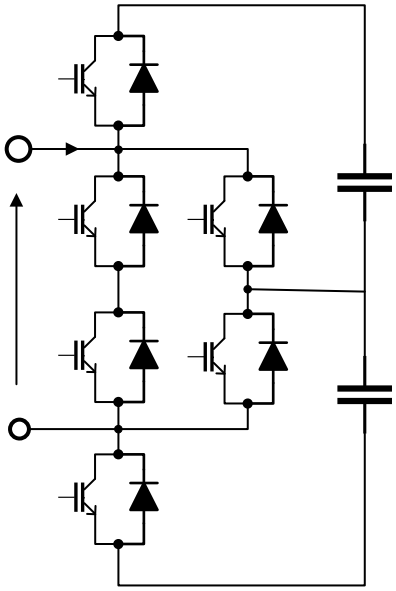


Fig. 8 ANPC Topology Structure [3]

2.2.4 Cross-Connected MMC

The Cross-Connected MMC, as shown in Fig. 8, is a common topology structure in power electronic converters, converting the input voltage into multiple different output levels [9]. The structure consists of multiple units connected in series, with each unit composed of two switches and one capacitor. The working principle is to charge the capacitors between different voltage levels through cross-conduction to achieve different output voltage levels. The advantages include multi-level output to adapt to different power requirements, improved harmonic performance, reduced filter capacity and cost, and increased conversion efficiency by reducing switch losses. However, this structure requires precise control of switch conduction time and switching frequency, increasing control complexity. Additionally, the output capacitors need to have higher capacitance to ensure output voltage stability and minimize ripple. Meanwhile, this structure requires more switches and capacitors, increasing cost and size. In summary, the Cross-Connected MMC is a commonly used and effective power electronic converter structure but suffers from some drawbacks in terms of control complexity, capacitor requirements, cost, and size.

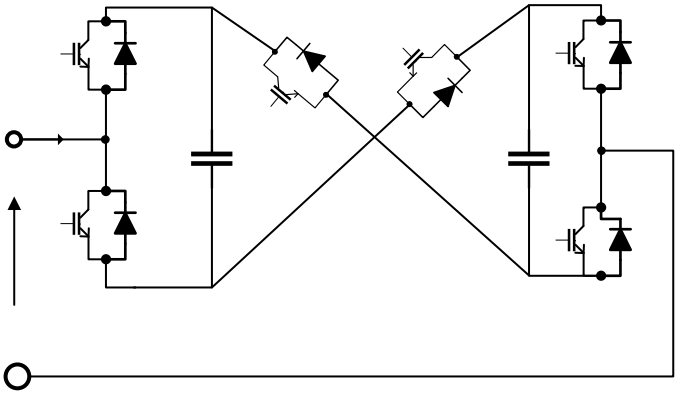


Fig. 9 Cross-Connected MMC [3]

2.2.5 Clamped Double Sub-Module

Clamped Double Sub-Module (CDSM), as shown in Fig. 9, is a device used for voltage conversion, which converts the input voltage into multiple different output levels through the input voltage control module. It maintains the stability of the output levels through the output level control module and the clamped double sub-module. It has the characteristics of multi-level conversion capability, high stability, and strong flexibility. However, it also has drawbacks such as high cost, energy losses, and increased system complexity. Nonetheless, CDSM is still widely used in electronic devices, especially in circuits that require multiple different levels. It can achieve different level conversions by adjusting the parameters of the input-output voltage control modules and ensure stable output levels through the clamped double sub-module, thereby improving circuit efficiency and reliability.

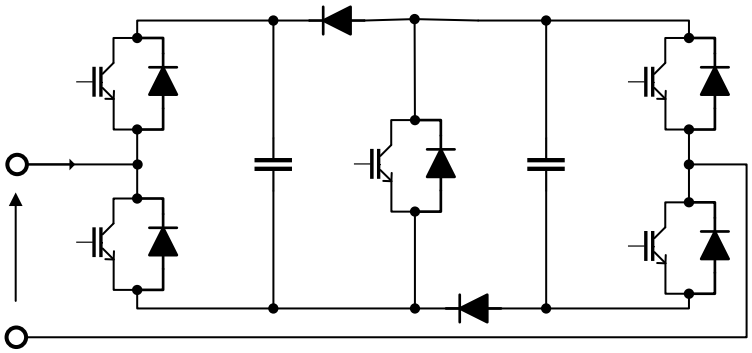


Fig. 10 Clamped Double Sub-Module [3]

2.2.6 Single Clamped Single-Module

Single Clamped Single-Module (SCSM), as shown in Fig. 10, is a device that converts the input voltage into multiple different output levels using the input voltage control module and maintains the stability of the output levels through a single clamped single-module [10]. It has the characteristics of multi-level conversion capability, high stability, and high precision. However, it also has drawbacks such as the inability to meet specific application requirements, sensitivity to input voltage changes, and difficulties in parameter adjustment. Nevertheless, SCSM is still widely used in some specific circuits, with certain practicality and reliability.

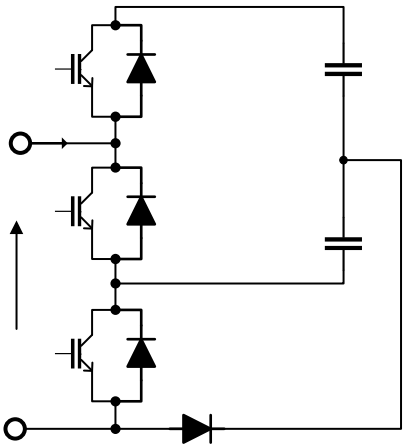


Fig. 11 Single Clamped Single-Module [3]

2.2.7 Integrated Gate-Commutated Thyristor Sub-module

Integrated Gate-Commutated Thyristor (IGCT) sub-module, as shown in Fig. 11, is a device used for voltage conversion. Its principle of operation involves controlling the conduction and turn-off of IGCT switches to achieve voltage conversion, and it has the ability to achieve multi-level outputs. By adjusting the conduction and turn-off states of different IGCT switches, multiple different output levels can be achieved. The IGCT sub-module of the multilevel converter has the advantages of multi-level outputs, high conduction capability, and high conversion efficiency. However, it also has disadvantages such as high manufacturing cost, high control requirements, and potential issues of losses and thermal management. In spite of this, the IGCT sub-module of the multilevel converter is still widely used in some specific circuits, demonstrating certain pragmatism and reliability.

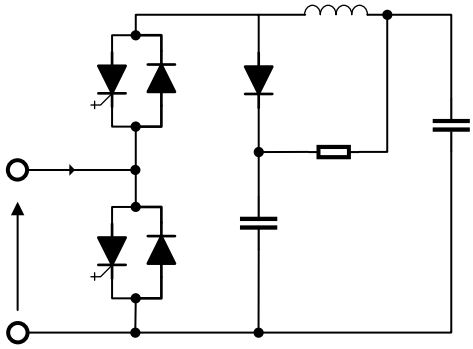


Fig. 12 IGCT Sub-module [3]

3. Control Strategies

3.1. Overview of Overall Structure

Control strategies for topology structures refer to the methods and techniques of adjusting and optimizing the structure in the network. These strategies aim to improve network performance, enhance network reliability and stability. Common control strategies include Pulse Width Modulation (PWM) strategy, Sinusoidal Pulse Width Modulation (SPWM) strategy, and Model Predictive Control (MPC) strategy.

3.1.1 Introduction to PWM

PWM control is a commonly used control strategy that adjusts the voltage or current magnitude by changing the pulse width of the signal [11]. It is implemented using a comparator and a timer. The comparator compares the reference signal with a triangular wave signal, and the timer generates a

periodic triangular wave signal. By changing the pulse width, control of the output voltage or current can be achieved. PWM control has the advantages of fast response, wide regulation range, and high efficiency. It finds wide applications in power electronics, motor control, and other fields.

3.1.2 Introduction to SPWM

SPWM control is a commonly used control strategy that adjusts the voltage or current magnitude by changing the pulse width. Similar to PWM control, SPWM control uses a sine wave signal as the reference signal. By adjusting the pulse width, the shape of the output signal can approximate a sine wave. SPWM control achieves more accurate voltage or current regulation and is suitable for applications that require high-quality output signals, such as audio amplifiers. It is widely used in power electronics, motor control, and other fields.

3.1.3 Introduction to MPC

Model Predictive Control is an advanced control strategy that achieves control objectives by predicting the system's behavior based on a model [12]. It is based on discrete-time models and optimizes the control variable sequence to minimize the error between the predicted model and the desired output. MPC has the following characteristics: consideration of multi-variable systems and multiple control objectives, consideration of constraints such as input and output limits, optimization of future dynamics to achieve better control performance. MPC is widely used in chemical engineering, mechanical systems, energy management, and other fields. It achieves more accurate, flexible, and robust control by modeling and predicting the system.

3.2. Analysis and Comparison

3.2.1 Principle and Output

PWM control is a method of controlling the output voltage or current by adjusting the pulse width of switching devices[13]. It generates a pulse signal based on a reference signal and the output of a comparator, and controls the magnitude of the output voltage or current by changing the duty cycle of the pulse signal. SPWM control is a special form of PWM control, where the duty cycle of the pulse signal is dynamically adjusted based on the amplitude and frequency of the reference signal to achieve an output waveform closer to a sine wave. MPC is a control strategy based on system models and prediction. It calculates the optimal control variables through optimization problem solving to achieve precise control of multilevel converters. In terms of output quality, PWM control is a switching control strategy that may contain higher harmonics in the output waveform, and may require filtering to improve the output quality[14]. SPWM control can achieve an output waveform closer to a sine wave with lower harmonic content by dynamically adjusting the duty cycle of the pulse signal. MPC control is a model predictive control strategy that can achieve precise control of multilevel converters with higher output quality. Therefore, when choosing a control strategy, the output quality requirements, required accuracy, and cost factors need to be considered and evaluated.

3.2.2 Complexity and Response

In terms of control, PWM control is a relatively simple strategy that only requires adjusting the pulse width based on the reference signal and the output of a comparator. SPWM control is slightly more complex than PWM control as it requires dynamically adjusting the duty cycle of the pulse signal based on the reference signal[15]. MPC control is a more complex strategy that requires establishing a system model and solving optimization problems to calculate optimal control variables. In terms of response speed, both PWM and SPWM control have the advantage of fast response and the ability to adjust the output voltage or current in real-time as they involve simple comparison and adjustment operations. However, due to the need for solving optimization problems, MPC control may have a relatively slower response speed as calculating the optimal control variables takes some time.

In conclusion, PWM control, SPWM control, and MPC control are different control strategies for multilevel converters, and they differ in principles, output quality, control complexity, and response

speed. In specific applications, the selection of a control strategy should be based on the requirements of the output quality and a comprehensive evaluation of the required accuracy and cost factors.

3.2.3 Cost and Complexity Differences

Single-phase multilevel inverter Relatively low Simple implementation of single-phase output, simple topology structure, relatively simple control strategy. Three-phase multilevel inverter Relatively high Need to achieve three-phase output, more switches and control circuits involved, may require more complex control strategies. Cascaded H-bridge multilevel inverter Relatively high Requires cascaded connection of multiple H-bridge units, requires more complex control strategies.

Modular multilevel inverter Relatively high Requires the combination of multiple modular units, may require more complex control strategies.

In summary, the choice of multilevel converters should be determined based on specific application requirements. Different topology structures have different characteristics and applicability, such as differences in input/output voltage levels, the number of switching devices, switching frequency, and control strategies. Additionally, the cost and complexity of multilevel converters are also important factors to consider. Therefore, when selecting multilevel converters, it is necessary to consider the factors mentioned above, evaluate them comprehensively, and make a decision based on the specific application requirements.

4. Outlook

In the future, modular multilevel converters will continue to play an important role in the power systems, and their development will not be limited. With the advancement of technology, modular multilevel converters are expected to be further enhanced through fusion and integration with other diverse technologies in the following aspects:

1) Improved Stability: Currently, modular multilevel converters generate and release a significant amount of heat when operating at high power density and high efficiency, which affects the stability of the system as the temperature rises. In the future, heat pipe technology can be combined with modular multilevel converters to optimize their heat dissipation design and improve the stability during transmission.

2) Increased Conversion Efficiency: In terms of level conversion, by researching deeper, multi-level conversion topologies, such as multilevel single-phase bridge and multilevel three-phase NPC, can reduce the voltage drop and switch losses of the switching devices, thereby improving the efficiency of the converters. Furthermore, combining inductive coupling and resonance technology can reduce switch losses and filter size, thus enhancing the conversion efficiency of the system.

3) Improved Response Speed: To enhance the response speed, advanced predictive control algorithms or model predictive control can be employed to adjust control parameters in real-time for faster response to input changes. Choosing switching devices with faster switching speeds or employing Zero Voltage Switching or Zero Current Switching techniques can reduce switch-on/off times and improve response speed, among other methods. These techniques contribute to enhancing the response speed of modular multilevel converters, making them adapt more quickly to input changes.

5. Conclusion

Modular multilevel converters, as a new type of multilevel converters, possess significant advantages such as strong scalability, high operating efficiency, strong fault tolerance, and high waveform quality. They are particularly suitable for high-voltage and high-power energy conversion applications and have gained widespread attention in industrial applications such as high-voltage motor drives, unified power flow controllers, wind power generation, photovoltaic power generation, DC/DC converters, HVDC tap changers, battery energy storage, and static var compensators. Therefore, research on modular multilevel converters is of great theoretical and practical significance.

Hence, the differences in modular multilevel converters are also crucial. Based on differences in topology structure and control strategy, this article has provided a detailed analysis of the similarities, differences, and advantages and disadvantages of multilevel converters. Also, the submodule topology structure, and differences in control strategies were explained, and a comparative analysis was conducted based on the differences and advantages of the control strategies.

Authors Contribution

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

References

[1] ZHAO Shitan. Research on low frequency operation control method of modular multilevel converter. Northeast Petroleum University, 2023.

[2] Yang Xiaofeng, Liu Yan, Chen Qian. Overview of DC Converter topologies Applied to DC Power Networks. Journal of Beijing Jiaotong University, 2022:1-16.

[3] Gao Gen N. Research on Converter control Technology in offshore wind power flexible DC transmission system. Yancheng Institute of Technology, 2023.

[4] You Shihong, Zhou Jun, Cheng Hua, Meng Gri Yi, Wang Meng. Design of DC Modular multilevel Converter for Efficient Interconnection of HVDC Power Networks with Different Line topologies. Journal of Power Sources 2022:1-16.

[5] Zheng Tong, Wang Kui, Zheng Zedong, Pang Jupeng, Li Yongdong. Research review of power electronic transformers based on MMC topology. Proceedings of the CSEE, 2022, 42(15): 5630-5649.

[6] Pan Xin. Research on orderly Charging and discharging strategy for electric vehicles based on MMC. Beijing University of Civil Engineering and Architecture, 2022.

[7] WEI Shenghui. Research on MMC Converter Connected to large-scale photovoltaic Power Station. Guizhou University, 2022.

[8] Ni Binye. Research on Fault current suppression technology of semi-bridge MMC flexible DC power grid. Huazhong University of Science and Technology, 2022.

[9] XIONG Shengtao, Liu Zhenxing, Liao Xuechao, Li Qunqiao. General Control Method of Modular multilevel Converter Topology. Power Electronics Technology, 2022, 56(01): 115-120.

[10] Li Yongfei. Research on Model Predictive Control Strategy of Modular multilevel Converter. Harbin Institute of Technology, 2021.

[11] Chen Lei, He Huiwen, Wang Lei, LI Guocheng, Chen Hongkun. Fault current limiting methods for flexible DC power grids based on half-bridge MMC. Power Systems Protection and Control, 2019, 49(21): 175-186.

[12] JIANG Youhua, Chen Fang, ZHAO Le, Cao Yilong, Yang Xingwu, WU Weimin. Review of MMC control strategy under unbalanced grid voltage. Journal of Power Sources, 2023, 21(04): 74-87.

[13] SHEN Y. Study on circulation control strategy of MMC-HVDC system. Lanzhou University of Technology, 2021.

[14] LI Yongdong, XU Jieyan, Yang Handi, Cheng Zhijiang, SHI Kunhong, Xu Lie. Overview and Prospect of multilevel Converter Topologies. Electric Machines and Control, 2019, 24(09): 1-12.

[15] Wang Yifan. Stability Analysis of direct drive Wind Farm Output System by modularized multilevel converter. North China Electric Power University (Beijing), 2020