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Multi carrier pulse width modulation-based cascade multilevel inverter

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Abstract— *For medium voltage, high power applications, the most efficient choice is the cascade multilevel inverter (CMI). Compared to the more popular two-level inverter, CMI is receiving interest that is more than typical because of its better voltage quality, higher harmonic performance, and decreased voltage strain on the switching electronics. For a considerable amount of time, there has been a great deal of research conducted on the PWM technique. Utilizing multi carrier pulse width modulation (MCPWM) technology, a cascade multilayer inverter's harmonic performance is enhanced. In this research, we study the theoretical underpinnings of spread spectrum PWM techniques and compare several implementations through a computational simulation. Due to its special properties, CMI can be applied in a variety of scenarios. In this study, we concentrate on*

Keywords: MCPWM, CMI, PWM, APOD, POD, IPD

INTRODUCTION

The multilevel inverter's fundamental idea is to link the power semiconductor switching components in a series arrangement. The output voltage waveform of the multilayer inverter is approximately sinusoidal because of the many dc voltage levels. The multilayer inverter improves the output waveform and harmonic performance while putting less strain on the switching electronics. Peak system performance and efficiency are not achieved by the two-level voltage source converter because of filter size, losses, and total harmonic distortion (THD). A multilayer inverter must be used in order to increase a high-voltage system's efficacy and effectiveness [1]. An estimate of the converter loss influences the power converter's cooling system cost. The cascade multilevel inverter (CMI), flying capacitor multilevel inverter, and neutral point clamped multilevel inverter are the three most used multilevel inverter topologies. A cascade multilevel inverter (CMI), a flying capacitor multilevel inverter, and a neutral point clamped multilevel inverter are the three most common types of multilevel inverters. A cascade multilevel inverter is the most popular type of multilevel inverter (CMI). With the most desirable qualities is the CMI topology. The converter's size and cost may be decreased by CMI, improving system dependability. Comparatively speaking, CMI uses a lot less capacitors and semiconductor devices than other topologies. The CMI output levels are determined by the formula $m = 2s + 1$, where s is the number of dc sources employed in a given phase and m is its voltage. Expanding the application of the CMI is largely dependent on the modulation approach. This study builds on earlier research by contrasting the MCPWM approach with alternative approaches and outlining the key applications of CMI. As seen in Figure 1, nine voltage output levels for each CMI phase are produced by connecting four cells in series.

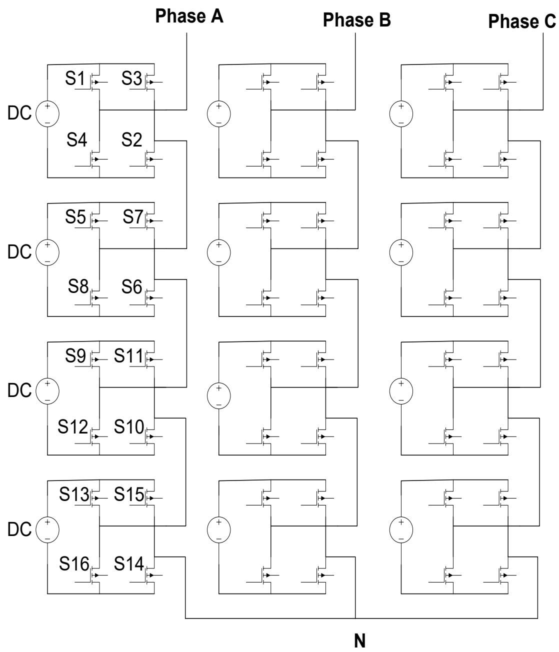


Fig.1 Three-Phase, Nine-Level CMI

TOPOLOGY OF CMI

Figure 2 displays a number of CMI topologies, including as the cascade H-bridge inverter and the single-phase cascade half-bridge inverter. As opposed to the cascade H bridge inverter, which produces multiple phase legs by using a continuous line of single phase full bridge inverters [3], the cascade half bridge has a single switching element that produces two output voltage levels. One benefit of the cascade H bridge architecture is the low voltage rating of the semiconductor components employed. Approximately 3300 volts can be obtained as the line-to-line voltage by employing a nine-level inverter. The quantity of power cells a cascade inverter uses affects both its manufacturing cost and operating voltage. In a cascade multilayer inverter, the DC sources for every phase leg have to be different. The output voltage from these sources needs to scale linearly with the number of cells used in order for a cascade H bridge inverter to function. Uneven DC sources are used by a cascade H bridge inverter to achieve higher levels without adding extra cells [4].

MODULATION SCHEME

As can be seen in Figure 4, multilayer inverters utilize either a constant switching frequency or a variable switching frequency for the carrier wave that drives the inverter's output voltage and current. The basic idea underlying multi carrier width modulation (mcpwm) is to compare a modulating signal to another multi carrier signal that may have had its level or phase altered. With MCPWM, the multilevel inverter's output waveform is more desired and total harmonic distortion (THD) is minimised. Lower switching losses and some indications of lower-order harmonics are seen in the constant switching frequency technique. The output voltage waveform also shows indications of higher-frequency harmonics when using the method with a higher switching frequency [5], which increases the switching losses. Phase-shift carrier-based modulation outperforms the SHE method in a shorter amount of time [6].

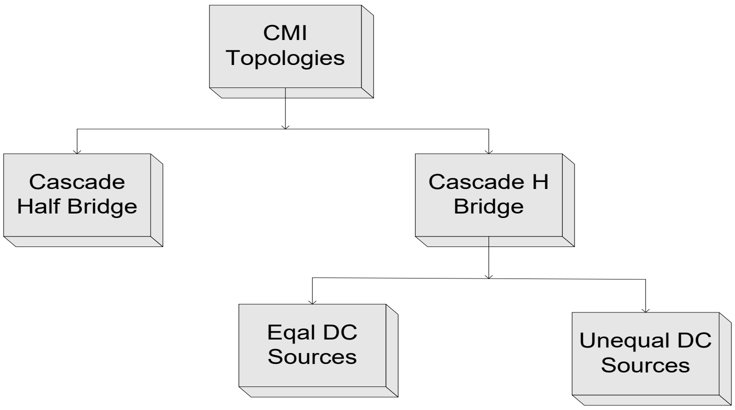


Fig.2 Topologies (CMI)

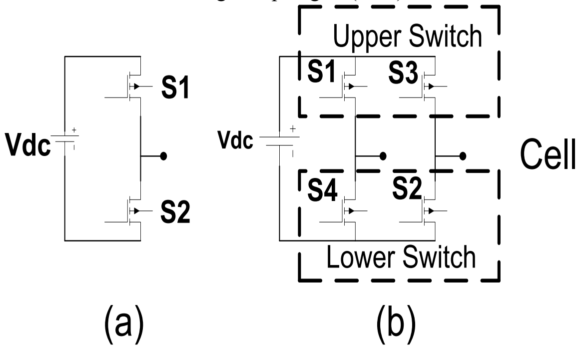


Fig.3 Single-phase cascade half-bridge inverter (a) and full-bridge (H) inverter (b)

This occurs as a result of the higher degree of complexity introduced by the modulation technique. A common characteristic of multilevel converters is redundancy in the switching state. One of its many benefits is the flexibility it provides when designing switching patterns, especially for space vector modulation schemes.

Phase Shifted MCPWM

Phase-shifted MCPWM is utilised in the multilayer inverter to attain a higher ripple frequency compared to the switching frequency [7]. In phase-shifted MCPWM, every triangular carrier oscillates at the same frequency and has the same peak-to-peak amplitude [8]. The phase shift between any two adjacent carriers is given by,where m is the number of output voltage levels, and,Φ-cr =,360-m−1. Figure 1 illustrates how this work uses phase-shifted MCPWM to build a nine-level CMI employing eight carrier waves with a 450 phase shift. In the left leg of phase A of fig.1, the four carrier waves cr1, cr2, cr3, and cr4 trigger the upper switches S1, S5, S9, and S13. In the right leg of phase A, the four carrier waves cr5, cr6, cr7, and cr8 trigger the switches S3, S7, S11, and S15, with a phase shift of 1800 with respect to cr1, cr2, cr3, and cr4. Phase A's lower switches operate against the phase's higher switches when they are engaged. The phase shift modulation pattern for a nine-level CMI is shown in Figure 5.

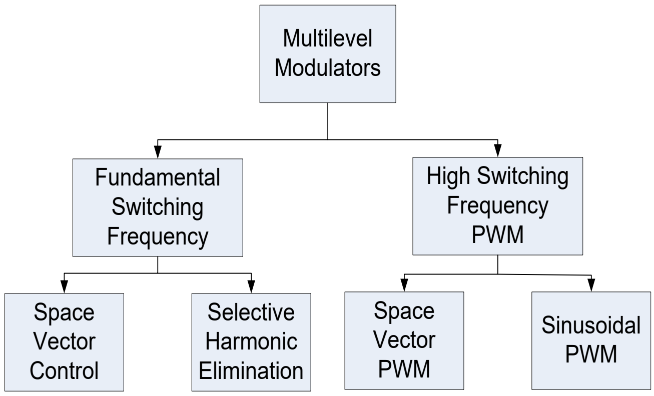


Fig.4 Modulation techniques for multilevel inverters and their classification

Level Shifted MCPWM

In level-shifted MCPWM, every k-1 carrier for a k-level CMI has the same frequency (750 Hz) and amplitude [9]. By comparing the modulating wave to the level-shifted carrier wave, one can ascertain the necessary voltage level. In phase disposition (IPD) is when all carriers are in phase; phase opposite disposition (POD) is when all carriers above the zero reference are in phase but opposing those below the zero reference; and alternative phase opposite disposition (APOD) is when all carriers alternately are in opposite disposition. As shown in fig. 1, we employ level-shifted MCPWM for a nine-level CMI in this study. When the modulating signal in IPD is greater than the corresponding carriers, switches S1, S5, S9, and S13 in the left leg of phase A are triggered by the carrier waves above the zero reference (cr1, cr2, cr3, and cr4), and switches S3, S7, S11, and S15 are triggered by the carrier waves below the zero reference (cr5, cr6, cr7, and cr8). Phase A involves the complimentary actuation of the lower switches in relation to the higher switches. The level shifting (IPD) modulation pattern for the nine-level CMI is shown in fig. 6. The scheme's intrinsically inefficient power distribution requires those pulses to be rotated throughout the cells since the devices in each cell have distinct switching requirements.

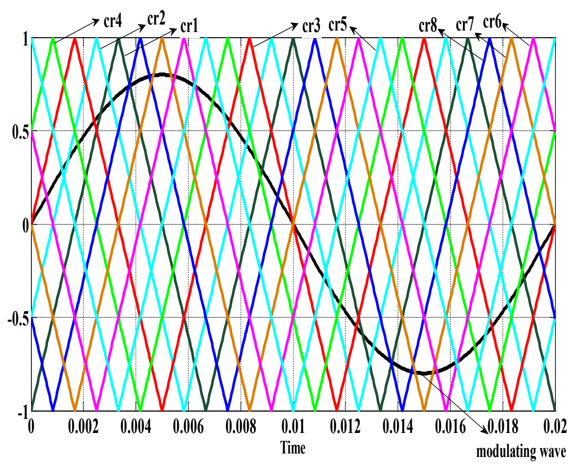


Fig.5 Nine-level CMI phase-shifted modulation pattern

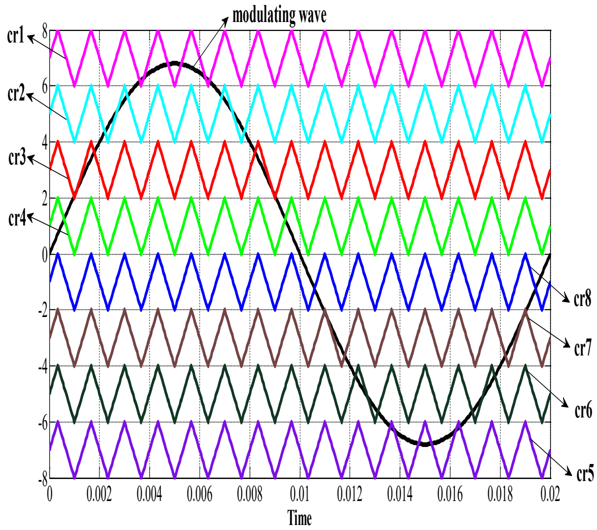


Fig.6 Level-shifted (IPD) modulation scheme for nine-level CMI

A comparison of the different modulation schemes is given in Table I. The parameters for this comparison are the switching frequencies, conduction times, switching pattern rotations, and overall harmonic distortion of the voltage of the devices.

Table I: Differences between phase-shifted modulation and level-shifted modulation are compared in

Comparison	Phase shifted modulation	Level shifted modulation
Device switching frequency	Same for all device	Different
Device conduction period	Same for all device	Different
Rotating of switching patterns	Not required	Required
Line to Line Voltage THD	good	Very good

CMI LOSS ESTIMATION

Power dissipation and switch losses are examples of switch device losses, which are crucial in determining the CMI's efficiency in any power converter. Turn-off losses are ignored by standard procedure because the current drawn in the off state is so small. Conduction losses are obtained by multiplying the steady state voltage by the steady state current. The average and peak conduction losses can be obtained using equations (1) and (2), respectively.

$$p_{on}(t) = |i_c(t)|(V_0 + R_{on}|i_c(t)|) \quad (1)$$

$$p_{avg} = \frac{1}{2\pi}\int_0^T p_{on}(t)dt \quad (2)$$

The threshold voltage V0 and the equivalent resistance R on of the semiconductor device are connected to the on-state current ic (t). Losses happen during the transition of a switching device from the off to the on state, or vice versa. By simply not employing the diodes, switching losses—which include on/off switch losses, diode off/on losses, and diode on/off losses—can be completely eliminated. The switching power dissipation of an IGBT is divided into its on, off, and diode off losses, respectively, by equations (3), (4), and (5):

$$E_{on}=\int_{t1}^{t2} v(t)*i(t)dt \quad (3)$$

$$E_{off}=\int_{t3}^{t4} v(t)*i(t)dt \quad (4)$$

$$E_{rr}=\int_{t5}^{t6} v_{rr(t)*i_{rr}}(t)dt \quad (5)$$

A power converter's switching losses depend on the temperature, dc-bus inductance, gate circuit inductance, and load conditions.

CMI APPLICATIONS

For usage in high-power applications including power factor correction (STATCOM) systems, traction systems, and renewable energy systems, CMI is well-suited due to its superior harmonics performance, high power capabilities, and reduced voltage stress on switching devices, to name just a few benefits.For usage in high-power applications including power factor correction (STATCOM) systems, traction systems, and renewable energy systems, CMI is well-suited due to its superior harmonics performance, high power capabilities, and reduced voltage stress on switching devices, to name just a few benefits.

RES

A fully renewable energy system (RES), which is often made up of fuel cells or photovoltaic (PV) panels, can power CMI. In this implementation, RES can be connected to the grid without the need for a dc-dc converter or other interface [10]. A maximum power point tracking technique is used to measure the dc link voltage of each H bridge in the CMI in order to calculate the maximum power that can be obtained from the sun's irradiation. This method can also be used to establish a maximum power output for the converter step. The modular architecture of CMI may help to reduce energy swings in PV systems. Raising the CMI voltage also lowers harmonics, thus there's no need for a boosting transformer. Grid-connected PV systems may perform noticeably better than their unconnected equivalents when using CMI. A solar system concept using a charge-coupled device is shown in Figure 7. (a).

STATCOM

CMI can be used to adjust for reactive power, just like STATCOM. Although it is not required, the voltage of the DC capacitor needs to be balanced against a reference. CMI as STATCOM performs better than other multilevel converter topologies [11] in terms of switching losses, output harmonics, and circuit component count. The compensation value for reactive power is determined using the grid voltage as a point of reference. On the other hand, the dc-link voltages are subtracted from the reference voltage to establish the STATCOM's active power demand [12]. Fig. 7 shows a direct link between CMI as STATCOM and medium-voltage networks to increase the network's capacity for power transfer and controllability (b)

Traction System

Railway traction systems exploit the benefits of CMI, such as its low total harmonic distortion (THD) and high-frequency switching output waveform. Traction systems can be powered directly from the mains without the requirement for a transformer by using a CMI as an interface between the mains and low voltage motor drives [13]. This intermediate conversion process increases productivity and can be customised to save weight and cost. In traction applications, CMI can be utilised to reduce harmonics, reactive power, and load voltage while also providing power quality adjustment.

Other Application

Recently, CMI has shown great interest in high-power medium-voltage motor drives, hydro pumped energy storage, and other applications. By increasing the number of voltage levels, CMI achieves good harmonic performance without the requirement for grid-side filters and boost transformers.

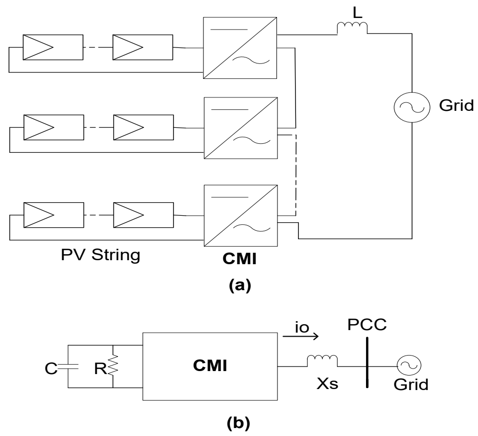
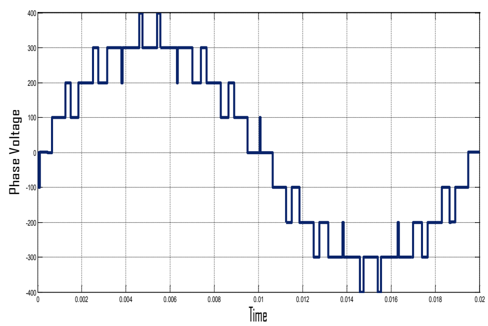


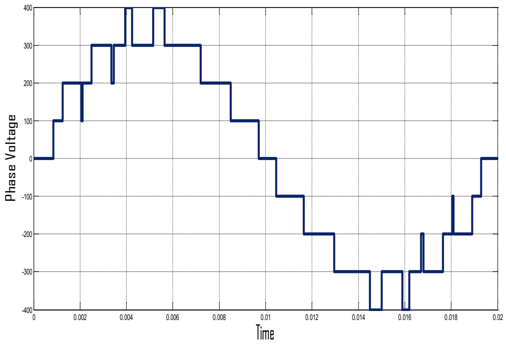
Figure 7: (a) a photovoltaic grid-connected system using CMI; (b) a STATCOM system using CMI (b)

SIMULATION RESULTS

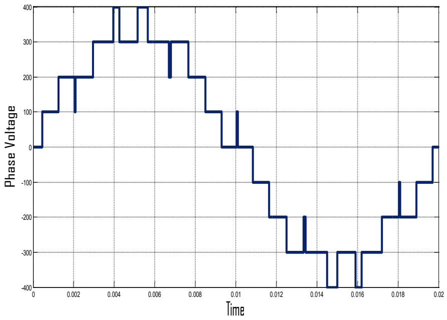
Fig. displays the phase voltage waveform of a multi carrier PWM simulation of a multilayer inverter with a nine-level cascade. 8. The inverter operates at a frequency of 50 Hz. Table 2. summarises the voltage THD and current THD at 0.8 power factor, filter-free, for each type of modulation scheme. For all modulation schemes, the three-phase line-to-line voltage has a lower total harmonic distortion (THD) than the single-phase voltage. In-phase deposition level shifted modulation produces the best line-to-line voltage total harmonic distortion (THD) profile when comparing level shifted and phase shifted modulation approaches.



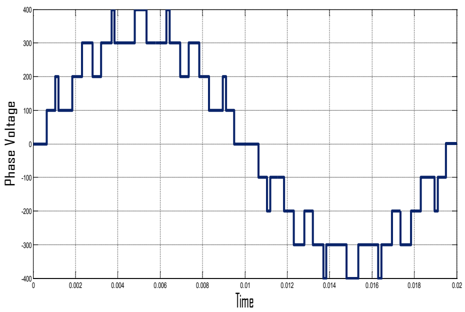
(a) Phase-shifted modulated voltage waveform with a single phase.



(b) Level-shifted (POD) modulated voltage waveform with single phase



(c) Level shifted (APOD) modulated voltage waveform with single phase



(d) Llevel shifted (IPD) modulated voltage waveform with single phase

CONCLUSION

In conclusion, the Cascaded Multilevel Inverter (CMI) is a very appropriate choice for many high-power applications such as power factor correction (STATCOM) systems, traction systems, and renewable energy systems. The excellence of this product is evident in multiple crucial aspects, including exceptional harmonics performance, strong high-power capability, and minimised voltage stress on switching devices, among other advantages. Within the realm of renewable energy systems (RES), namely those utilising sources such as fuel cells or photovoltaic (PV) panels, the integration of CMI emerges as a highly effective choice. RES can effortlessly integrate with the grid without requiring any extra dc-dc converters or interfaces, thanks to its creative implementations. By utilising advanced maximum power point tracking techniques, CMI enhances the efficiency of power extraction from solar irradiation while ensuring compatibility with the electrical grid. Furthermore, the modular structure of the system helps to stabilise energy fluctuations in photovoltaic (PV) systems, hence eliminating the requirement for boosting transformers and enhancing the overall performance of the system. In addition, CMI's adaptability also includes the ability to compensate for reactive power, similar to STATCOM systems, but with simplified control needs. The effectiveness of this technology in controlling reactive power, combined with its excellent performance in terms of minimising energy losses during switching, reducing harmonics, and requiring fewer components, highlights its appropriateness for various applications, including railway traction systems. CMI functions as a very effective intermediary between high-voltage power sources and low-voltage motor drives, providing superior power efficiency, minimised harmonic distortion, and increased operational efficiency. CMI's increasing importance in high-power medium-voltage motor drives, hydro pumped energy storage, and other fields is underscored by recent advancements. CMI provides remarkable harmonic performance by expanding the number of voltage levels, eliminating the need for additional grid-side filters or boost transformers. Simulations and analysis have shown that different modulation techniques are effective, with in-phase deposition level shifted modulation being particularly promising for reducing total harmonic distortion (THD) profiles.

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