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Review on Multilevel Inverters: Topologies, Control and Modulation Techniques

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ABSTRACT:

An inverter is a power electronic device that transforms DC power into AC power, with the appropriate output voltage and frequency. A multilevel inverter produces a multistep voltage waveform with amplitude, phase, and frequency that are all controllable. Due to their many benefits, including lower voltage stress on the power switches, lower electromagnetic interference (EMI), higher DC link voltages, and a low dv/dt ratio that supplies lower harmonic contents in the output voltage and current. Multilevel inverters (MLI) have become increasingly popular in recent years for medium voltage and high-power applications. However, these devices also come with a number of other built-in disadvantages, such as a greater number of switches, a greater need for sources, and intricate control mechanisms. This paper is about different topologies, their control strategies and emerging technology of Modular Multilevel Inverters (MMC).

Key Words: *Electromagnetic Interface (EMI), dv/dt ratio, lower harmonic content*

1. INTRODUCTION

Multi-level inverters are being used more often in industrial settings and low- and medium-voltage distribution systems these days in order to reap a number of advantages. MLI inverters are the power electronic devices which convert direct current (DC) to alternating current (AC).MLI inverters are designed to address limitations of traditional two-level inverters, which produce a high switching losses for high power and voltage applications. By using multiple voltage levels in the output waveform, multilevel inverters aim to achieve a more sinusoidal output, reducing harmonic distortion. Multilevel inverters are an essential technology in

Multilevel inverters are the advanced players in the game of power conversion, providing a more refined and high-quality output. They are employed in applications, such as renewable energy systems, motor drives, electric vehicles, and grid applications power systems.

1.1 Multilevel Inverters over Conventional Inverters

Conventional inverter only produces the two levels of voltage at the output i.e., +v and -v. The conventional inverters operate at very high switching frequencies which results in high switching losses and rating constrains. This also results in harmonic distortion, Electromagnetic Interference. It is challenging to directly to power electronic switches with high, medium voltage grids due to these issues. Because of these issues, MLI has grown in interest as a high- and medium-power industrial application area. Multilevel inverter is a structure which consists of dc sources and switches leads to attracting researchers and industries. Multilevel inverters take the place of all the barriers found in conventional inverters.

Comparison between Conventional and Multilevel inverter

Conventional inverters	**Multilevel inverters**
Total Harmonic Distortion is high	Total Harmonic Distortion is is less
Switching stress is high	Switching stress is low
Not used for high voltage applications	Applied for high voltages
High dv/dt and Electro Magnetic interface	Low dv/dt and Electro Magnetic Interface
Switching frequency is high	Switching frequency is low
Switching losses are more	Switching losses are less

2. INVERTER TOPOLOGIES

Multilevel inverters are categorized based on the number of voltage levels they can produce at the output and the topology used to achieve these levels. Here are some common types of multilevel inverters:

2.1 Diode-Clamped Multilevel Inverter (Neutral-Point Clamped Inverter or NPC):

This is also known as the neutral-point clamped (NPC) inverter, this topology uses diodes and clamping capacitors to create multiple voltage levels. The NPC inverter has a central neutral point that is clamped to a reference voltage. It is characterized by its ability to produce more voltage levels with a relatively simple structure. The important purpose of this is to reduce the voltage stress in the power electronic devices.

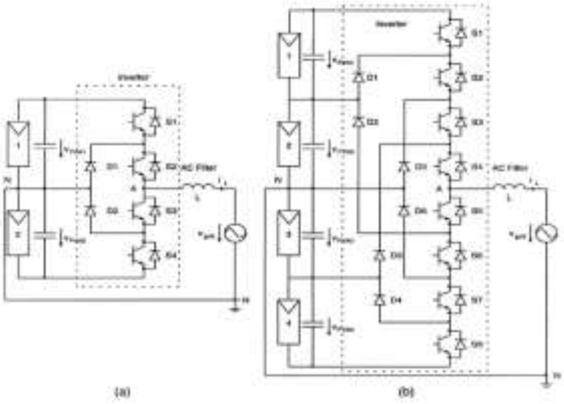


Fig 1: Diode clamped multilevel inverter (a)3-level (b)5-level

The fig 2(a) shows the three-level diode clamped inverter for which the dc voltage is divided into three levels by the two capacitors. The capacitors C_1 and C_2 are connected in series. The switches S_1, S_2, S_3 and S_4 need to operate in a manner to get the output voltage in three levels.

Table 2: Switching operation for three level diode clamped inverter

S1	S2	S3	S4	state	Van
1	1	0	0	+	$V_{dc}/2$
0	1	1	0	0	0
0	0	1	1	-	$V_{dc}/2$

The Fig 2(b) represents the five-level diode clamped inverter which consists of four capacitors C_1, C_2, C_3 and C_4. The voltage across the each of the capacitors is $V_{dc}/4$. The switching operation can be as follows:

Table 3: Switching conditions for 5 level diode clamped inverter

S1	S2	S3	S4	S5	S6	S7	S8	State	V_{an}
1	1	1	1	0	0	0	0	+	$V_{dc}/2$
0	1	1	1	1	0	0	0	+	$V_{dc}/4$
0	0	1	1	1	1	0	0	0	0
0	0	0	1	1	1	1	0	-	$V_{dc}/4$
0	0	0	0	1	1	1	1	-	$V_{dc}/2$

Compared to other types of inverters, back-to-back inverters offer distinct advantages. They are suitable for use in various applications, and the capacitors employed in this system are pre-charged and operate at the fundamental frequency, contributing to high efficiency. However, it's worth noting some drawbacks. As the number of clamping diodes increases with each level, there's a risk of DC level discharge, impacting the precision of control and monitoring. Despite these limitations, back-to-back inverters find prominent applications in high-voltage power drives and power compensators. An **'n'** level diode clamped inverter require:

1. Devices for switching = 2n-2
2. Input voltage source= n-1
3. Number of diodes= (n-1) (n-2)

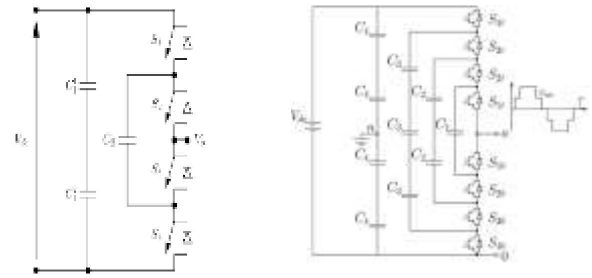
2.2 Capacitor-Clamped Multilevel Inverter (Flying Capacitor Inverter or FC):

The capacitor-clamped multilevel inverter, also known as the flying capacitor inverter, employs flying capacitors to create additional voltage levels.

The count of voltage levels in the output waveform of a Flying Capacitor Multilevel Inverter (FCMLI) is contingent on the number of flying capacitors and their respective voltage levels. These flying capacitors serve as energy storage elements, strategically connected between different voltage levels within the inverter. The switching strategy in FCMLIs involves precise control over the state of these flying capacitors to attain the desired output voltage levelsFCMLIs exhibit the capability to regulate both active and reactive power flow. Noteworthy advantages of FCMLIs include the elimination of clamping diode issues, a reduction in dv/dt stress, and the facilitation of additional switching, which aids in maintaining charge equilibrium across the capacitors.

An ‘**n**’ level flying capacitor inverter requires:

1. Switches = 2n-2
2. Number of capacitors= n-1



(a) (b)

Fig 2: Flying capacitor multilevel inverter (a)3 level (b)5 level

The 3-level flying capacitor multilevel inverter produces 3 levels voltage at the output [1]. The switching operation to get 3 levels of output voltage is as follows. The 5-level flying capacitor multilevel inverter is more flexible than the diode-clamped inverter. This produces five levels of sinusoidal waveform at the output. To get the required output the switches need to be triggered in the below manner.

Table 4: Switching operation of 3 level flying capacitor inverter

S1	S2	S3	S4	STATE	V_o
1	1	0	0	+	$V_{dc/2}$
0	0	1	1	-	$V_{dc}/2$
1	0	1	0	0	0
0	1	0	1	0	0

A 5-level flying capacitor inverter can produce five different voltage levels at the output. The voltage levels are typically -2V_dc, -Vdc, 0, Vdc, and 2V_dc, where Vdc is the DC voltage source.

Table 5: Switching operation of 5 level flying capacitor inverter

S1	S2	S3	S4	S1’	S2’	S3’	S4’	Van
1	1	1	1	0	0	0	0	Vdc/2
1	1	1	0	1	0	0	0	Vdc/4
0	1	1	1	0	0	0	1	
1	0	1	1	0	0	1	0	
1	1	0	0	1	1	0	0	0
0	0	1	1	0	0	1	1	
1	0	1	0	1	0	1	0	
1	0	0	1	0	1	1	0	
0	1	0	1	0	1	0	1	
0	1	1	0	1	0	0	1	
1	0	0	0	1	1	1	0	-Vdc/4
0	0	0	1	0	1	1	1	
0	0	1	0	1	0	1	1	
0	0	0	0	1	1	1	1	-Vdc/2

2.3 Cascaded H-Bridge Multilevel Inverter

The cascaded H-bridge inverter consists of multiple H-bridge cells connected in series. Each H-bridge cell can independently generate a voltage level, and the overall output voltage is the sum of these individual levels. This topology provides excellent modularity and ease of scalability. Cascaded H-bridge inverters are a popular topology that are widely produced by businesses and are beneficial for power conversion. To create a synthesized voltage waveform, cascaded H-bridge converter switches are typically used with the SPWM or MSPWM technique. These methods switch at a higher frequency and produce fewer harmonics.

If n cells are there then number of output voltage levels is 2n+1

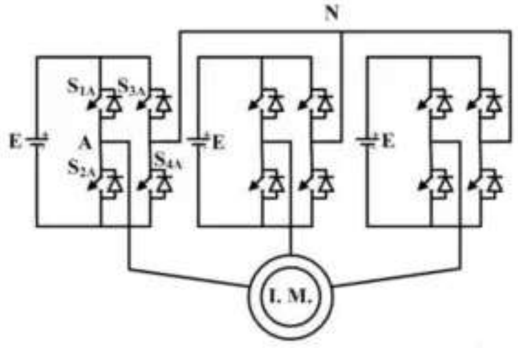


Fig 3: 3 level cascade h bridge inverter

The switching operation of the 3-level cascade inverter as follows

Table 6: switching operation of the 3-level cascade inverter

S1	S2	S3	S4	Van
1	0	0	1	+V
1	0	1	0	0
0	1	0	1	
0	1	1	0	-V

2.4 H-Bridge Multilevel Inverter

The H-bridge inverter is one of the simplest multilevel inverters. By connecting multiple H-bridge cells together, it is possible to achieve multiple voltage levels. Each H-bridge cell can produce three voltage levels: +Vdc, 0, and -Vdc. The combination of these levels results in a stepped approximation of a sine wave.

2.5 Hybrid Multilevel Inverter

Hybrid multilevel inverters combine different multilevel inverter topologies to achieve improved performance or to address specific requirements. For example, a hybrid inverter might combine an NPC topology with cascaded H-bridge cells to benefit from the advantages of both.

2.6 Modular multilevel Converter

Modular Multilevel Converters (MMCs) represent a significant advancement in power electronic converters, particularly in the context of medium- and high-voltage direct current (MVDC and HVDC) applications. The fundamental structure of MMCs involves numerous series-connected sub-modules, each with a relatively low voltage rating. This modular design allows for a flexible and scalable architecture, making MMCs well-suited for various power system applications.

The key feature of MMCs is their ability to generate multiple output voltage levels, which is instrumental in enhancing the efficiency and control of high-power electrical systems. The modular architecture enables the converter to adapt to different voltage levels and tailor its output accordingly, providing a versatile solution for a wide range of grid configurations.

The widespread adoption of MMCs is crucial in driving the ongoing energy transition. Their application contributes to improved overall system efficiency, enhanced power quality, fault tolerance, and increased power density. These advantages make MMCs pivotal in supporting the integration of renewable energy sources, such as solar and wind, into the power grid.

One of the noteworthy benefits of MMCs is their capability to operate in both AC and DC grids. This versatility is essential for the development of modern power systems, accommodating the increasing complexity and diversity of energy sources. The adaptability to various voltage ranges positions MMC technology as a corners tone for building resilient and sustainable energy infrastructures.

In summary, Modular Multilevel Converters play a pivotal role in shaping the energy landscape towards a sustainable future. Their modular design, multiple voltage levels, and adaptability to different grids contribute to improved efficiency, reliability, and the integration of renewable energy sources, marking MMCs as a key technology in the evolution of our energy systems.

Comparison of various classical topologies of MLI

Table 7: Comparison of various MLI'S

Characteristic	NPC	FCI	CHB
Switching devices	2(n-1)	2(n-1)	2(n-1)
Diodes	2(n-1)	2(n-1)	2(n-1)
Clamping diodes	0	(n-1)(n-2)	0
Dc bus capacitor	(n-1)/2	(n-1)	(n-1)
Balancing capacitor	0	0	(n-1)(n-2)/2
Redundancy	Redundant	Not Redundant	Redundant
Dc bus sharing	Separate dc source	Dc bus sharing	Dc bus sharing
Structure	Modular	Not Modular	Not Modular
Flexibility	Flexible	Not flexible	Not flexible

Each type of multilevel inverter has its own set of advantages and disadvantages, and the choice of a specific topology depends on factors such as the application requirements, voltage levels needed, efficiency considerations, and cost constraints. For modularity and redundancy cascade h bridge MLI are effective. For cost effectiveness and efficiency diode clamped is used. For redundancy and cost flying capacitor can be effective. Researchers and engineers continue to explore and develop new configurations and control strategies to enhance the performance of multilevel inverters in various applications.

3. MODULATION AND CONTROL STRATAGIES

3.1 Modulation Techniques

Depending on the switching frequency, multilevel inverters' modulation techniques can be categorized. High switching frequency methods allow for multiple commutations of the power semiconductors within a single fundamental output voltage period. The traditional carrier-based sinusoidal PWM (SPWM) approach, which employs phase-shifting to lower the harmonics in the load voltage, is a highly used technique in industrial applications.

A. Sinusoidal PWM

Sinusoidal Pulse Width Modulation (PWM) is a common PWM method used in inverters. In this methodology, a sinusoidal AC voltage reference (Vref) undergoes continuous comparison with a high-frequency triangular carrier wave (Vcarrier). This real-time comparison is instrumental in determining the switching states for each pole in the inverter, following specific rules:

If Vref > Vcarrier: The upper switch is activated, resulting in a pole voltage of Vcarrier/2.

If Vref < Vcarrier: The lower switch is activated, leading to a pole voltage of -Vcarrier/2.

The peak-to-peak value of the triangular carrier wave represents the DC-link voltage (Vdc). In this technique, for linear modulation to occur effectively, it is crucial that the amplitude of Vref remains below the peak of the triangular carrier, i.e., $|Vref| \leq Vdc/2$. This method falls under the category of carrier-based Pulse Width Modulation (PWM) techniques, more specifically known as Sinusoidal Pulse Width Modulation (SPWM) due to the use of a sine wave as the reference shape. It is also referred to as the triangle-comparison PWM technique because it involves comparing the reference signal with a triangular carrier wave.

Different SPWM techniques based on the amplitude, frequency and magnitude of the carrier waveforms

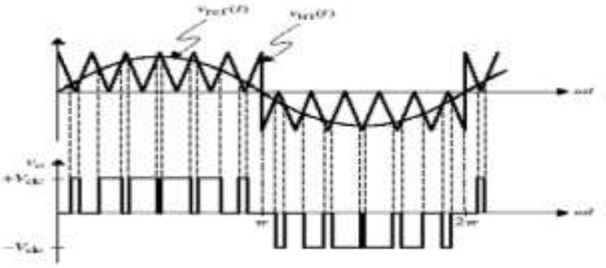


Fig 4: Sinusoidal Pulse Width Modulation

1. Phase Disposition SPWM

In this method, multiple carrier waveforms, each vertically shifted, are compared with a sinusoidal reference waveform. This approach results in the generation of (N + 1) levels of output voltage. The output voltage levels are determined as follows:

1. When the sinewave exceeds both upper triangular waves, the voltage is +Vdc/2.

2. If the sine wave is below the uppermost triangular wave but above the first triangular wave from above the zero axis, the voltage is +Vdc/4.

3. Zero voltage is obtained when the sinewave is below the upper triangular wave and above the lower triangular wave.

4. If the sine wave surpasses the lowermost triangular wave but is below the first triangular wave from below the zero axis, the voltage is -Vdc/4.

5. When the sine wave is below both lower triangular waves, the voltage is -Vdc/2.

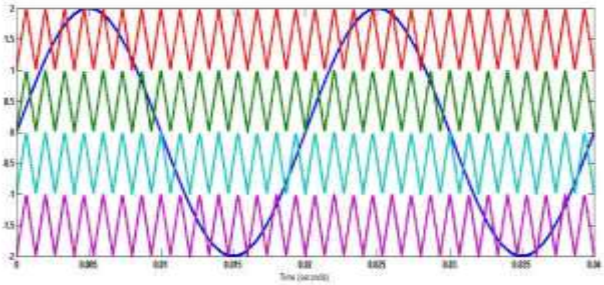


Fig 5: Phase disposition PWM

2. Phase Opposition Disposition SPWM

This method involves the segmentation of a carrier waveform into two parts: one above the zero axis and the other below it. Both segments share identical frequency, magnitude, and phase characteristics. Notably, the portion above the zero axis is distinguished by a 180-degree phase shift compared to the portion below the zero axis. The converter operates by switching between positive and negative voltages based on a comparison between a sine wave and a triangular wave.

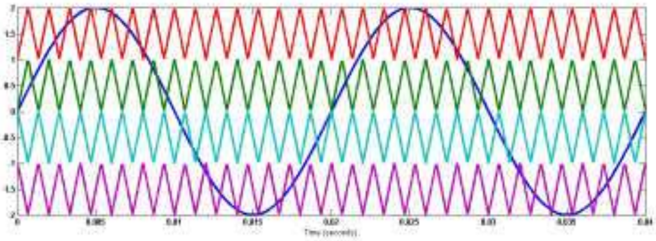


Fig 6: Phase Opposition Disposition SPWM

3. Alternate Phase Opposition Disposition (APOD)

In the Alternate Phase Opposition Disposition Pulse Width Modulation (APOD) technique, each carrier waveform is intentionally set 180 degrees out of phase with its adjacent carrier wave. All the carrier waveforms share the same frequency and amplitude. However, when comparing one carrier waveform to its neighboring carrier waveform, a phase shift of 180 degrees is introduced. Specifically, odd-numbered carrier waveforms are in phase with each other, while they are 180 degrees out of phase when compared to even-numbered carrier waveforms. This alternation in phase relationships, where odd carrier waveforms exhibit alignment and 180-degree phase shift with respect to even carrier waveforms, characterizes the APOD Pulse Width Modulation method.

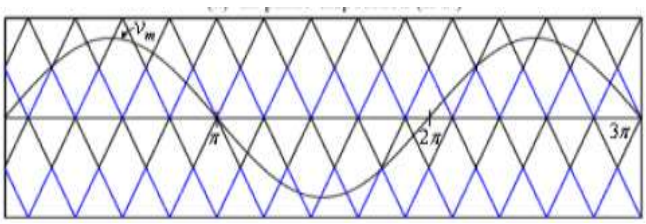


Fig 7: Alternate Phase Opposition Disposition

B. Selective Harmonic Elimination

This multilevel inverters is to selectively eliminate or minimize specific harmonics in the output voltage waveform. Multilevel inverters use multiple voltage levels to approximate a sinusoidal output waveform with reduced harmonic distortion compared to traditional two-level inverters. Multilevel inverters generate an output voltage waveform using several voltage levels, often achieved by connecting multiple power semiconductor devices in series. The primary goal of SHE in multilevel inverters is to determine the appropriate switching angles or modulation indices for the semiconductor devices in order to eliminate or minimize specific harmonics in the output waveform. Multilevel inverters inherently introduce fewer harmonics compared to two-level inverters. However, SHE can be employed to further tailor the harmonic spectrum based on specific requirements. Various optimization techniques, such as mathematical programming or numerical algorithms, can be used to solve the SHE equations and determine the optimal switching angles or modulation indices. The solutions obtained from the optimization process are then implemented to control the switching of the semiconductor devices in the multilevel inverter.

The complexity of the SHE problem increases with the number of levels in the multilevel inverter. Solving the optimization problem may require advanced mathematical techniques and computational resources.

C. Space Vector Control

Space Vector Modulation is a widely used technique for controlling the output of multilevel inverters. SVM operates in the space vector plane, which represents the instantaneous voltage vector applied to the load. Space vector control allows the generation of the desired output voltage by appropriately selecting the voltage vectors**.** The main advantages of SVC are higher efficiency and lower harmonic distortion, improved output waveform quality and better utilization of the DC bus voltage.

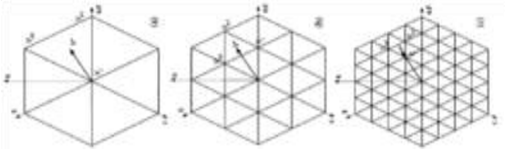


Fig 8: Space Vector of 2-level,3-level and 5-level

Comparison of Modulation techniques:

Table 8: Comparison of modulation Techniques

Modulation technique	**Advantages**	**Disadvantages**
PS-SPWM	1. Easy structure Switching 2.patterns need not be rotated	1.THD is higher 2.Voltage balancing is not flexible 3.Response is poor
LS-PWM	1**.**Simple structure 2.Quality of output waveform is better	1. THD is higher 2.In high level structure voltage balancing is not flexible 3.Dynamic response is poor
SVM	1. Switching states are redundant 2.Dynamic response is good 3.Efficiency is high 4.THD is low for output	1.High-level structures may lead to complexity
SHE	1.Used for high power applications 2.Steady state response is good 3.Efficiency is higher	1.Dynamic response is slow 2.voltage balancing is poor 3.Large capacitors are required

Carrier-based methods are straightforward but lack flexibility, especially in maintaining capacitor and neutral point voltage balance in high-level structures of multilevel inverters. This limitation becomes more pronounced in advanced configurations. Low-frequency techniques like Sinusoidal Harmonic Elimination (SHE) and Natural Levels

Modulation (NLM) are unsuitable for low-power traction drives due to the need for large capacitors, which adversely affects power density. In contrast, Space Vector Modulation offers excellent flexibility and responsiveness. However, its complexity escalates in high-level structures with an increased number of voltage vectors. On the other hand, the Discontinuous Pulse Width Modulation (DPWM) scheme mitigates switching losses in inverter switches, albeit at the cost of higher Total Harmonic Distortion (THD) in the output.

3.2 CONTROL TECHNIQUES

A. PI based Techniques

The proportional component of the PI controller responds to the immediate error between the reference and actual voltages. It adjusts the output voltage proportionally to this error, providing a quick response. The integral

component of the PI controller considers the accumulated error over time. It helps eliminate any steady-state error by integrating the error signal. This component is particularly crucial for maintaining accurate voltage regulation over the long term. The PI controller operates in a closed-loop control system. The output of the controller adjusts the modulation index or other control parameters of the multilevel inverter to ensure the output voltage aligns with the reference voltage.

Capacitor and Neutral Point Control: In multilevel inverters, capacitor and neutral point voltage balancing is essential for the reliable operation of the system. The PI controller can be extended to include control strategies specifically aimed at maintaining balance in capacitor voltages and neutral points. PI controllers provide a balance between quick response to sudden changes (proportional action) and steady-state accuracy (integral action). This is crucial in applications where the load or operating conditions may vary. The implementation of PI control in multilevel inverters may face challenges related to non-linearity, system complexity, and the need for tuning parameters. However, once properly tuned, PI controllers can offer effective control in a variety of operating conditions. In some cases, adaptive PI control strategies may be employed to dynamically adjust controller parameters based on the operating conditions, enhancing the controller's robustness and performance.

B. Hysteresis Techniques

Hysteresis techniques are often used in the context of Multilevel Inverters (MLI) to control the switching states of the inverter. In hysteresis-based control for MLI, the key idea is to use hysteresis bands to determine when to switch the inverter states. Hysteresis controllers operate by comparing the desired reference signal with the actual system output. When the difference between the

reference and the output signal exceeds a predefined hysteresis band, a switching action occurs. Hysteresis bands are set around the reference signal. These bands define the acceptable error range between the reference signal and the actual output signal. The width of the hysteresis bands determines the sensitivity of the control system. The actual output signal from the MLI is continuously compared with the reference signal. When the difference between the two signals exceeds the hysteresis band width, a switching event is triggered.

The switching logic determines the direction and magnitude of the required switching event. This information is used to control the switching device (typically IGBTs or MOSFETs) in the MLI. The control system operates in a closed-loop fashion, continuously adjusting the switching states to minimize the difference between the reference and actual signals.

C. Model Predictive Control Technique

Essentially, Model Predictive Control (MPC) relies on a system model to predict its behavior over a specified horizon. It employs a cost function to outline system objectives, determining control actions by minimizing the differences between predicted and desired values. MPC generates a sequence of control actions for each cycle, but only the initial action is implemented.

In the realm of Multilevel Inverters (MLIs), various MPC approaches have been explored, leading to two main categories: direct MPC and indirect MPC. Direct MPC involves applying the controller action, represented as an integer vector, directly to the system without the need for a modulation stage. In other words, the controller outputs the switching signals. On the other hand, indirect MPC produces the control action as a real-valued vector. Subsequently, a modulator is used to generate the switching pulses based on the controller's output.

D. Sliding Mode Control Technique

Sliding Mode Control (SMC) stands out as a compelling and effective approach to steering a system's representative point along a predefined sliding surface within a specified timeframe. The hallmark of SMC lies in its use of switching control elements, irrespective of the system's initial conditions. This technique showcases remarkable robustness, particularly in the face of parameter uncertainties. The selection of the sliding surface in SMC typically relies on system errors or a linear combination of various system states. Through this strategy, SMC excels in achieving stable and swift control responses, making it

particularly well-suited for scenarios where system dynamics encounter uncertainties or variations. Building upon the foundation of SMC, a refined version has emerged, incorporating variable weighting factors within the sliding functions. This enhanced SMC method has been specifically crafted for controlling common and differential mode currents in both single-phase and three-phase Modular Multilevel Converters (MMCs). Notably, the proposed SMC approach not only showcases steady-state performance comparable to traditional Proportional-Integral (PI) controllers but also outperforms them in terms of achieving a faster dynamic response. Notably, this enhanced SMC technique imposes a reduced computational load when compared to Model Predictive Control (MPC)-based methods, enhancing its practical applicability in real-time control scenarios.

E. Deadbeat Control Techniques

Deadbeat control involves designing a control strategy to force the system to track a reference signal with minimal delay and zero steady-state error. In multilevel inverters, deadbeat control calculates the necessary control inputs at each sampling interval to achieve precise tracking of the reference signal in a predetermined number of steps. The objective is to rapidly and accurately bring the output of the multilevel .The implementation involves designing a controller that

calculates the optimal control inputs based on the system's discrete-time model and the desired reference signal.

F. ANN based Techniques

Artificial Neural Networks (ANNs) serve as simplified models of human neurons, utilizing diverse learning techniques to establish a mapping algorithm between input and output values. In the realm of Sliding Mode Control in Multilevel Inverters (SDCS-MLI) applications, ANNs play a dual role: 1)estimating crucial parameters within the control law, and 2) acting as the controller to generate control decisions. The preferred neural network topology for these applications is the multilayer perceptron (MLP), characterized by three layers: the input layer, the hidden layer, and the output layer. Each layer is populated with neurons, with the input layer providing essential data for decision-making its number of neurons aligning with the input parameters. The neurons in the hidden layer are intricately interconnected based on the architectural design of the network, incorporating weighting factors for each connection and biasing parameters for each neuron. This intricate structure allows the MLP to effectively capture and process the complex relationships within the control system, making it a preferred choice for ANNs in SDCS-MLI applications

Comparison of various control techniques

Table 9: Comparison of control techniques

Control Techniques	Advantages	Disadvantages
PI-based Technique	1.Implementation of this technique is easy. 2.Switching frequency is fixed 3.The voltage balancing of capacitors are done by using redundant switching states.	1. Dc capacitor voltage is regulated by using external circuits. 2.Complexity is higher when compared to other conventional techniques.
Hysteresis based techniques	1. Accuracy is more. 2.Dynamic response is faster. 3. Implementation is also easy.	1.To get the accuracy more, the switching frequency is higher.
Model Predictive Control	1.Dynamic response is faster. 2. Modulation stage is not required. 3. Switching frequency is fixed.	1.Delay of time.
Sliding Mode Control	1.The function of switching is easier for the systems like hybrid systems. 2.Computational difficulty is low.	1. Switching frequency is variable
Deadbeat Control Technique	1. Dynamic response is faster. 2. Steady state error is zero.	1.Sensitivity is higher.
ANN based Techniques	1.The system performance is increased.	1. Accuracy changes due to change in collection of data

The choice of control strategy for multilevel inverters depends on the specific application requirements, system complexity, and the desired trade-off between performance and computational resources. While simpler techniques like

SPWM and SVM are commonly used for their balance between performance and complexity, advanced strategies such as MPC and fuzzy logic control may being used in applications where robustness to system variations is crucial.

CONCLUSION:

In conclusion, the exploration of multilevel inverters has shed light on the significant advancements and promising prospects in power electronics and energy conversion systems. Through this review, we have delved into the key principles, topologies, and control strategies employed in multilevel inverters, recognizing their ability to address the challenges associated with traditional two-level inverters.

The analysis of various multilevel inverter topologies has highlighted their capacity to enhance voltage waveforms, reduce harmonics, and improve overall system efficiency.

These inverters have proven to be instrumental in applications requiring high voltage and power conversion, like renewable energy systems, motor drives, and uninterruptible power supplies. the exploration of multilevel inverters signifies not only a technological advancement in power electronics but also a pathway toward a more sustainable and resilient energy landscape. As research and development in this field progress, we anticipate further innovations and widespread implementation of multilevel inverter technologies, fostering a greener and more energy-efficient future.

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