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# Study of control methods for three-level, five-level and multilevel inverters

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**Abstract:**

With the rapid development of power electronics technology, multilevel inverters have gained wide attention in high-voltage and high-power applications due to their advantages of high output waveform quality and low switching loss. The article firstly introduces the basic topologies and control strategies of three-level inverters, including midpoint clamp type, flying capacitor type and H-bridge cascade type, etc. It focuses on analyzing the principles and characteristics of the control methods, such as space-vector pulse-width modulation and selective harmonic elimination. The research progress of five-level inverters is summarized, and the advantages and disadvantages of different topologies and their control techniques, such as modular multilevel and hybrid cascade types, are discussed. Subsequently, the article outlines the development trend of higher level number inverters and discusses the key technical issues facing multilevel inverters, such as voltage balance control, fault diagnosis and fault tolerance. The future research directions of multilevel inverter control methods are envisioned, including the application of intelligent control algorithms and the development of high-efficiency and high-reliability control strategies. This review provides a theoretical foundation and reference for the in-depth research of multilevel inverter control technology.

**Keywords:** multilevel inverter, control method, space vector modulation, voltage balancing, fault diagnosis

## 1. Introduction

*a) Background of the study*

In recent years, with the rapid development of power electronics technology, multilevel inverters have received wide attention and application due to their excellent performance. Compared with traditional two-level inverters, multilevel inverters have the advantages of multiple output voltage levels, low harmonic content and small switching loss, which show obvious technical advantages in the field of high-voltage and high-power. Especially in the fields of new energy generation and high-voltage frequency conversion speed control, multilevel inverter has be-

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come the key equipment.

With the transition of power system to clean and low-carbon direction, and the proposal of “double carbon” target, new energy power generation technology has been developed rapidly. As the key interface between new energy and public power grid, multilevel inverter plays an important role in improving the utilization rate of new energy and enhancing the stability of power grid.

In terms of multilevel inverter topology, diode clamped type (NPC), capacitor clamped type (FC), cascaded H-bridge (CHB), etc. have become mainstream. In recent years, new control strategies such as space vector PWM (SVPWM) and model predictive control (MPC) have also been intensively studied and applied.

*b) research purpose*

The main objective of this study is to deeply analyze the control principles and explore advanced control methods for three-level, five-level and higher-level multilevel inverters in order to improve the performance indexes of the inverters. Specific research objectives include: analyzing and comparing the main topologies of multilevel inverters, establishing accurate mathematical models, and laying the foundation for the design of subsequent control strategies. Focus on the mainstream topologies such as NPC-type and CHB-type, and analyze their operating principles, switching states and other characteristics.

Research on advanced modulation techniques applicable to multilevel inverters. Based on the traditional PWM method, focus on exploring the application of SVPWM, MPC and other new control strategies in multilevel inverters. By optimizing the control algorithm, the output voltage quality is improved and the switching loss is reduced.

For grid-connected application scenarios, the grid-connected control strategy of multilevel inverters is studied. It focuses on solving the problems of current control and harmonic suppression under unbalanced grid conditions to improve the grid-connected performance and reliability of the inverter. Through the above research, we aim to comprehensively improve the control performance of multilevel inverters, and provide theoretical support and technical guarantee for their application in new energy generation, high voltage inverter and other fields.

*c) research significance*

Theoretically, the grid-connected control strategy of multilevel inverter is studied for grid-connected application scenarios. It focuses on solving the problems of current control and harmonic suppression under unbalanced grid conditions to improve the grid-connected performance and reliability of the inverter. Through the above research, we aim to comprehensively improve the control performance of multilevel inverters, and provide theoretical support and technical guarantee for their application in new energy generation, high voltage inverter and other fields.

This study is of great significance in terms of practical applications. By improving the control method of the multilevel inverter, the quality of its output voltage can be significantly improved and the harmonic content can be reduced, so as to enhance the power quality and reduce the pollution to the power grid. The optimized control strategy can reduce the switching loss of the inverter, improve the system efficiency, and contribute to energy saving and emission reduction.

## 2. Theoretical overview

Multilevel inverter technology is an important power electronic conversion technology, which has been widely noticed and applied in the field of high-voltage and high-power applications in recent years. Compared with the traditional two-level inverter, multilevel inverter has the advantages of multiple output voltage levels, good output waveform quality, and low switching stress. According to the different topologies, multilevel inverters can be mainly categorized into three basic types: diode-clamped (NPC), capacitor-clamped (FC) and cascaded H-bridge (CHB). Among them, NPC-type multilevel inverters are widely used because of their simple structure and convenient control.

The control methods for multilevel inverters mainly include two categories: carrier modulation method and space vector modulation method. The carrier modulation method is simple to realize, but for high level number inverters, it requires a large number of carriers and is complicated to realize. The space vector modulation method is intuitive, flexible and can achieve better DC bus voltage utilization, but the number of vectors grows exponentially with the increase of the number of levels, and the computation increases dramatically. Therefore, how to simplify the space vector modulation algorithm and improve the computational efficiency is an important research direction for multilevel inverter control.

In recent years, with the development of digital control technology, the multilevel inverter control method based on model predictive control (MPC) has been widely studied.The MPC method can consider multiple control objectives at the same time, and is characterized by fast dynamic response. However, the traditional MPC method has problems such as large computation and unfixed switching frequency. Therefore, how to simplify the MPC algorithm, reduce the computation amount and realize the fixed switching frequency control is an important challenge for the application of MPC in multilevel inverters.

## 3. Synthesis of domestic and international research

*a) Review of overseas studies*

In recent years, with the rapid development of power electronics technology, multilevel inverters have been widely noticed and applied in high-voltage and high-power applications due to their advantages of multiple output voltage stages, low harmonic content and low switching losses. Foreign scholars have carried out in-depth research on the control methods of multilevel inverters, mainly focusing on space vector pulse width modulation (SVPWM), model predictive control (MPC) and so on.

In the study of SVPWM control methods, Cardenas et al. proposed a novel SVPWM algorithm for cascaded H-bridge (CHB) multilevel inverters. The method realizes the SVPWM control of an arbitrary n-level inverter by a simple mapping, and the calculation of the vector action time is only determined by the sector and two specific parameters, which greatly simplifies the calculation process.

In terms of model predictive control, Williams et al. proposed a finite control set model predictive control (FCS-MPC) method for T-type three-level inverters. The method simultaneously achieves multiple control objectives such as current tracking, switching loss minimization and midpoint potential balance by designing a multi-objective cost function.

To further improve the control performance of multilevel inverters, some scholars have begun to apply artificial intelligence techniques to the design of control algorithms. Brown et al. proposed an adaptive model predictive control method based on neural networks. The method utilizes neural networks to identify and update the system model online, which effectively improves the accuracy of the predictive model and thus improves the control performance.

Foreign scholars have achieved fruitful results in the research of multilevel inverter control methods, and the control algorithms have been constantly innovated and improved from the traditional SVPWM to the advanced model predictive control and then to the artificial intelligence control. These research results have laid a theoretical foundation for the high-performance control of multilevel inverters in various application scenarios, and promoted the progress and application of multilevel inverter technology.

*b) ) Synthesis of national studies*

In recent years, with the rapid development of China's power electronics technology and the booming of new energy industry, domestic scholars have made significant progress in the research of multilevel inverter control methods. The research mainly focuses on space vector pulse width modulation (SVPWM), model predictive control (MPC), sliding mode control, etc., and a variety of innovative control strategies have been proposed for different application scenarios.

In the research of SVPWM control methods, Li Zhou et al. proposed a modulation method and output waveform improvement strategy for a high-voltage multilevel modular inverter [1]. This strategy realizes the improvement of the module output voltage and current waveforms by adding a micro-regulability module, which effectively improves the output waveform quality. Mengqian Wang et al. proposed an improved SVPWM modulation method [6] for an active midpoint clamped five-level (ANPC-5L) inverter by combining with the imaginary coordinate transformation method.

In terms of model predictive control, Qian Jinyue et al. proposed an NPC three-level inverter control strategy based on a model predictive control algorithm [5]. The strategy considers the midpoint potential, switching frequency and common mode voltage, constructs a multi-constraint objective function, and selects the optimal vector through rolling optimization, which effectively reduces the common mode voltage and decreases the operation time. Lulu Fu et al. proposed an improved model predictive control algorithm based on optimal vector synthesis for a three-level grid-connected converter [8]. The algorithm effectively reduces the computation by selecting seven real switching vectors to be traversed in each control cycle and selecting the optimal switching vectors based on the cost function.

To solve the multilevel inverter midpoint voltage balancing problem, Chen Miao et al. proposed a midpoint potential balancing control method based on virtual center vector [7]. The method analyzes the causes of midpoint potential imbalance in a diode-clamped three-level inverter from the perspectives of space vectors and the influence of midpoint currents, and the effectiveness of the method is verified by simulation and experiment. Xiangping Kong and Ping proposed a midpoint voltage balancing control method based on five-level pulse width modulation (5L-PWM) for a full-bridge diode neutral point clamped (NPC) three-level LLC resonant converter [4]. The method effectively solves the problem of midpoint voltage offset by selecting the appropriate operating mode according to the midpoint voltage offset without the need of a proportional-integral (PI) controller.

In terms of sliding mode control, Jianchao Zhang proposed an improved second-order super-helical sliding mode observer [10] for the sensorless control system of a permanent magnet synchronous motor. The method employs fuzzy control to regulate the sliding mode gain and uses a saturation function with variable boundary layer

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instead of the traditional sign function, which effectively suppresses the jitter vibration phenomenon and improves the comprehensive performance of the permanent magnet synchronous motor.

For special application scenarios, Dongming Chen et al. investigated the control method of an actively supported three-phase PWM converter under an unbalanced grid [2]. By adding a power regulation circuit on the DC side, the decoupling control of the AC and DC sides was realized, which effectively solved the control conflict between DC bus voltage fluctuation and grid-side current quality. Hao Jengeng proposed an optimized modulation strategy by predicting the instantaneous total voltage of all sub-module capacitors of each bridge arm for AC/AC MMC for single-phase power supply system of high-speed railways, which effectively improves the dynamic response performance of the system [3].

Some scholars have also studied the fault diagnosis and fault-tolerant control of multilevel inverters. Song Mingxuan et al. proposed a real-time switching characteristic online detection method [9]. For NPC three-level inverters. Using only three current detection units and three voltage detection units, the method is able to obtain the operating status of four IGBTs and two clamp diodes of a single-phase bridge arm, which provides an effective means for fault prevention. Li et al. proposed a current-tracking hysteresis loop SVPWM fault-tolerant control method [11]. For a single-phase modified populated U-shaped cell (MPUC) five-level inverter. This method ensures accurate output current tracking under the inverter single-tube open-circuit fault state by voltage-vector equivalent substitution, without the need to add a spare hardware redundancy unit.

Domestic scholars have achieved fruitful results in the research of control methods for multilevel inverters, and the control algorithms have been constantly innovated and improved from the traditional SVPWM to the advanced model predictive control and sliding mode control, and then to the innovative control strategies for special application scenarios. These research results provide important theoretical support and technical guarantee for the application of multilevel inverters in the fields of new energy generation, power transmission and rail transportation.

c) *summarize*

As can be seen from the review of domestic and international research on control methods for multilevel inverters, the research hotspots in this field are mainly focused on SVPWM, model predictive control, and sliding mode control. Foreign research focuses more on basic theory innovation and the proposal of new control algorithms, such as the introduction of artificial intelligence technology into the design of control strategies; while domestic research focuses more on the optimization of control strategies for specific application scenarios. The future research trend may develop in the direction of intelligent, adaptive, and multi-objective optimization to cope with the control demand under complex working conditions. Meanwhile, the reliability and efficiency improvement of multilevel inverters as well as the expansion in emerging applications will also be important research directions.

## 4. . Literature review

In recent years, research for multilevel inverter control methods has focused on the following aspects:

In the area of space vector modulation, it is mainly studied how to simplify the algorithm and improve the computational efficiency. Li et al. proposed a new multilevel SVPWM method, which realizes the control of an arbitrary n-level inverter through a simple mapping and effectively reduces the computational complexity. Bo et al. proposed a multilevel optimal space vector PWM method, which can realize online control with the advantages of low harmonic content and low switching frequency. These studies provide new ideas to simplify the space vector modulation algorithm for multilevel inverters.

There are also many researches for the control problems of multilevel inverters in specific application scenarios. He et al. designed a current tracking method based on sliding mode control and a chaotic CPS method for off-grid CHB inverters, which effectively improves the quality of current tracking and reduces the risk of harmonics. Chen et al. proposed a LADRC-based control method for the three-phase grid-connected inverter control problem under unbalanced grid conditions, which improves the system's anti-interference capability. These studies enrich the control strategies of multilevel inverters in different application scenarios.

## 5. Conclusions and outlook

Significant progress has been made in the research of multilevel inverter control methods, but some problems and challenges still exist. The future research directions mainly include the following aspects:

With the development of artificial intelligence technology, the application of intelligent algorithms, such as deep learning and reinforcement learning, to multilevel inverter control is an important research direction. Adaptive control can be realized through intelligent algorithms to improve the robustness and control performance of the system. For example, deep neural networks can be used to predict the system state and achieve more accurate model predictive control; reinforcement learning algorithms can also be used to automatically optimize the control parameters and improve the overall system performance.

The application of multilevel inverters in new energy generation, electric vehicles and other emerging fields will bring new control requirements and challenges. For example, in the new energy grid-connected power generation system, how to realize the coordinated control of multilevel inverters and power grid to improve the reliability and stability of the system is an important research direction. In the field of electric vehicles, how to realize the high-efficiency and high-power density control of multilevel inverters is also an issue of concern.

Fault diagnosis and fault-tolerant control of multilevel inverters is also an important research direction. With the increased application of multilevel inverters in high-reliability occasions, how to realize the rapid diagnosis and isolation of faults to ensure the reliable operation of the system has become an urgent problem to be solved. In the future, data-driven fault diagnosis methods can be explored to realize fault-tolerant control of the system in combination with model predictive control to improve the reliability and robustness of the multilevel inverter system.

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