

Multi Carrier Pulse Width Modulation-Based Cascade Multilevel Inverter

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ABSTRACT

Cascade multilevel inverter (CMI) is the most efficient option for medium-voltage, high-power applications. Higher than usual interest is being paid to CMI in comparison to the more commonplace two-level inverter because of its reduced voltage pressure on the switching electronics, higher harmonic performance, and better voltage quality. The technique of pwm technique, commonly known as PWM, has been the focus of extensive research for quite some time. Multi carrier pulse width modulation (MCPWM) technology is used to improve the harmonics performance of a cascade multilayer inverter. In this paper, we examine the theoretical foundations of spread spectrum PWM strategies and use a computational simulation to contrast the various implementations. CMI's unique features allow it to be used in many situations. In this research, we focus on the most significant uses of CMI.

Keywords: MCPWM; CMI; PWM; APOD; POD; IPD.

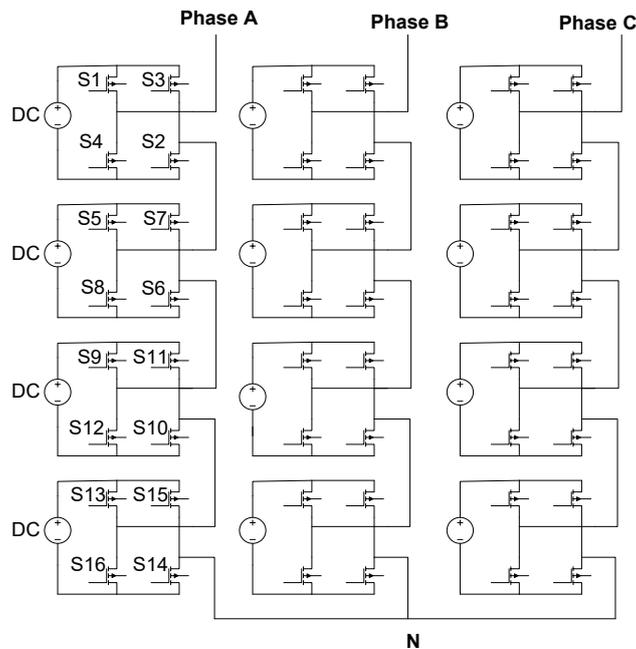
1.0 Introduction

The core notion that supports the multilevel inverter is to connect the power semiconductors switching devices in a series configuration. The several dc voltage levels are what enable the multilevel inverter to produce an output voltage waveform that is roughly sinusoidal. The switching electronics are less stressed by the multilayer inverter, and the inverter's output waveform and harmonic performance are also improved. Filter size, losses, and total harmonic distortion (THD) prevent the two-level voltage source converter from achieving peak system performance and efficiency. In order to improve the effectiveness and effectiveness of a high-voltage system, it is necessary to use a multilayer inverter [1]. The cost of the cooling system for the power converter relies in part on an estimate of the converter loss. The three most common multilevel inverter topologies are the cascade multilevel inverter (CMI), the flying capacitor multilevel inverter, and the neutral point clamped multilevel inverter. The most popular kind of multilevel inverter is called a neutral point clamped multilevel inverter, followed by a cascade multilevel inverter (CMI) and a flying capacitor multilevel inverter. The most common form of multilevel inverter is called a cascade multilevel inverter (CMI). The CMI topology has the best desirable properties. CMI may reduce the size and expense of the converter, which helps to increase the system's reliability. The number of semiconductor devices and capacitors used in CMI is much lower than that used in other topologies. $m = 2s + 1$ determines the output levels in CMI, where m is the voltage of the output phase and s is the number of dc sources used in that phase. The modulation technique plays a critical role in expanding the use of the CMI. This research expands on previous

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work by comparing the MCPWM method to others and discussing the most important uses of CMI. Four cells are linked in series to provide nine levels of voltage output for each phase of the CMI, as shown in Figure 1.

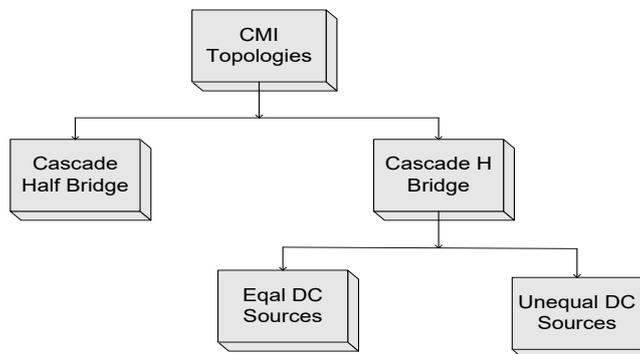
Figure 1: Three-Phase, Nine-Level CMI



2.0 Topology of CMI

Several CMI topologies, including the single-phase cascade half-bridge inverter and the cascade H-bridge inverter, are shown in fig.2. In contrast to the cascade H bridge inverter, which employs a continuous string of single phase full bridge inverters to generate multiple phase legs [3], the cascade half bridge has just one switching element to give two levels of output voltage.

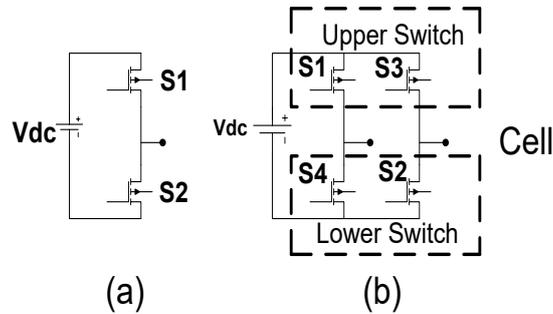
Figure 2: Topologies (CMI)



The semiconductor components used in the cascade H bridge architecture have a low voltage rating, which is an advantage. This line-to-line voltage of around 3300 volts may be achieved using a nine-level inverter. The manufacturing cost and operating voltage of a cascade inverters are both determined by the number of power cells used by the device. The DC sources for each phase leg of a

cascade multilevel inverter must be distinct. For a cascade H bridge inverter to work, the output voltage from these sources must to scale linearly with the number of cells used. A cascade H bridge inverter uses unequal DC sources to reach more levels without increasing the number of cells [4].

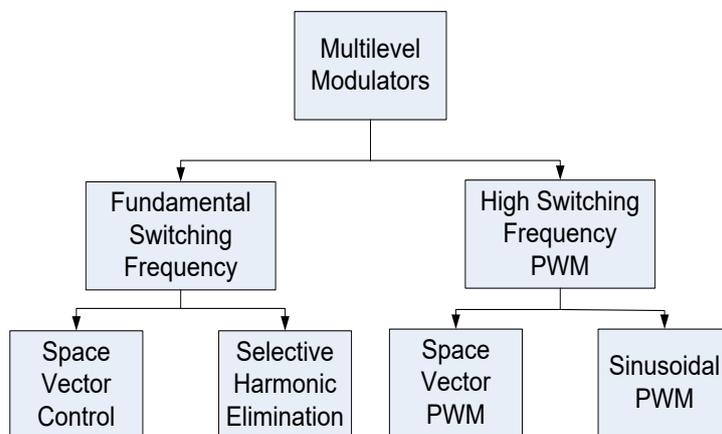
Figure 3: Single-Phase Cascade Half-Bridge Inverter (a) and Full-Bridge (H) Inverter (b)



3.0 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]. 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.

Figure 4: Modulation Techniques for Multilevel Inverters and their Classification



3.1 Phase shifted MCPWM

For the multilayer inverter, phase-shifted MCPWM is employed to achieve a greater ripple frequency than the switching frequency [7]. Each triangle carrier in phase-shifted MCPWM oscillates at the same frequency and has the same peak-to-peak amplitude [8], with the phase shift between any two adjacent carriers being provided by $\Phi_{cr} = \frac{360}{m-1}$ where m is the number of levels of output voltage.

As can be seen in Figure1, eight carriers waves with a phase shift of 450 are utilised in this study to implement nine-level CMI using phase shifted MCPWM. Upper switches S1, S5, S9, and S13 in fig.1's left leg of phase A are triggered by the four carrier waves cr1, cr2, cr3, and cr4, while switches S3, S7, S11, and S15 are triggered by the four carrier waves cr5, cr6, cr7, and cr8 in the right leg of phase A, with a phase shift of 1800 with respect to cr1, cr2, cr3, and cr4. When phase A's lower switches are activated, they act in opposition to the phase's higher switches. Figure 5 depicts the phase shift modulation pattern for a nine-level CMI.

3.2 Level shifted MCPWM

All k-1 carriers for a k-level CMI have the identical amplitude and frequency (750 Hz) in level-shifted MCPWM [9].

A desired voltage level is determined by comparing the modulating wave to the level-shifted carrier wave. Phase opposite disposition (POD) occurs when all carriers above the zero reference are in phase but in opposition with those below the zero reference, alternative phase opposite disposition (APOD) occurs when all carriers alternately are in opposite disposition, and in phase disposition (IPD) occurs when all carriers are in phase. In this research, we use level-shifted MCPWM for a nine-level CMI, as seen in fig. 1. In IPD, the carrier waves above the zero reference (cr1, cr2, cr3, and cr4) are used to trigger switches S1, S5, S9, and S13 in the left leg of phase A when the modulating signal is greater than the corresponding carriers, and the carrier waves below the zero reference (cr5, cr6, cr7, and cr8) are used to trigger switches S3, S7, S11, and S15 when the modulating signal is less than the corresponding carriers. During phase A, the lower switches are actuated in a complementary fashion with regard to the higher switches. In fig.6, we see the level shifted (IPD) modulation pattern for nine-level CMI.

Since each cell's devices have different switching requirements, the scheme's inherently inefficient power distribution necessitates those pulses be rotated among the cells.

Figure 5: Nine-level CMI Phase-Shifted Modulation Pattern

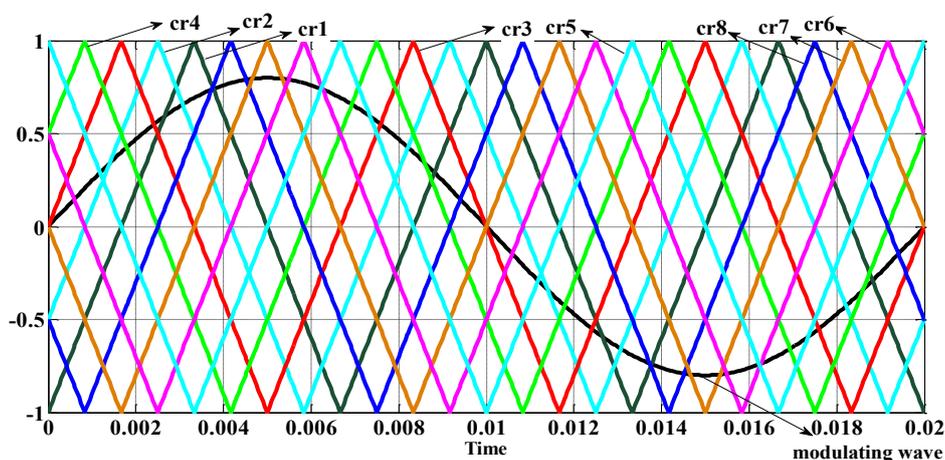


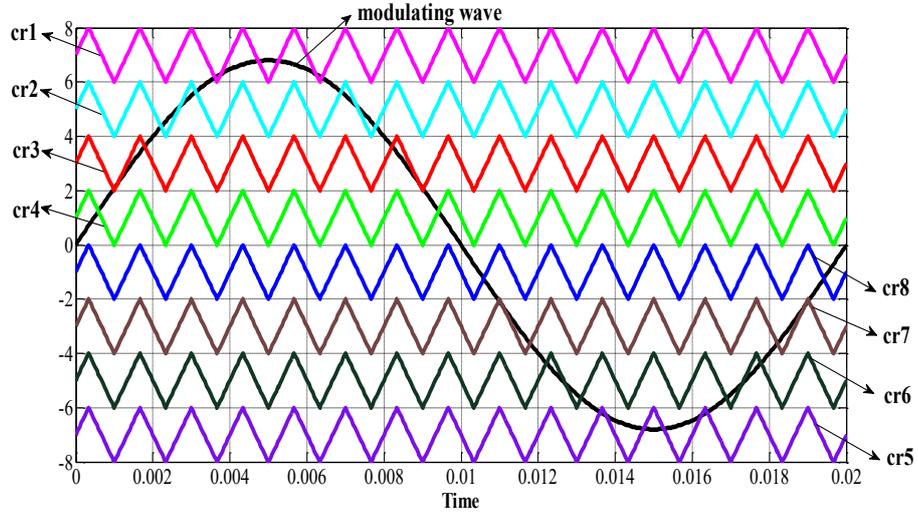
Figure 6: Level-shifted (IPD) Modulation Scheme For Nine-Level CMI

Table 1 provides a comparison of the various modulation strategies. The devices' switching frequencies, conduction times, rotations of the switching patterns, and total harmonic distortion of the voltage are the criteria for this comparison.

Table 1: 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

4.0 CMI Loss Estimation

Switch device losses, which include power dissipation and switch losses, are an essential part of any power converter's evaluation of the CMI's efficiency. Standard procedure disregards turn-off losses since the current drawn in the off state is so minimal. Multiplying the steady state voltage by the steady state current yields the conduction losses. Equations (1) and (2) may be used to get the peak and average conduction losses, respectively.

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

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

The on-state current i_c is related to the threshold voltage V_0 and the equivalent resistance R on of the semiconductor device (t).

When a switching device is switched from its off to its on state, or vice versa, losses occur during the transition. Switching losses, which consist of on/off switch losses, diode off/on losses, and diode on/off losses, may be eliminated by simply not using the diodes. The equations (3), (4), and (5) break down the switching power dissipation of an IGBT into its on, off, and diode off losses, respectively:

$$E_{on} = \int_{t_1}^{t_2} v(t) * i(t) dt \quad \dots(3)$$

$$E_{off} = \int_{t_3}^{t_4} v(t) * i(t) dt \quad \dots(4)$$

$$E_{rr} = \int_{t_5}^{t_6} v_{rr}(t) * i_{rr}(t) dt \quad \dots(5)$$

The switching losses of a power converter are sensitive to the load situation, dc - bus inductance, gate circuits inductance, and temperature.

5.0 CMI Applications

Superior harmonics performance, high power capability, and low voltage stress on switching devices are only some of the reasons why CMI is well-suited for use in high-power applications such renewable energy systems, power factor correction (STATCOM) systems, and traction systems.

5.1 RES

CMI may be powered by a completely renewable energy system (RES), often comprised of photovoltaic (PV) panels or a fuel cell. In this implementation, a dc-dc converter or other interface is not necessary for connecting RES to the grid [10]. To determine the highest power possible from the sun's irradiance, the dc link voltage of each H bridge in the CMI is measured using a maximum power point tracking technique. It is also possible to use this approach to set a maximum power output for the converter step. Energy fluctuations in PV facilities may be mitigated with the help of CMI's modular design. There is no need for a boosting transformer if the voltage in CMI is raised, which also reduces harmonics. Using CMI, grid-connected PV systems may significantly outperform their unconnected counterparts. Figure 7 shows a schematic of a solar system using a charge-coupled device (a).

5.2 STATCOM

As with STATCOM, CMI may be used to compensate for reactive power. While active power injection is not necessary, dc capacitor voltage must be balanced against a standard. When compared to alternative multilevel converter topologies [11], CMI as STATCOM excels in areas such as switching losses, output harmonics, and circuit component count. The reactive power's compensation value is established relative to the grid voltage as a reference. The STATCOM's active power requirement, on the other hand, is determined by subtracting the dc-link voltages from the reference voltage [12]. A direct connection between CMI as STATCOM and medium-voltage networks is presented in Fig. 7 to improve the network's power-transfer capacity and its ability to be controlled (b)

5.3 Traction system

The advantages of CMI, including as its high-frequency switching output waveform and low total harmonic distortion (THD), are used in railway traction systems. By employing a CMI as an interface between the mains and low voltage motor drives, a traction system may be powered directly from the mains without the need for a transformer [13]. This intermediary conversion step improves performance efficiency, and it may be tailored to save on weight and money.

CMI may be used as a power quality compensation in a traction application, decreasing harmonics, reactive power, and load voltage.

5.4 Other application

Hydro pumped energy storage, high-power medium-voltage motor drives, and other applications have recently found CMI to be quite interesting. Good harmonic performance is achieved by CMI without the need for grid-side filters and boost transformers by increasing the number of voltage levels.

Figure 7: (a) A Photovoltaic Grid-Connected System Using CMI; (b) STATCOM System Using CMI (b)

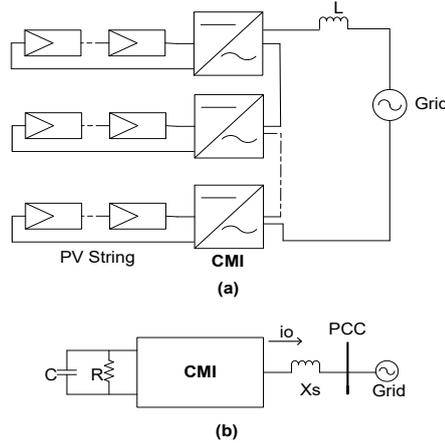
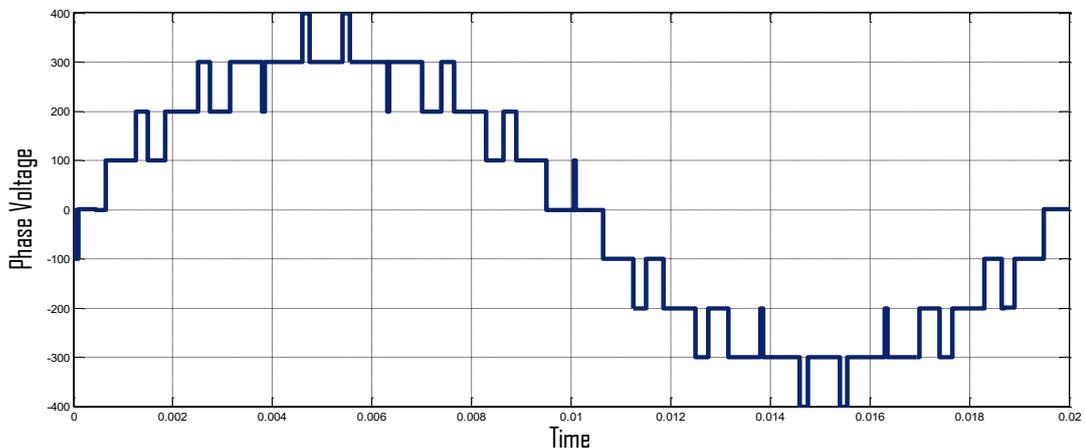


Table 2: Harmonic Distortion Voltage/Current for Various Modulation Techniques

Modulation Techniques	Voltage THD		Current THD (0.8 P.f.)	
	1- Φ	3- Φ	1- Φ	3- Φ
Phase shifted modulation	17.68%	14.03%	5.13%	5.11%
LS (POD) modulation	16.40%	14.66%	5.81%	5.80%
LS (APOD) modulation	16.41%	14.47%	5.91%	5.11%
LS (IPD) modulation	19.77%	10.62%	5.33%	5.12%

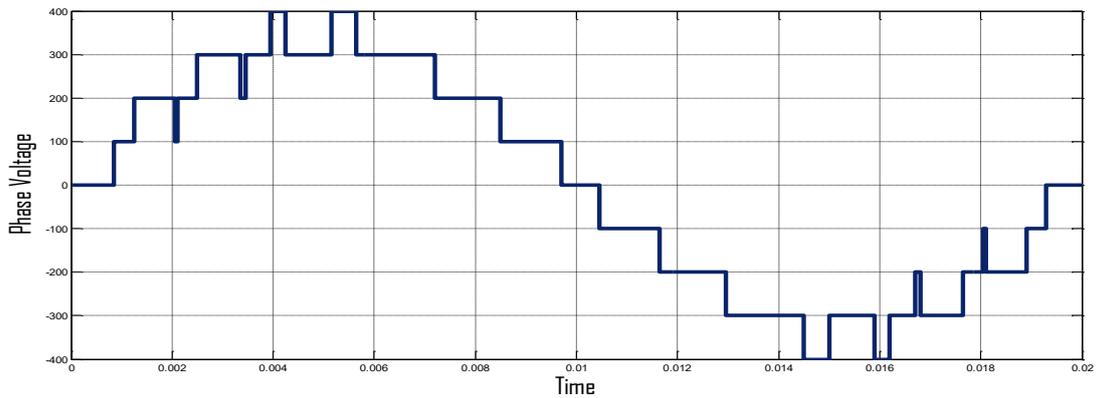
6.0 Simulation Results

(a) Phase-Shifted Modulated Voltage Waveform With A Single Phase

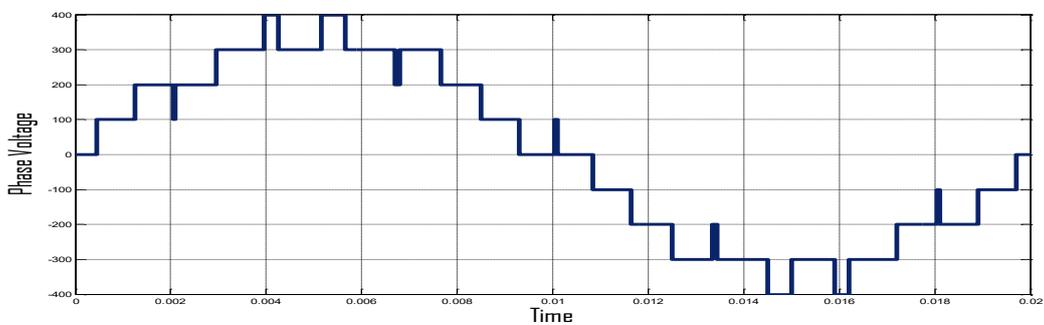


The phase voltage waveform of a multi carrier PWM simulation of a nine-level cascade multilevel inverter is shown in Fig. 8. 50 Hz is the frequency at which the inverter works. Table.2 summarises, for each kind of modulation technique, the voltage THD and current THD at 0.8 power factor, filter-free. The total harmonic distortion (THD) of three-phase line-to-line voltage is reduced compared to that of single-phase voltage for all modulation schemes. When comparing level shifted and phase shifted modulation techniques, in-phase deposition level shifted modulation yields the most desirable line-to-line voltage total harmonic distortion (THD) profile.

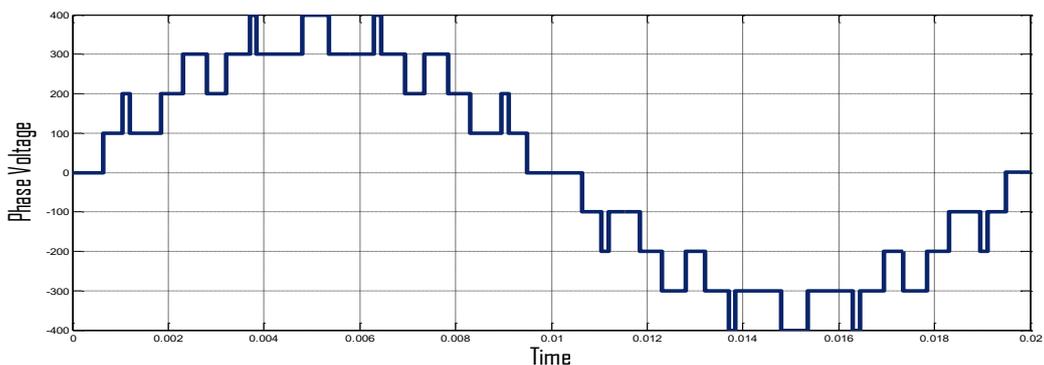
(b) Level-Shifted (POD) Modulated Voltage Waveform With Single Phase



(c) Level shifted (APOD) Modulated Voltage Waveform With Single Phase



(d) Level Shifted (IPD) Modulated Voltage Waveform With Single Phase



7.0 Conclusion

The simulation results validate the basic working concept of the given nine-level cascade multilevel inverter. In order to achieve nine levels of CMI, multicarrier PWM is used. Comparisons have been made between the different modulation techniques to examine the THD performance of phase voltage and line voltage. Throughout this article, we have covered the major uses of CMI.

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