Study on PWM Strategies for Single Phase Quasi-Z-Source Fed Seven Level Modified Cascade H-Bridge Inverter

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Abstract—This paper portraits the survey on various PWM control strategies for single phase Quasi-Z-Source fed seven level Modified Cascade–H-Bridge inverter. The chosen multi-level inverter is controlled by a bipolar trapezoidal reference, triangular carrier signals with and without overlapping of Alternative Opposition and Disposition (APOD), Phase Disposition (PD) and Phase Opposition and Disposition (POD) PWM strategies. The performance of proposed strategies are evaluated through MATLAB-SIMULINK. The variation of V_{rms} (fundamental) and Total Harmonic Distortion (THD) are observed for various shoot through duty cycle. The simulation results indicates that trapezoidal reference with APOD PWM provides output with relatively low distortion. It is also seen that CO-POD PWM strategy is found to perform better since it provides relatively higher fundamental RMS output voltage.

Index Terms—Quasi Z-Source, cascade-H-Bridge, Shoot through Duty Cycle, CO-APOD, CO-PD, CO-POD

I. INTRODUCTION

Now a days, quality of power supply is a major concern for any power utilities due to increase in industrial and residential activities. Multilevel Pulse Width Modulation (PWM) inverters have been gained importance in high performance power applications without requiring high ratings on individual devices, as static var compensators, drives and active power filters [1],[2]. Basic classification of MLI are noticeable in high power applications. But few demerits like components count and voltage balancing problem are found to be existing in Diode-Clamped MLI (DCMLI), Flying Capacitor (FCMLI) MLI types. To overcome those problem reduced switch MLI topologies are developed in past decades [6] in cascade–H-Bridge type inverter [3]-[6]. Z-source networks are extensively used due to its relatively simple start-up, Provides a low-cost, reliable and highly efficient single stage for buck and boost conversions [7]. For further improvement of reliability, the improvised version of Z-source network called quasi-Z Source network is introduced [8]. The quasi Z-source is very much similar to the Z-source inverter. The quasi Z-source inverter have several advantages like reduce source stress, lower component ratings and simplified control strategies [9]. Like Z-source inverter, quasi Z-source inverter also suitable for applications which require large range of gain such as in motor controllers or renewable energy sources.

II. SINGLE PHASE QUASI-Z -SOURCE FED MODIFIED CHB MLI TOPOLOGY

This topology comprises of three voltage sources, ten switches, three diodes, six inductors and six capacitors. It consists of three Z-Source fed half H-bridge modules cascaded as shown in the Fig.1 through another H-bridge module and load. All the three modules are symmetrical in nature. In the quasi-Z-Source module-1, Vin feeds energy to the quasi-Z network-1. One port of the quasi-Z network-1 is connected to the voltage source Vin and the other port of the is connected to the half H-bridge circuit-1. The midpoint of the half H-bridge circuit-1 is connected to the top common point of the full H-bridge circuit as shown in Fig.1. The bottom point of the half H-bridge circuit-1 is connected to the mid-point of second half H-bridge module. Similarly, other two quasi-Z-Source network fed half H-bridge circuit-2 and half H-bridge circuit-3 are cascaded as in Fig.1. to provide seven level output voltage.

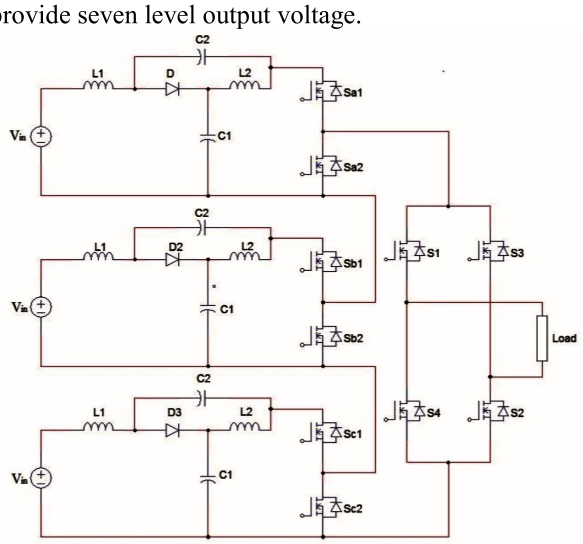

Fig. 1. Circuit diagram of the quasi-Z-source fed modified CHB seven level inverter

The operation of the seven level quasi-Z-Source fed modified CHB inverter is as described further. The DC input voltage is fed to the quasi-Z-Source network. The quasi-Z-Source network boosts the applied DC voltage depending upon the boost factor. The boosted DC link voltage, which is the output of the quasi-Z-Source network, is fed as input to the multilevel inverter. The boosted DC link voltage is inverted to synthesized AC by the switching circuit. The boosting operation is done through two modes i.e., shoot-through mode and non shoot-through mode.

Shoot-through mode

The network i.e., LC and diode network defends the circuit from damage during the shoot-through zero state (Fig. 2) by storing energy in L and C.

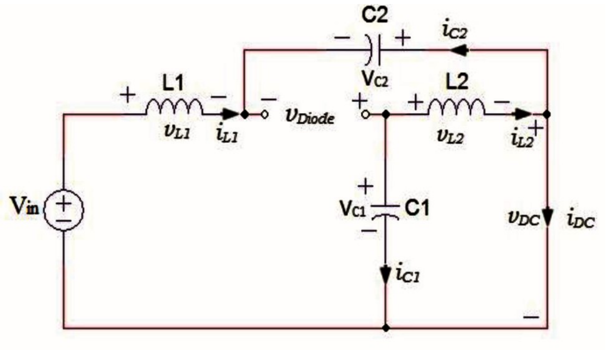

Fig.2. Equivalent circuit of quasi-Z-network in shoot-through state

This method of switching is done either at the beginning or end of the zero state, when the available voltage across the load is zero. This is purposely done to avoid damages of the switches. During this mode, the diode D1 is reverse biased and the inductor L1 receives energy from the input source and capacitor C2. Furthermore, inductor L2 is energized by capacitor C1 in parallel. Thus, the two capacitors discharge the stored energy to the two inductors. Hence, the network boosts the dc-link voltage with the help of stored energy in the network elements during the shoot-through mode.

Non shoot-through mode

The non-shoot-through mode (Fig. 3) has two states namely active state and zero state. During this mode, the diode D1 is forward biased. The inductors L1 and L2 are connected in series with input source. Capacitor C1 is charged by input source and inductor L1. The capacitor C2 is charged by the inductor L2 alone. The capacitors C1 and C2 are charged simultaneously. The input source and inductors L1, L2 provide energy to the load.

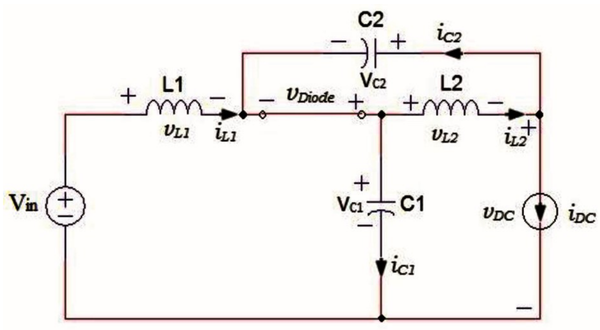

Fig.3. Equivalent circuit of quasi-Z-network in non-shoot-through state

This boosted dc-link voltage is to be inverted to AC by the multilevel inverter switches. To synthesize the different levels of DC input, the MLI switches must be switched ON and OFF in such a way that desired fundamental output voltage is obtained with low harmonic distortion. This is done with the help of PWM technique. There are several PWM strategies to generate pulses for multilevel inverter switches. In this work, the required gate signals for the switches are generated using various Pulse Width Modulation (PWM) strategies. Depending upon the type of PWM strategy, some or all of the zero states are replaced by the shoot-through states. The distribution of shoot-through state in the switching wave pattern generated using PWM strategy is the ultimate key factor to control the seven level quasi-Z-Source fed CHB inverter.

In quasi-Z-Source inverter an extra shoot-through zero state is possible which results in the boost factor B for the dc-link voltage given by :

$$D_{Sh} = \frac{T_O}{T}$$

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

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

III. BIPOLAR MULTI–CARRIER PWM STRATEGIES

The required gate signals for the switches are generated using the below mentioned PWM strategies.

Phase Disposition (PD) PWM Strategy

In PD PWM, all six carriers are arranged in phase and the carriers are disposed so that the bands they are in close immediacy. The modulation wave is placed in mid most of the carrier set as shown in the Fig .4.

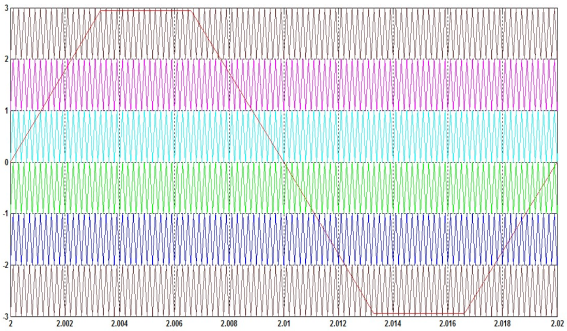

Fig.4. PD PWM Strategy carrier arrangement

Phase Opposition Disposition (POD) PWM Strategy

In this strategy, above the zero reference value the carrier waveforms are in phase and below zero the carrier waveforms are also in phase but are 180 degrees phase shifted from those above zero. The organization of multicarrier for PODPWM method is as shown in the Fig.5.

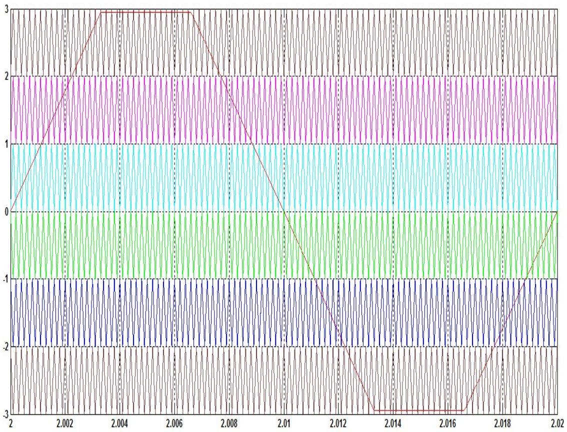

Fig.5. POD PWM Strategy carrier arrangement

Alternative Phase Opposition Disposition (APOD) PWM Strategy

In this strategy each of the six carrier waves to be phase displaced from each other by 180° alternately .The organization of multicarrier for APODPWM method is as shown in the Fig.6.

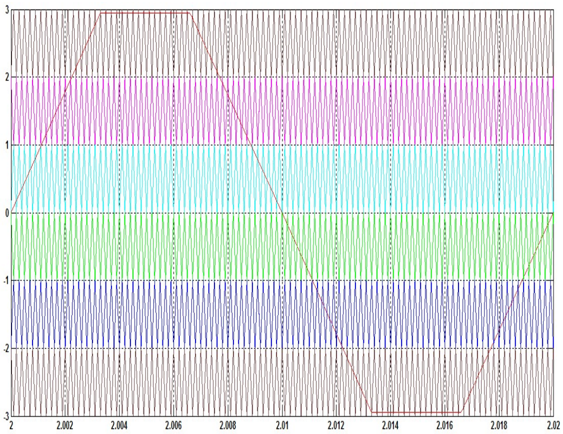

Fig.6. APOD PWM Strategy carrier arrangement

Carrier Overlapping Phase Disposition PWM Strategy (CO-PD PWM)

The below Fig.7 describes CO-PD PWM strategy, in which the carriers of same frequency fc and same amplitude Ac are arranged such that the bands they occupy overlaps each other. The vertical distance between overlapping carrier is Ac / 2. The trapezoidal reference waveform is placed in the middle of the carrier waveforms.

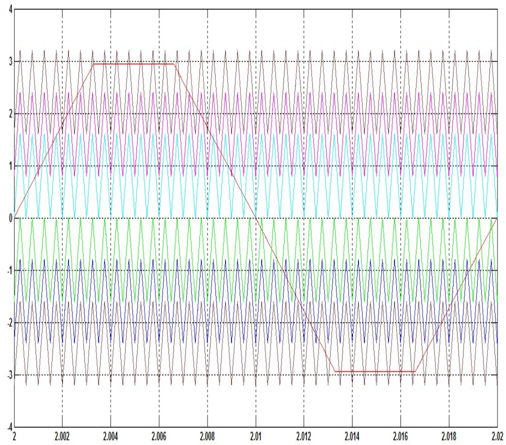

Fig.7. CO-PD PWM Strategy carrier arrangement

Carrier Overlapping Phase Opposition Disposition PWM Strategy (CO-POD PWM)

The below Fig.8 describes CO-POD PWM strategy, in which the carriers of same frequency fc and same amplitude Ac are arranged such that the bands they occupy overlaps each other. The vertical distance between overlapping carrier is Ac / 2. The trapezoidal reference waveform is placed in the middle of the carrier waveforms. All the carrier waveforms above the zero reference are in phase. Whereas the carrier waveforms below are also in phase, but are 180 degrees phase shifted from those above zero.

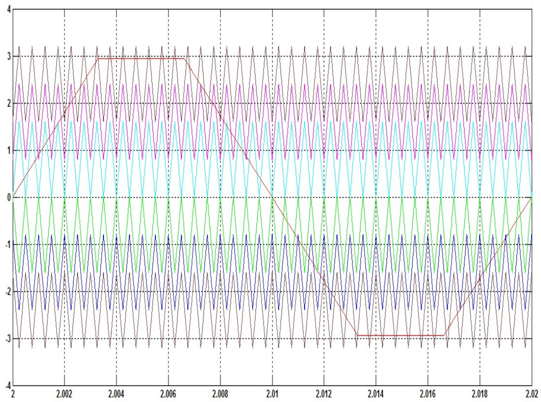

Fig.8. CO-POD PWM Strategy carrier arrangement

Carrier Overlapping Alternative Phase Opposition Disposition PWM Strategy (CO-APOD PWM)

The below Fig.9 shows the CO-APOD PWM strategy, in which the carriers of same frequency fc and same amplitude Ac are phase displaced from each other by 180 degrees alternately such that the bands they occupy overlaps each other. The vertical distance between overlapping carrier is Ac/ 2. The trapezoidal reference waveform is placed in the middle of the carrier waveforms.

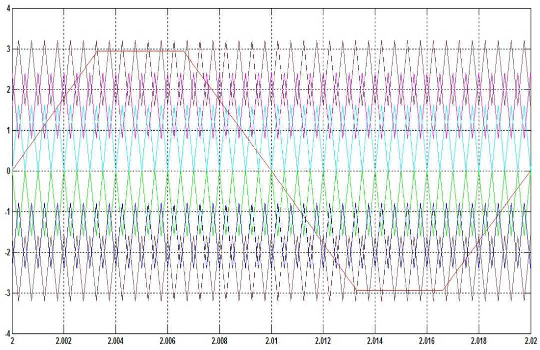

Fig.9. CO-APOD PWM Strategy carrier arrangement

IV. SIMULATION RESULTS AND ANALYSIS

The Simulation study using MATLAB software is carried for chosen topology as follows. The circuit parameters for simulation are as follows: L1=L2=L3= 40 m H and C1=C2=6000 μF. Switching frequency fs = 5kHz.The input voltage Vin1=Vin2=Vin3 = 100V and R load = 50 Ω. The important performance indices namely Vrms (fundamental) and %THD of simulated output voltage for Dsh = 5%,10%,15% and 20% are noted down .

The sample output voltage waveforms and the corresponding FFT plot for quasi-Z-Source Fed MCHB with trapezoidal reference , triangular carrier , CO–POD PWM strategy and shoot through duty ratio Dsh = 10% which provides relatively higher fundamental RMS output voltage is shown in the Fig.10 and 11.

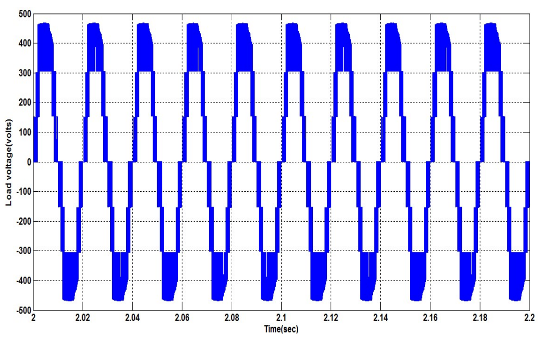

Fig.10. Simulated output voltage waveform of quasi-Z-Source Fed 7 level MCHB with CO-POD PWM strategy (trapezoidal ref) for Dsh = 10%

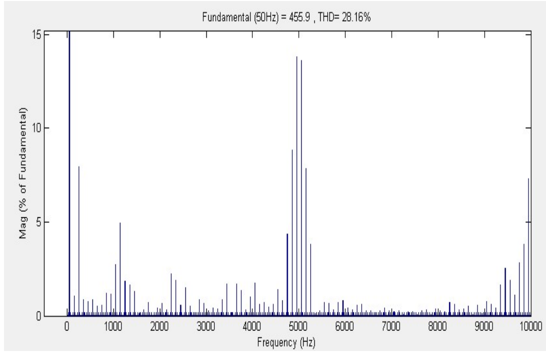

Fig.11: FFT plot of quasi-Z-Source fed 7 level MCHB with COPOD PWM strategy (trapezoidal ref) for Dsh = 10%

The sample output voltage waveforms and the corresponding FFT plot for quasi-Z-Source Fed MCHB with trapezoidal reference , triangular carrier , APOD PWM strategy and shoot through duty ratio Dsh = 5% which provides output with relatively low distortion is shown in the Fig.12 and 13.

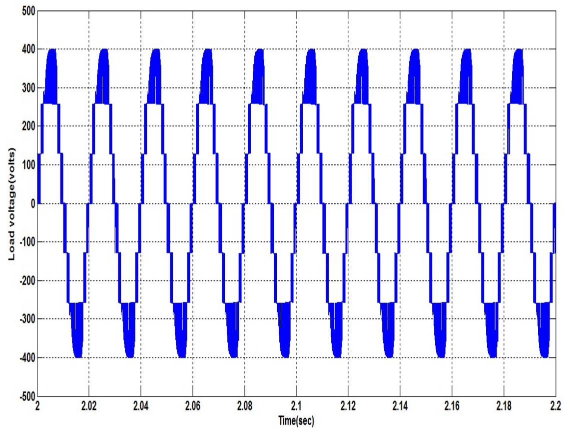

Fig.12. Simulated output voltage waveform of quasi-Z-Source Fed 7 level MCHB with APOD PWM strategy (trapezoidal ref) for Dsh = 5%

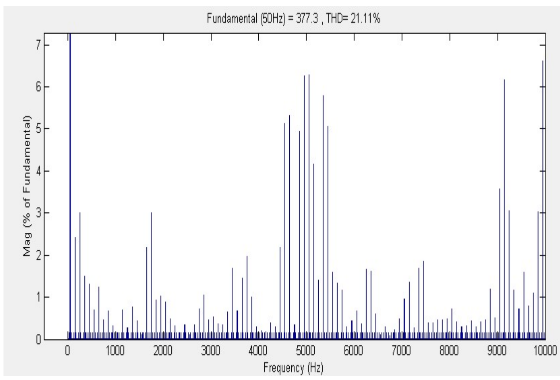

Fig.13. FFT plot of quasi-Z-Source fed 7 level MCHB with APOD PWM strategy (trapezoidal ref) for Dsh = 5%

The important performance indices namely Vrms(fundamental) and %THD of simulated output voltage for Dsh = 5%,10% ,15% and 20% of all mentioned PWM strategies are tabulated below in Table 1 and 2.

Table1.Performance Index Vrms (fundamental) of quasi-Z-Source Fed MCHB with Trapezoidal Reference and Triangular Carrier

PWM STRATEGY	QZ-MCHB(Trapezoidal reference and triangular carrier) Vrms(V)			
	DSH =5%	DSH =10%	DSH =15%	DSH =20%
PD	265.4	264.9	260.8	259.1
POD	267.1	266.6	263	260.9
APOD	266.8	266.3	263.3	260.9
CO-PD	310.5	316.8	316.2	314.1
CO-POD	315	322.4	321.7	319.6
CO-APOD	302	306.2	305.3	302.8

Table2. Performance Index THD of quasi-Z-Source Fed MCHB with Trapezoidal Reference and Triangular Carrier

PWM STRATEGY	QZ-MCHB(Trapezoidal reference and triangular carrier) THD(%)			
	DSH =5%	DSH =10%	DSH =15%	DSH =20%
PD	21.51	21.58	21.93	22.14
POD	21.37	21.44	21.88	21.63
APOD	21.11	21.18	21.36	21.62
CO-PD	28.43	29.03	28.97	29.54
CO-POD	27.57	28.16	28.11	28.38
CO-APOD	30.33	31.72	31.75	32.48

V. CONCLUSION

The simulation results vouch the development of the various PWM strategies for the chosen single phase seven level bipolar Modified quasi-Z-Source cascade H bridge inverter. It is seen that CO-POD PWM strategy is found to perform better for the above mentioned inverter since it provides relatively higher fundamental RMS output voltage for Dsh = 10%. The above simulation results also indicate that the inverter performs better with APOD PWM by providing output with relatively low distortion.

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