

Multi Carrier PWM and Selective Harmonic Elimination Technique for Cascade Multilevel Inverter

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ABSTRACT

This paper presented the multi carrier pulse width modulation (MCPWM) and selective harmonic elimination (SHE) method for lowering the overall harmonic distortion in the output voltage of a cascade multilevel inverter (CMI). It was discovered that multi carrier pulse width modulation is a more effective technique for removing harmonics than the more common selective harmonic removal approach. The MCPWM and SHE approaches, as well as an FFT-based result derived from simulations of nine-level cascade multilevel inverters, are compared with one another in terms of Total Harmonic Distortion in order to validate the validity of the former. A result that was derived from simulations of a nine-level cascade multilevel inverter.

Keywords: *Cascade multilevel inverter (CMI); Multi Carrier Pulse Width Modulation (MCPWM); Selective Harmonic Elimination (SHE) Technique; Total Harmonic Distortion (THD).*

1.0 Introduction

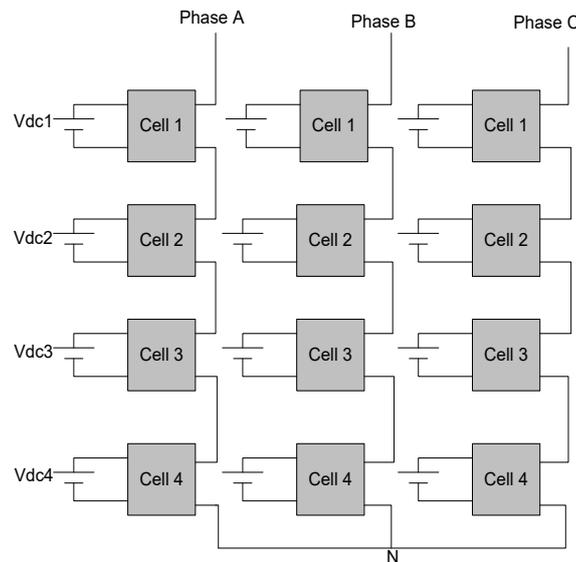
There has been a lot of study done on multilevel inverters, which are a kind of power converter. Multilevel inverters have a modular design and are often used to generate sinusoidal voltage from many DC sources. However, the filter size, losses, and total harmonic distortion (THD) of a two-level voltage source converter fall short of ideal, and a multilayer inverter is necessary for a high-voltage system to attain optimal performance and efficiency [1, 2]. The output voltage quality, measured in terms of Total Harmonic Distortion, improves as the number of levels in a multilayer inverter rises. But as the tiers expand, so do the difficulty of the control methods and the likelihood of voltage imbalance. When compared to the neutral point clamped, cascade multilevel inverter, and flying capacitor commercial topologies of multilevel voltage source inverters [2, 3], CMI's modular architecture achieves the highest output voltage and power levels (13.8KV, 30MVA) and the highest dependability. CMI levels are defined as $m = 2s + 1$, where m is the output phase voltage and s is the number of dc sources in a single phase. Reduced voltage stress on switching devices [3], lower harmonic distortion, smaller common mode voltage generation, fewer electromagnetic compatibility issues, and higher voltage attainment with a given maximum device rating are the primary drivers behind the widespread adoption of multilevel inverters.

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Due to its modular design and user-friendly interface, the CMI is an excellent option for managing complex environments. Figure 1 depicts the fundamental architecture of a CMI, which consists of four cells coupled in series to provide nine levels of output voltage per phase.

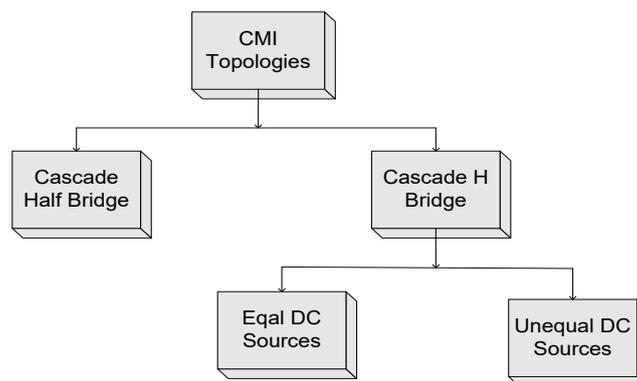
Figure 1: Three-Phase Nine-Level CMI



2.0 Cascade Multilevel Inverter Topologies

As can be seen in Figure 2, numerous CMI configurations are available for both single- and three-phase applications. The single-phase cascade half-bridge is a one-leg converter made up of two switching elements that generates a two-level voltage-source converter output.

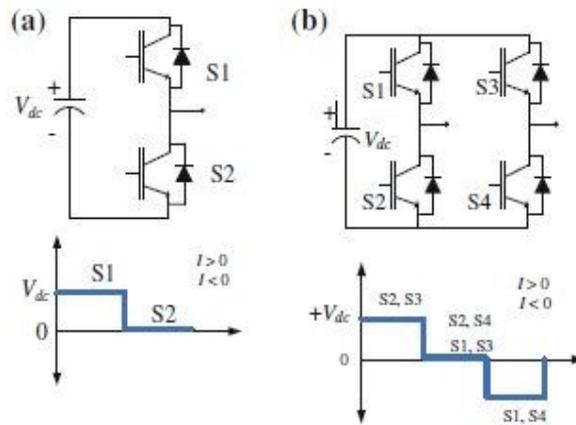
Figure 2: CMI Topologies



A cascading H bridge inverter builds a multiple phase leg out of single phase full bridge inverters connected in series [4]. Because of the nature of the cascade H bridge architecture, semiconductors may operate at lower voltages. The operating voltage and production cost of a cascade H bridge inverter are the primary factors in determining the inverter's number of power cells. For medium-voltage (MV) drives with a line-to-line voltage rating of 3,300 volts, for instance, a nine-

level inverter may be utilised. Cascade H bridge inverters need a DC source for each phase leg, with each source being able to provide an output voltage that is directly proportionate to the number of cells in the inverter. Cascade H-bridge inverters employ uneven DC sources to achieve a greater number of levels with the same number of cells.

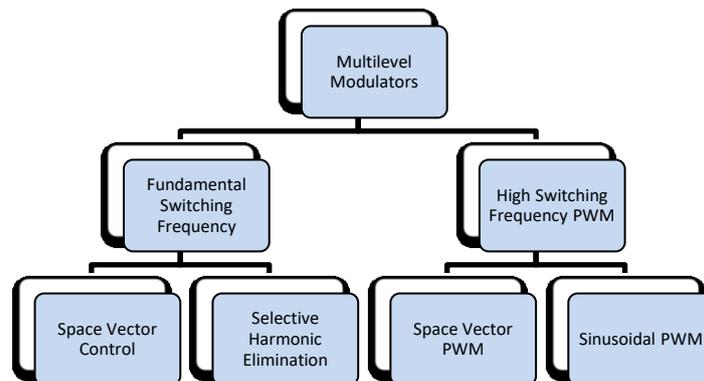
Figure 3: Single-phase Cascade Half Bridge Inverter (a), Single-phase cascade H Bridge (Full Bridge) Inverter (b)



3.0 Modulation Techniques

Figure 4 illustrates how the modulation approach used by's multilevel inverters may be categorised in terms of their switching frequency [5]. The switching losses are less and the output voltage harmonic content is lower with the fundamental switching frequency approach than it is with the PWM technique, which uses a higher switching frequency [6]. As opposed to space vector and phase shifted carrier PWM, SHE-PWM offers better harmonic performance for low level numbers. Nonetheless, phase-shift carrier base modulation's performance scales more quickly with an increasing number of levels compared to the SHE method [7]. Because of the prevalence of redundant switching states in multilevel converters, designers have a lot of leeway when creating switching patterns, which is particularly useful for space vector modulation techniques.

Figure 4: Classification of Modulation Techniques for Multilevel Inverter



3.1 Multi carrier PWM

PWM technology based on multiple carriers is used to adjust output voltage and eliminate harmonics. The switching output voltage for the converters is derived by comparing a single sinusoidal with each carrier in the multi carrier PWM approach [8].

For multilevel inverters, two common modulation techniques are phase shifted modulation and level shifted modulation [9].

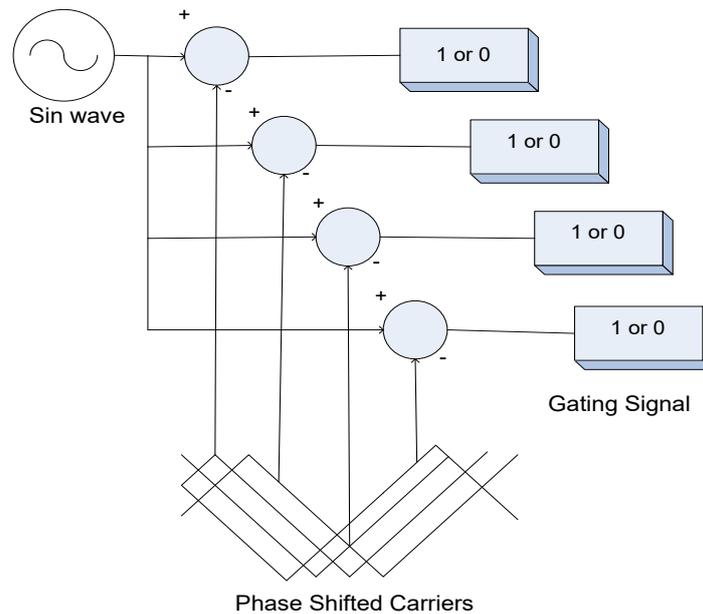
3.1.1 Phase shifted modulation

The most typical technique for the cascade multilevel inverter is phase-shift modulation, with higher harmonic performance attained when each single-phase inverter is controlled by three-level modulation [9]. The phase-shifted PWM may be used for the multilayer inverter to obtain a larger ripple frequency than the switching frequency [10].

All triangular carriers in phase-shifted multi carrier modulation have the same frequency and peak-to-peak amplitude [11], but there is a phase shift between any two adjacent carrier waves, given by $\Phi_{cr} = \frac{360}{m-1}$, where m is the number of output voltage levels. Φ_{cr} will be 45° , for nine-level CMI.

Figure 5 depicts a simple phase shifted modulation scheme.

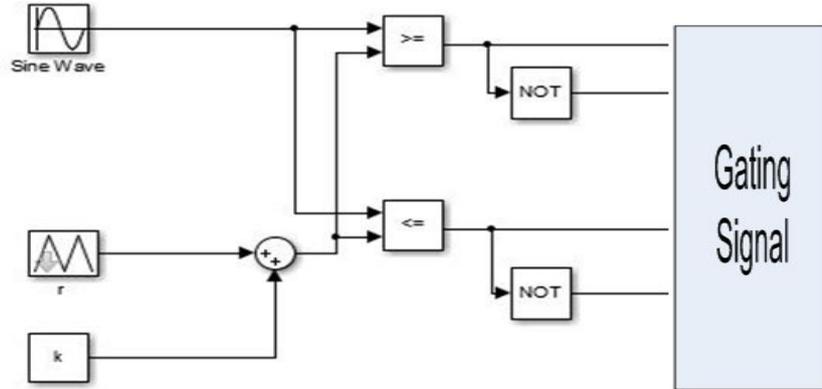
Figure 5: Simplified Phase Shifted Modulation Schematic



3.1.2 Level shifted modulation

For m level CMI, (m-1) triangular carriers with the same frequency and amplitude are needed such that they completely fill contiguous bands spanning the range +V dc to -V dc [8]. There are three approaches for level shifted multi carrier modulation [8]. (a) in phase disposition (IPD), in which all carriers are in phase; (b) alternative phase opposite disposition (APOD), in which all carriers are alternately in opposite disposition; and (c) phase opposite disposition (POD), in which all carriers above the zero reference are in phase but oppose those below the zero reference. Figure 6 depicts a simple level shifted modulation scheme.

Figure 6: Simplified Level Shifted Modulation Schematic



3.2 Selective harmonic elimination technique

Thermal losses restrict the maximum switching frequency in high-power applications [12], [13]. SHE is a more efficient modulation approach for obtaining output signals with lower harmonic content than other modulation techniques. SHE-PWM is a pulse-width modulation technique that is ideal for high-power medium-voltage cascaded multilevel voltage source inverters with both equal and unequal dc sources utilised in constant frequency utility applications. SHE-PWM is based on the Fourier series decomposition of the power electronics converter’s periodic PWM voltage waveform, as shown in equation (1) [14]. Selective harmonic elimination eliminates specified harmonics with the fewest amount of switching operations. The SHE approach is used to optimise the switching angles of a cascaded multilevel inverter in order to provide the desired fundamental voltage as well as an enhanced harmonic staircase waveform. If the number of cells employed in the cascade multilevel inverter is s per phase, the number of non-linear transcendental equations will be s and the number of harmonics to be removed will be $(s-1)$.

$$f_N(t) = \frac{a_0}{2} + \sum_{n=1}^N (a_n \cos\left(\frac{2\pi n t}{T}\right) + b_n \sin\left(\frac{2\pi n t}{T}\right)) \quad \dots (1)$$

Table.1 shows a comparison of several modulation techniques based on device switching frequency, device conduction period, rotation of switching patterns, and voltage THD.

Table 1: Comparison Among Phase Shifted, Level Shifted and SHE Modulation

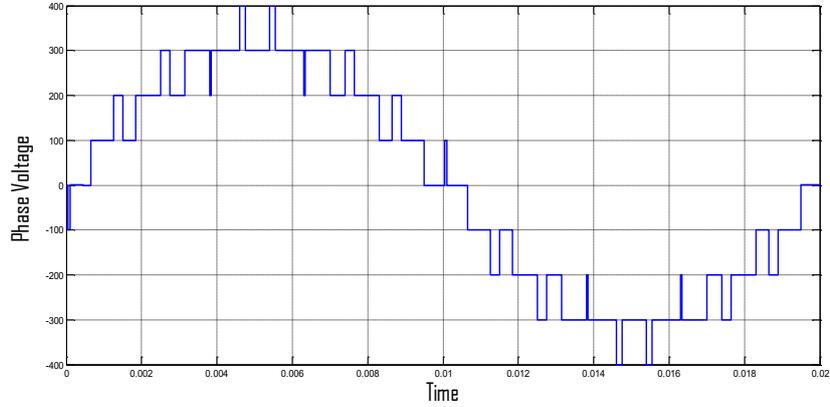
Comparison	Phase shifted modulation	Level shifted modulation	SHE modulation
Device switching frequency	Same for all device	different	Same for all device
Device conduction period	Same for all device	different	Same for all device
Rotating of switching patterns	Not required	required	Not required
Line to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

4.0 Simulation Result

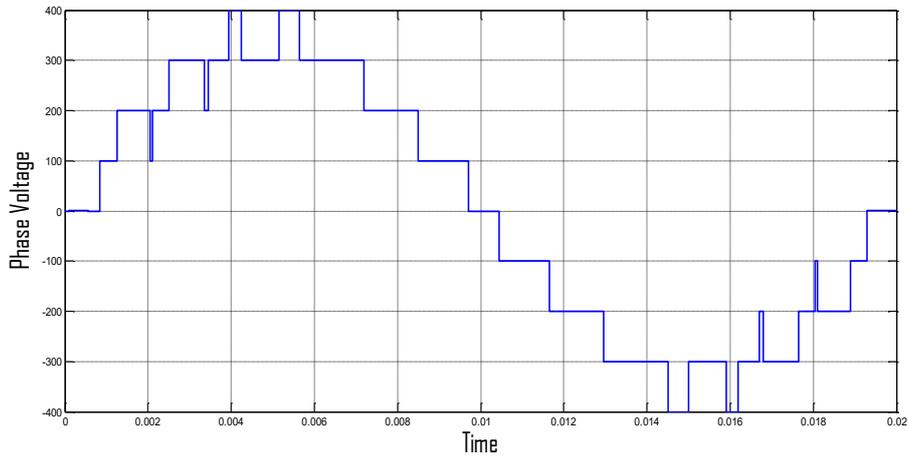
The simulated phase voltage waveform for a nine-level cascade multilevel inverter employing multi carrier PWM and SHE is shown in Figure 7. The inverter runs at a frequency of 50 hertz.

Figure 7: Modulated Voltage Waveform

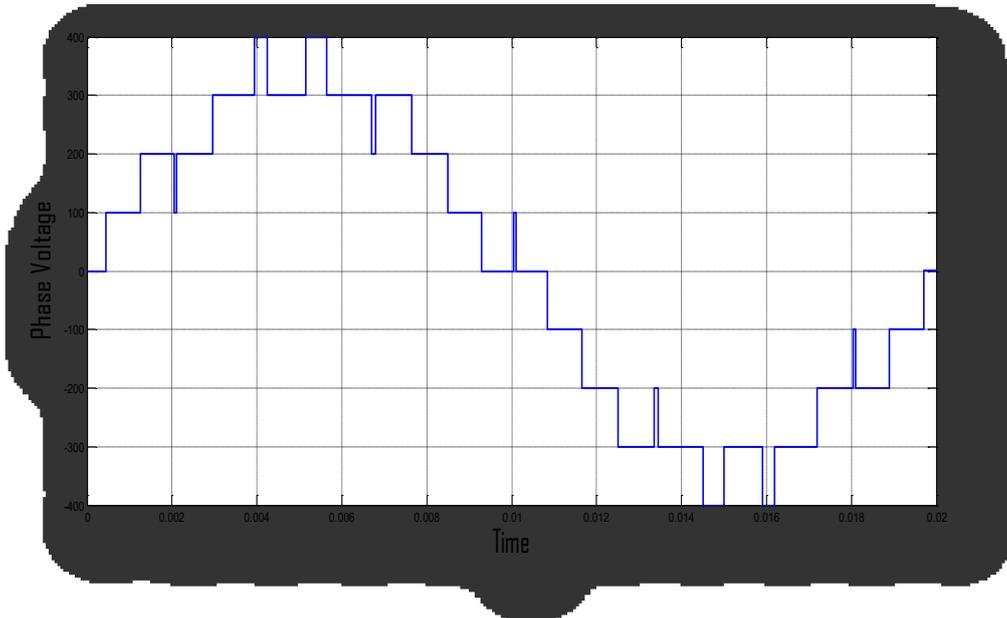
(a) Phase Shited Modulated Single-Phase Voltage Waveform



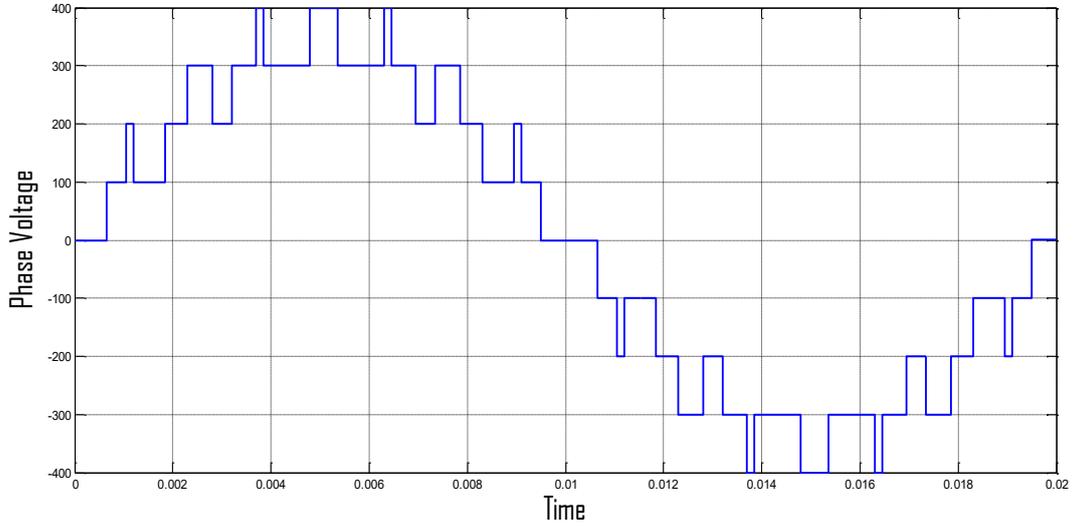
(b) Level Shited (POD) Modulated Single-Phase Voltage Waveform



(c) Level Shited (APOD) Modulated Single-Phase Voltage Waveform



(d) Level Shited (IPD) Modulated Single-Phase Voltage Waveform



(e) SHE Modulated Single-Phase Voltage Waveform

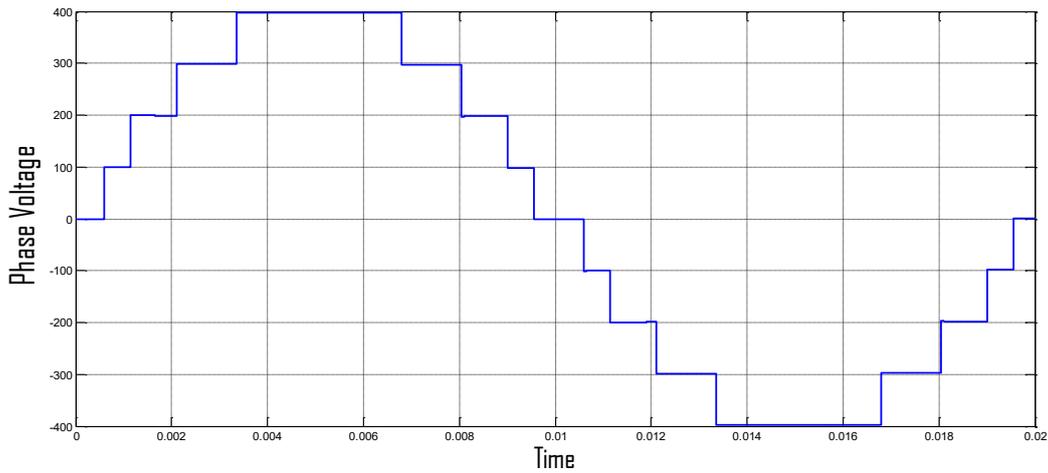


Table 2 displays the voltage THD for various modulation schemes. THD of the SHE approach is substantially lower as compared to phase shifted and level shifted modulation. THD is also reduced when comparing three phase line to line voltage to single-phase for all modulation schemes. Among all level shifted and phase shifted modulation techniques, in-phase deposition level shifted modulation delivers the best line to line voltage THD profile.

Table 2: Voltage THD for Different Modulation Methods

Modulation Techniques	Voltage THD	
	1- Φ	3- Φ
Phase		
Phase shifted modulation	17.62%	14.82%
LS (POD) modulation	16.22%	14.98%
LS (APOD) modulation	16.35%	12.72%
LS (IPD) modulation	19.67%	11.12%
SHE modulation	9.60%	6.89%

5.0 Conclusion

A nine-level cascade multilevel inverter was proposed, and its working principle was proven by simulation results. For nine-level CMI, multicarrier PWM and SHE modulation are used. A comparison of the THD performance of phase voltage and line voltage among the different modulation techniques was performed. The simulation result validates the accuracy of SHE approach above other modulation techniques.

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