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Research Paper

Performance analysis on bipolar PWM strategies for single phase quasi-Z-source fed seven level modified cascaded H-bridge inverter with asymmetric switched-inductor cell

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Abstract

Multilevel inverters are adopted for high power applications due to its lower harmonic distortion and reduced device voltage stress which also permit to use the renewable energy resources effectively. This paper presents performance study of various PWM strategies for single phase Quasi-Z-source fed seven level Modified Cascaded H-Bridge Inverter with asymmetric switched-inductor cell. Simulation using MATLAB-SIMULINK is performed with bipolar multi-carrier PD, APOD, POD PWM techniques with sine wave reference and trapezoidal reference for the chosen Quasi-Z-source modified CHB MLI. This paper suggests notably improved results to yield great boosting in root mean square value of the fundamental component with enriched voltage enhancement techniques along with suitable PWM strategy.

Keywords: *Cascaded H-Bridge(CHB), Quasi Z source(QZ), shoot through duty cycle (Dsh), switched-inductor(SL), PWM, THD.*

1. Introduction

In recent years, the necessity of high power equipment in the range of megawatt level emanate in industries. Connecting single power semiconductor switch directly to medium voltage grids is troublesome. The development of multilevel inverter provided us the solution. Its unique structure permit us to reach higher voltages without the use of transformers [1],[2].Among diverse multilevel converters topologies, cascaded multilevel H-Bridge converter plays an exceptional priority due to its simple and modesty control. From separate DC sources, it utilizes full H-Bridges connected in series to produce inverted AC. when compared to other conventional inverters, diminution in this topology is a greatest advantage due to reduction in number of devices used. The output is fairly sinusoidal in nature without filter. In this structure Soft-switching can be used to avoid lossy and bulky resistor capacitor-diode snubbers. For high power applications, it is a agreeable structure since at higher modulation frequencies it provides higher voltage with a low switching frequency. It means for the same THD, low switching loss. In a traditional voltage source inverter (VSI), short circuit occurs when two switches of same-phase leg is switched ON at the same time. Hence switches might get destroyed. Z-source inverter (ZSI) helps to overcome this limitation [4]. The credibility of inverter is greatly improved because the shoot through due to Electro Magnetic Interference (EMI) noise never destroy the circuit.

ZSI is inexpensive and consists of active state and shoot through state [8]. In Z-source MLI, by adjusting the shoot through time period of pulses, the input voltage can be bucked or boosted. The output voltage THD is limited by appropriate selection of firing pulses in ZSMLI. The passive components of Quasi-Z-source are sketched in a way to yield a maximum boost capability with less number of switches, in turn leads to an efficient system [5],[6]. Its unique features are boost capability and single stage voltage inversion. For the generation of shoot through states many modulation strategies are available. For the proposed Quasi-Z-source multilevel inverter (QZMLI), simple boost control technique is used. The shoot through is added to the pulse width modulation so as to achieve voltage boost [7],[9]-[13].

2. Quasi-Z-Source Fed Seven Level Modified Cascaded H-Bridge Inverter Topology

The layout of the Single phase Quasi-Z-Source fed seven level Modified Cascaded H-Bridge Inverter with asymmetric switched-inductor cell is shown in Fig. 2.1. The topology consists of three voltage sources, twelve diodes, nine equal valued inductors, six equal valued capacitors to function as Quasi-Z-source fed seven level Modified Cascaded H-Bridge Inverter with asymmetric switched-inductor cell as in Fig. 2.1. The number of output voltage levels is determined by the number of H-bridge inverter modules and DC sources used. The role of switched-inductor cell during switching action of main circuit is storing of energy and transfer of energy from the capacitor to the DC bus. The principle of operation of Quasi-Z-source fed seven level Modified Cascaded H-Bridge Inverter with asymmetric switched- inductor cell with shoot-through and non -shoot-through states is as explained below. as shown in Fig. 2.2 and Fig. 2.3.

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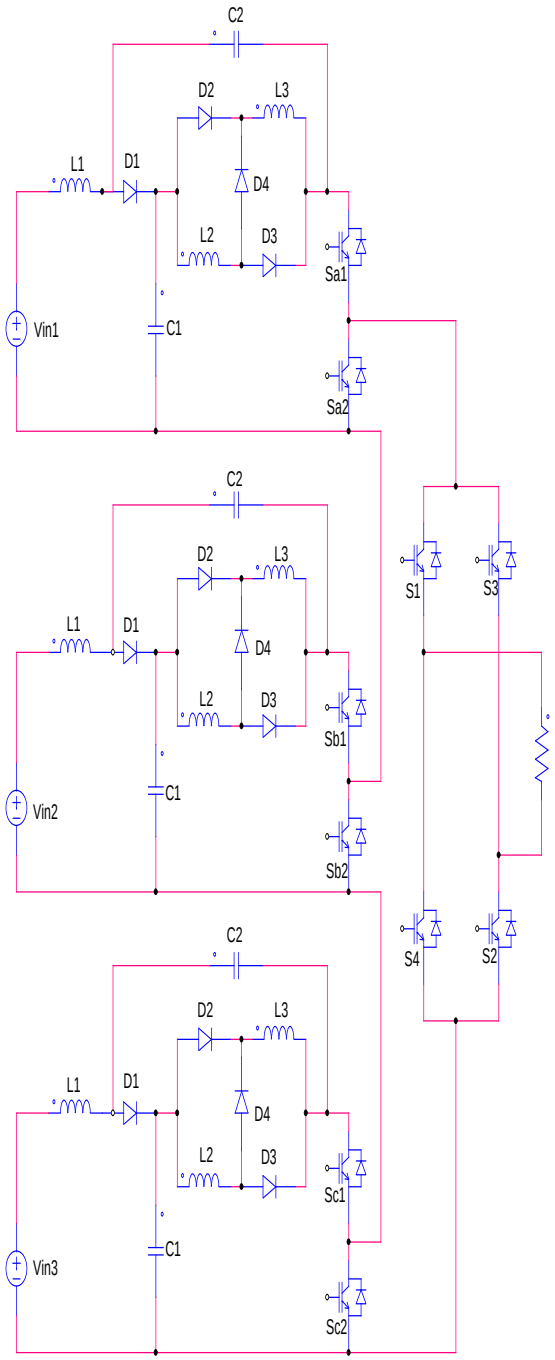


Fig. 2.1: Configuration of single phase Quasi-Z-source fed seven level Modified CHB Inverter with asymmetric switched-inductor cell

2.1 Shoot-through state

In the shoot-through state, the inverter side is shorted by both the upper and lower switching devices of any leg. The SL-QZ network i.e., LC and diode network defends the circuit from damage during the shoot-through zero state (Fig. 2.2) by storing energy in L and C. During this mode, the diodes D1, D4 are reverse biased while D_2, D_3 are ON. The inductor L_1 receives energy from the input source and capacitor C_2. Furthermore, inductors L_2 and L_3 are energized by capacitor C_1 in parallel. Thus, the two capacitors discharge the stored energy to the three inductors.

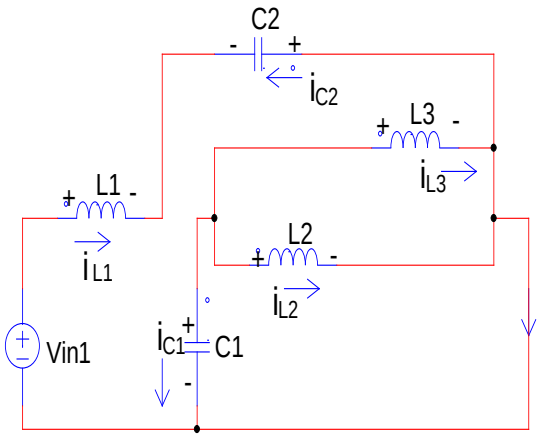


Fig. 2.2: Shoot-through state of QZ network fed CHB MLI topology with asymmetrical SL

2.2 Non shoot-through state

The non-shoot-through mode (Fig. 2.3) has two states namely active state and zero state. During this mode, the diode D2, D3 are reverse biased and D_1 and D_4 are ON which connects the inductors L1, L2 and L3 in series with input source. Capacitor C_1 is charged by input source and inductor L_1. The capacitor C_2 is charged by the inductors L_2 and L_3. The capacitors C_1 and C_2 are charged simultaneously. The input source and inductors L_1, L_2, L_3 provide energy to the load. Hence, asymmetric SL-QZ network boosts the dc-link voltage with the help of stored energy in the network elements during the shoot-through mode. The boost factor B, Shoot-through Duty Ratio Dsh and modulation index M for this topology is given by

$$\text{Boost factor } B = \frac{V_{dc}}{V_{in}} = \frac{(1+D_{\text{sh}})}{(1-2D_{\text{sh}}-D_{sh}^2)}$$

Shoot-through Duty Ratio, $D_{Sh} = \frac{T_O}{T}$

Where To is the duration of shoot-through zero state, T is the switching cycle

Modulation index, $M = 1 - D_{Sh}$

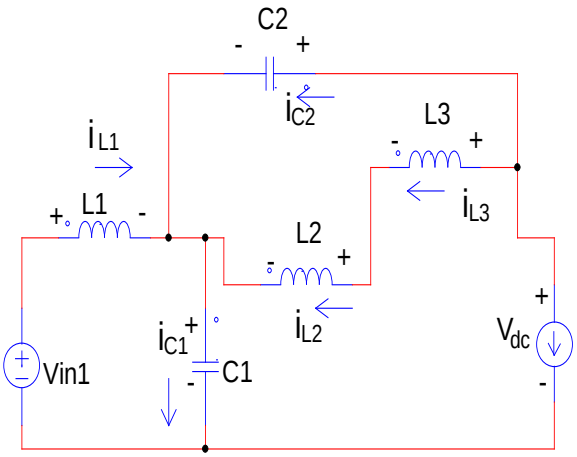


Fig. 2.3: Non Shoot-through state of QZ network fed CHB MLI topology with asymmetrical SL

3. Bipolar Multi–Carrier PWM Stratergies

In the suggested work, a bipolar sine wave with a triangular carrier is used to generate firing pulses for a seven level inverter. For an m-level inverter using bipolar multi-carrier technique, (m-1) carriers with the same frequency and same peak-to-peak amplitude are used. The reference wave is continuously compared with each of the carrier signals. If the reference wave is more than a carrier signal,

then the active devices corresponding to that carrier are switched on. If the reference wave is less than a carrier signal, then the active devices corresponding to that carrier are switched off.

3.1 Phase Disposition (PD) PWM Strategy

This technique uses several carriers with single modulating waveform. In phase disposition, all the six carriers are arranged in phase and the carriers are disposed so that the bands they occupy are in close proximity. The modulation wave is centered in the middle of the carrier set. The multicarrier arrangement for PDPWM technique is as shown in the Fig 3.1.

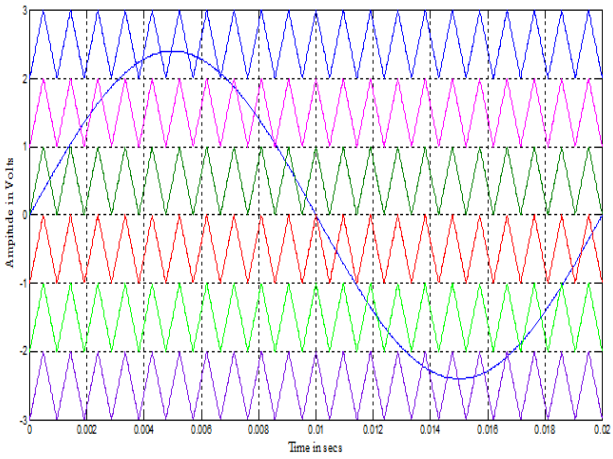


Fig. 3.1: PDPWM Strategy carrier arrangement

3.2 Phase Opposition Disposition (POD) PWM Strategy

In this strategy, the carrier waveforms above the zero reference value are in phase and the carrier waveforms below zero are also in phase but are 180 degrees phase shifted from those above zero. The multicarrier arrangement for PODPWM method is as shown in the Fig 3.2.

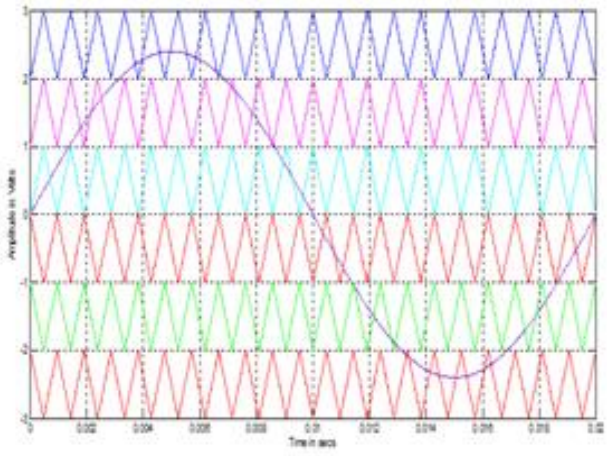


Fig. 3.2: PODPWM Strategy carrier arrangement

3.3 Alternative Phase Opposition Disposition (APOD) PWM Strategy

Each of the six carrier waves for a seven level inverter to be phase displaced from each other by 180° alternately for this strategy. The multicarrier arrangement for APODPWM method is as shown in the Fig 3.3.

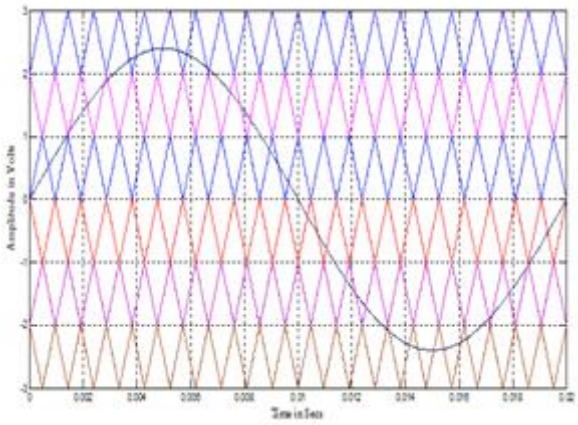


Fig. 3.3: APODPWM Strategy carrier arrangement

Simulation using MATLAB-SIMULINK is performed with bipolar triangular fixed amplitude multi-carrier alternate Phase opposition disposition (APOD), Phase opposition disposition (POD), Phase Disposition (PD) PWM strategies with rectified sine wave reference and trapezoidal reference for the single phase Quasi-Z-source fed seven level Modified CHB Inverter with asymmetric switched-inductor cell. The performance indices, peak value and root mean square value of the fundamental component and THD of the output voltage are evaluated and compared for various shoot through duty cycle for the chosen inverter topology.

To identify PWM technique with best performance for the proposed topology, the following PWM strategies for the proposed MLI is carried out.

1. Bipolar triangular fixed amplitude multi-carrier Phase Disposition (PD) PWM with rectified sine reference
2. Bipolar triangular fixed amplitude multi-carrier Phase Opposition Disposition (POD) PWM with rectified sine reference
3. Bipolar triangular fixed amplitude multi-carrier Alternative Opposition Disposition (APOD) PWM with rectified sine reference
4. Bipolar triangular fixed amplitude multi-carrier Phase Disposition (PD) PWM with trapezoidal reference
5. Bipolar triangular fixed amplitude multi-carrier Phase Opposition Disposition (POD) PWM with trapezoidal reference
6. Bipolar triangular fixed amplitude multi-carrier Alternative Opposition Disposition (APOD) PWM with trapezoidal reference.

4. Simulation Results and Analysis

The Simulation study using MATLAB software is carried for the Single phase Quasi-Z-Source fed seven level Modified Cascaded H-Bridge Inverter with asymmetric switched-inductor cell topology. The circuit parameters for simulation are as follows: $L_1=L_2=L_3=40$Mh and $C_1=C_2=6000\mu$F. Switching frequency fs = 5kHz.The input voltage Vin1=Vin2=Vin3 = 100V and R-load = 50Ω. The important performance indices namely Vrms (fundamental), and %THD of simulated output voltage for Dsh = 5% and 10% are observed.

With bipolar triangular fixed amplitude multi-carrier alternate Phase opposition disposition (APOD), Phase opposition disposition (POD), Phase Disposition (PD) PWM strategies with rectified sine wave reference and trapezoidal reference for the single phase Quasi-Z-source fed seven level Modified CHB Inverter with asymmetric switched-inductor cell is carried out. The sample output voltage waveforms and the corresponding FFT plot for QZ-Source fed MCHB with Phase opposition disposition (POD) PWM strategies with rectified sine wave reference and shoot through duty ratio Dsh = 10% is showed in the Fig. 4.1 and Fig. 4.2

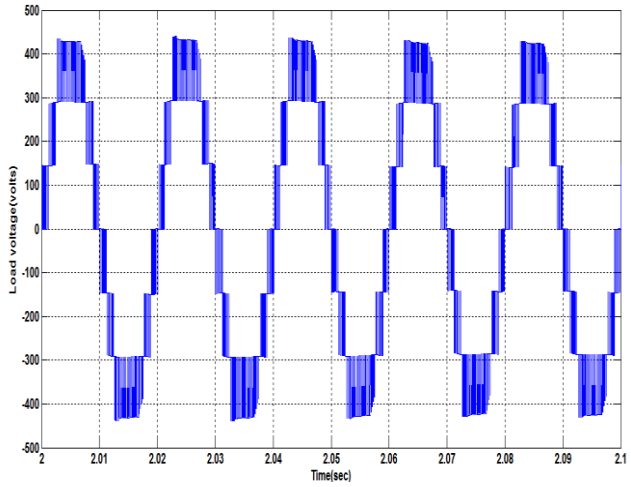


Fig. 4.1: Simulated output voltage waveform of QZ Source fed 7 level MCHB with asymmetric SL cell using POD (sine ref) for Dsh = 10%

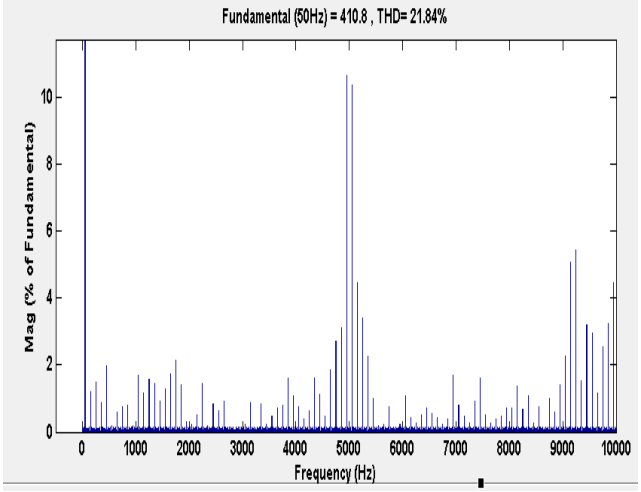


Fig. 4.2: FFT plot of QZ Source fed 7 level MCHB with asymmetric SL cell using POD (sine ref) for Dsh = 10%

The sample output voltage waveforms and the corresponding FFT plot for QZ Source fed seven level MCHB with a asymmetric SL cell with alternate Phase opposition disposition(APOD) strategies with trapezoidal reference and shoot through duty ratio Dsh = 5% is shown in the Fig 4.3 and Fig 4.4

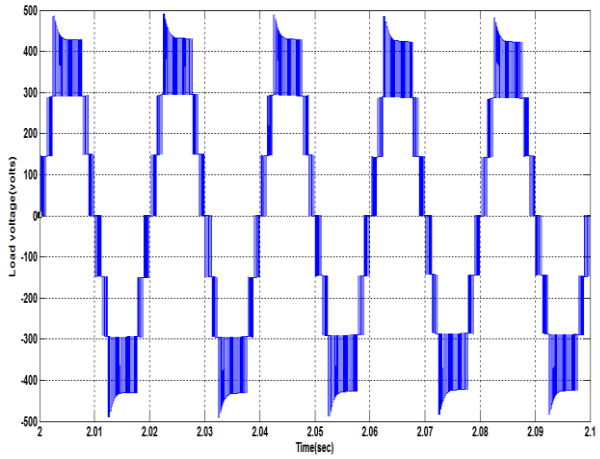


Fig. 4.3: Simulated output voltage waveform of QZ Source fed 7 level MCHB with asymmetric SL cell using APOD (trapezoidal reference) for Dsh = 5%

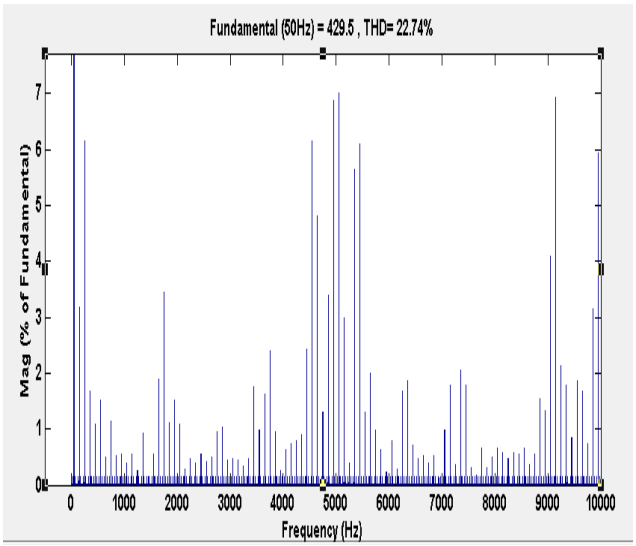


Fig. 4.4: FFT plot of QZ Source fed 7 level MCHB with a asymmetric SL cell using APOD (trapezoidal reference) for Dsh = 5%

The important performance indices namely Vrms (fundamental) and %THD of simulated output voltage for Dsh = 5% and 10% is presented in Table I and II

Table 1. Performance indices of QZ Source fed 7 level MCHB with asymmetric SL cell with sine reference and triangular carrier

	MCHB(SINE reference – TRIANGULAR carrier)			
	D_{SH} =5%		D_{SH} =10%	
	V_{rms}(V)	THD(%)	V_{rms}(V)	THD(%)
APOD	284	21.72	289.4	21.91
PD	282.5	21.96	289.5	21.96
POD	283.7	22.25	290.5	21.84

Table 2. Performance indices of QZ Source fed 7 level MCHB with asymmetric SL cell with trapezoidal reference and triangular carrier

	MCHB(TRAPEZOIDAL reference –TRIANGULAR carrier)			
	D_{SH} =5%		D_{SH} =10%	
	V_{rms}(V)	THD(%)	V_{rms}(V)	THD(%)
APOD	303.7	22.74	303.2	22.78
PD	301.7	23.20	301.2	23.24
POD	301.4	22.94	303.5	22.99

5. Conclusion

The simulation results affirm the development of PWM strategies for the chosen single phase Quasi-Z-source fed seven level Modified CHB Inverter with asymmetric switched-inductor cell. Performance factors like % THD and V_{rms} have been evaluated presented and analyzed The above simulation results also indicate that single phase Quasi- Z-source fed seven level Modified CHB Inverter along with voltage enhancement technique performs better with bipolar triangular fixed amplitude multi-carrier APOD PWM strategies with trapezoidal reference for Dsh = 5% by providing higher fundamental RMS output voltage with lower THD than other PWM strategies.

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