International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 13, No. 1, March 2022, pp. 322~329
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v13.i1.pp322-329

Implementation of multicarrier PWM based 7-level Z-source cascaded H-bridge inverter

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Article Info

Article history:

Received Jul 26, 2021
Revised Jan 19, 2022
Accepted Jan 26, 2022

Keywords:

Cascaded H-bridge inverter
Multicarrier pulse width modulation
Total harmonic distortion
Z-source network

ABSTRACT

This paper elucidates the realization of multicarrier pulse width modulation (MC-PWM) based 7-level Z-source cascaded H-bridge inverter. MC-PWM technique is developed to generate switching pulses for Z-source inverter; it leads to boost the inverter output voltage with help of shoot through mode of operation. The output of Z-source inverter is connected to 7-level cascaded H-bridge inverter. Cascaded H-bridge inverter system much suitable for AC load drive, high voltage and high power and industrial applications. This proposed system provides reduced total harmonic distortion, improved stepped output voltage and current, nearly sinusoidal output voltage and reduced voltage stress across the switching devices. The inductors and capacitors values are selected based on the boosting level of Z-source inverter. The simulation results of proposed 7-level Z-source cascaded H-bridge inverter with MC-PWM technique is verified using MATLAB/Simulink.

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1. INTRODUCTION

In recent days, the usage and necessity of multilevel inverter topologies are increasing due to more alternating current (AC) power demand and various applications like AC electric drive, high voltage and high power applications, industrial applications and electric vehicles [1]–[4]. The multilevel inverter systems has attractive advantages like reduced common mode voltage range, minimized total harmonic distortion (THD), low voltage stress and electromagnetic interference issues, staircase output voltage and low switching losses. The various multilevel inverter topologies are introduced and each system has separate merits and demerits [5]–[7]. Among the various multilevel inverters (MLIs) systems, cascaded H-bridge inverter has multiple direct current (DC) sources and connected with multiple number of H-bridge inverters to increase the number of levels [8], [9].

Generally, DC to DC converters were utilized to boost or buck the DC voltage level in conventional systems, during some cases which not able to meet the power demand [10]. To avoid these cases Z-source network is introduced to boost the DC voltage level with help of shoot through condition, its leads to boost the voltage range with help of by selecting the various ranges of inductors and capacitors [11]–[13]. Also, the output of Z-source can be connected to direct DC load applications or with various DC to AC converter for AC load applications [14]. Similarly, it is much suitable to various DC fixed input sources and variable sources like fuel cell, photovoltaic system and battery; it leads to provide the variable DC to DC output voltage with DC load applications and inverter with AC load applications [15]–[17].

To control the various power converter topologies, the different PWM methods were developed and tested to the same [18]. The different pulse width modulation PWMs methods are phase disposition (PD), sinusoidal PWM, hysteresis current control, nearest state method, space vector modulation and multicarrier PWM [19]. Among these various PWM methods, MC-PWM provides better performance inters of minimized THD, controlled output voltage and current, simple in switching pulse generation compare other PWM methods, where different reference and carrier signals are used for switching pulse generation [20]‒[23].

In this proposed paper, MC-PWM based 7-level Z-source cascaded H-bridge inverter. MC-PWM technique is developed to generate switching pulses for Z-source inverter; it leads to boost the inverter output voltage with help of shoot through mode of operation. The output of Z-source inverter is connected to 7-level cascaded H-bridge inverter. This system provides reduced total harmonic distortion, improved stepped output voltage and current, nearly sinusoidal output voltage and reduced voltage stress across the switching devices. The simulation results of proposed 7-level Z-source cascaded H-bridge inverter with MC-PWM technique is verified using MATLAB/Simulink. The block diagram of proposed 7-level Z-source cascaded inverter with MC-PWM is shown in Figure 1.

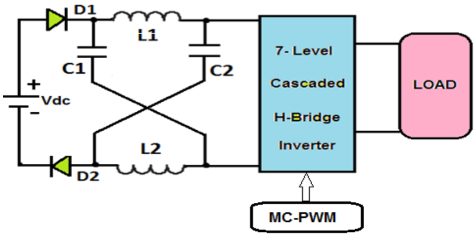


Figure 1. Block diagram of proposed Z-source cascaded inverter

2. 7-LEVEL Z-SOURCE CASCADED H-BRIDGE INVERTER

Among different multilevel inverter circuit, cascaded H-bridge inverter has less number of power devices and capacitors [24], [25]. This topology is designed with series connection of H-bridge circuit with separate DC input sources to attain the different level of output voltage [26]. The output terminals of H-bridges are connected in series to provide simultaneously three phase output voltages [27]. The Figure 2 shows the power circuit of 7-level cascaded H-bridge inverter. This cascaded type of multilevel inverters is much suitable for AC load applications, industrial applications and renewable energy sources.

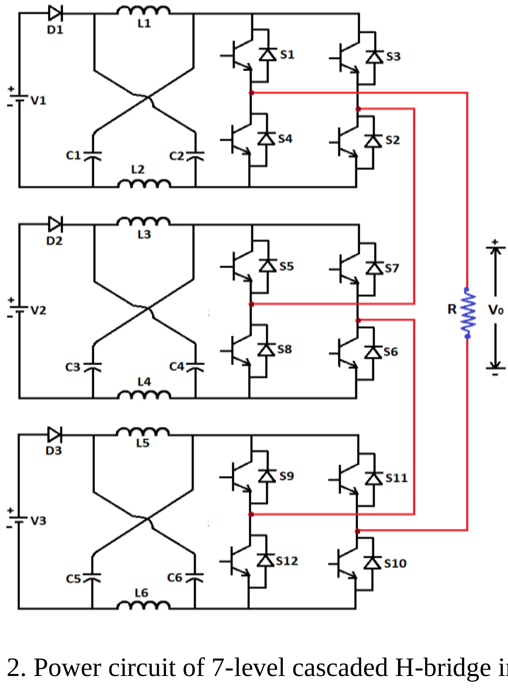


Figure 2. Power circuit of 7-level cascaded H-bridge inverter

This single phase 7-level cascaded H-bridge inverter includes 3 DC input sources, 3 half H-bridge inverter, and Z-source network separately for each phase of the circuit. Where each single circuit has 4 power switches, which is controlled by MC-PWM scheme. With help of this power structure, 7-level stepped output voltage obtained to connect with AC load applications. It consists of many units in terms of back to back manner to attain 7-level output voltage. Each H-bridge switches are operated with different combinations to get voltage levels as –Vdc, 0 +Vdc; where S1 and S3 are connected in positive side, and S2 and S4 are connected in negative side. Total amount of output voltage range from a cascaded H-bridge circuit depends on the number of DC sources are connected with the system.

Cascaded H-bridge system much suitable for various applications like static var compensators design, electric motor drives, power quality applications, to interconnect with renewable energy sources and AC grid connection and power factor correction methods [28]. In this proposed system, 7-level cascaded H-bridge inverter gets DC source from the Z-source network.

2.1. Z-source network

Generally Z-source network is designed to improve/boost the inverter output voltage. Z-source inverter overcomes the restrictions and demerits of conventional voltage source inverter (VSI). The desired stepped output voltage is obtained by boosting the DC link voltage from PV system with help of shoot through state, which is not possible in traditional VSI inverter. Three phase three level Z-source inverter (ZVI) with single impedance network, it has 2 inductors (L1&L2) and 2 capacitors connected between 3-level neutral point clamped (NPC) inverter and DC input voltage source. In order to attain the voltage operation, shoot through state is included in switching sequences. It is simple process to introduce the shoot through state, when all the switches are on position in a particular leg simultaneously. the boost factorlof Z-source network is defined as (1).

$$B_f = \frac{T_s}{T_a - T_b} \tag{1}$$

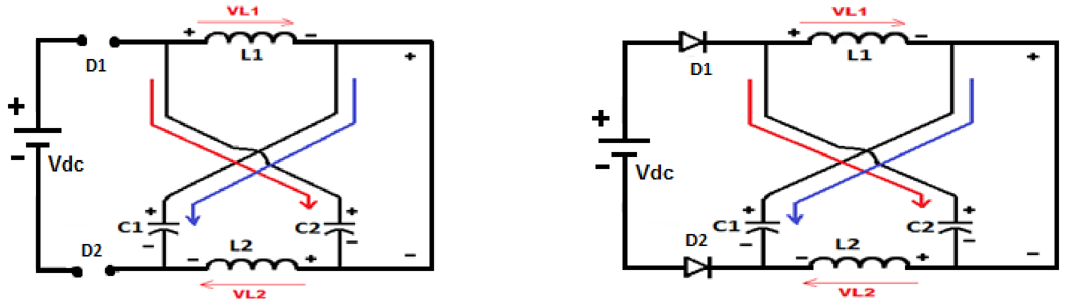
Where T_s - Total switching timelperiod, T_a – non shoot through state time period, T_b –shoot through state time period. There are two working states of operation available in Z-source network: shoot through and non shoot through state. In Figure 3 (a), both upper and lower switches in a leg switched ON simultaneously and short circuit current will flow, the two inductors are starts charging by the capacitors and the diode acting as reverse biased condition. The change in inductor current written as (2).

$$\frac{di_L}{dt} = \frac{-V_C}{L} \tag{2}$$

Where i_L - inductor current, V_C – average capacitor voltage. The input DC source and inductors are starts suppling electic energy to load and at same time charging capacitors, which is shown in Figure 3(b). The inductor current in non shoot through state is defined as (3).

$$\frac{di_L}{dt} = \frac{V_C - V_{PV}}{L} \tag{3}$$

Based on these 2 working states output voltage in Z-zouce inverter can boosted better than conventional boost converters, which is defined as $Vac = 0$.



(a) (b)

Figure 3. Z-source modes of operation (a) non-shoot through (b) shoot through

3. MULTICARRIER PWM (MC-PWM)

Multicarrier sinusoidal pulse width modulation (PWM) is the advanced method of sinusoidal PWM scheme, where reference signal is compared with multiple carrier signals. Here sinusoidal wave is considered as reference signal and triangular wave is considered as multiple carrier signals. For generating multiple switching pulses to cascaded H-bridge inverter, multiple numbers of triangular signals are compared with single sinusoidal signal. By comparing the signals the required numbers of switching pulses are obtained. The Figure 4 shows multicarrier pulse width modulation for 7-level Z-source cascaded H-bridge inverter.

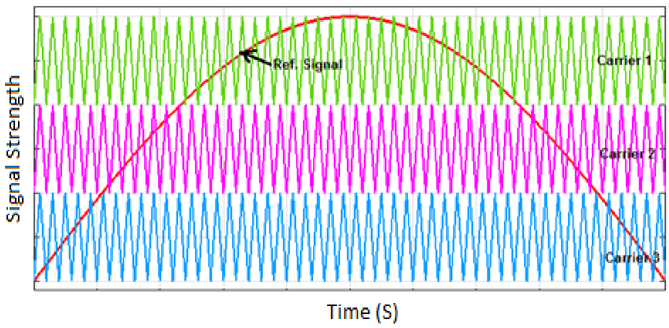


Figure 4. Multicarrier pulse width modulation

The MC-PWM is developed to control the multiple switching devices of 7-level cascaded H-bridge inverter, where its essential to preserve the shoot through proportion as stable. Also, this system used to diminish the voltage stress across the various power devices, the boosted voltage with appropriate distinction of intonation index. This method attains better voltage gain with constant value of shoot through state and non-shoot through state condition. Based on the MC-PWM control, the Z-source inverter activates either on upper shoot through or lower shoot through mode of operation. The power devices are switched based on the switching pulses are generated using MC-PWM control method, it leads to generate shoot through mode & which is used to boost the inverter output voltage.

4. SIMULATION RESULTS AND DISCUSSION

Multicarrier pulse width modulation PWM based 7-level Z-source cascaded H-bridge inverter is simulated using MATLAB/Simulink. This system includes MC-PWM as control method; 7-level Z-source inverter has 12 power devices with 16 A rating. It has designed value of inductors L1 & L2 of 4 mH and capacitors C1 & C2 of 270 uF, freewheeling diode D and DC input voltage of Vdc. Figure 5 shows the switching pulse generation using MC-PWM method.

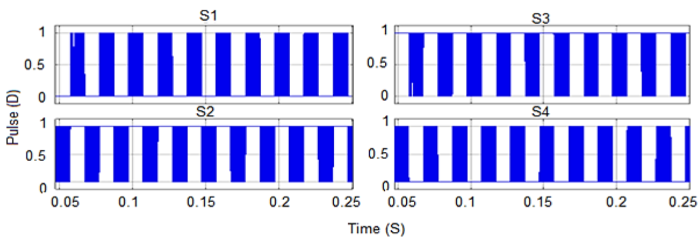


Figure 5. Switching pulse generation using MC-PWM

This proposed 7-level Z-source cascaded H-bridge inverter is controlled using MC-PWM scheme, the switching pulses generation achieved using MC-PWM. Output stepped voltage of 7-level Z-source cascaded H-bridge inverter is shown in Figure 6, which is 266.2 V for the DC input voltage of 110 V. The output stepped current of 7-level Z-source cascaded H-bridge inverter is shown in Figure 7, which is 5.32 A. Voltage across Z-source network is shown in Figure 8 in that voltage stress across the switching device is controlled, it is obtained using MC-PWM control method. The Figure 9 shows the voltage across the capacitors C1 & C2, with capacitor C1 of 74.5 V and capacitor C2 of 74.8 V. Similarly, the inductor placed in the Z-source network value varies for inductor L1 of 73.2 V and inductor L2 of 73.8 V, which is shown in Figure 10. The total harmonic distortion for this proposed system is shown in Figure 11; in that Figure 11 (a) shows THD analysis for stepped inverter output voltage with 2.65 %, in Figure 11 (b) shows THD analysis for stepped output current with 1.5 %.

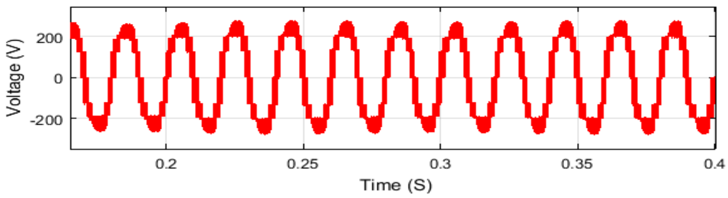


Figure 6. Output stepped voltage of 7-level Z-source cascaded Hbridge Inverter (CHBI)

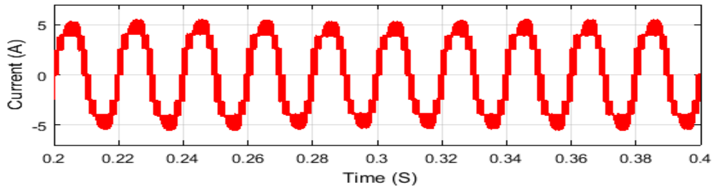


Figure 7. Output stepped current of 7-level Z-source CHBI

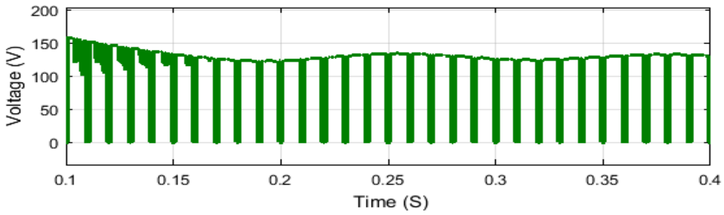


Figure 8. Voltage across Z-source network

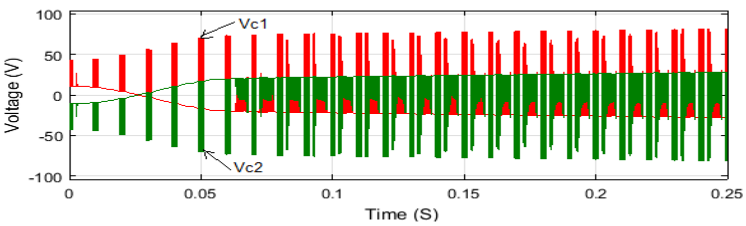


Figure 9. Voltage across the capacitors C1 & C2

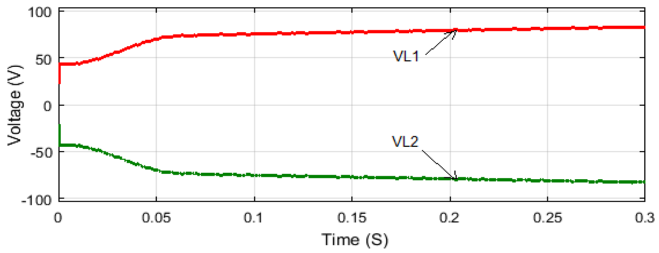
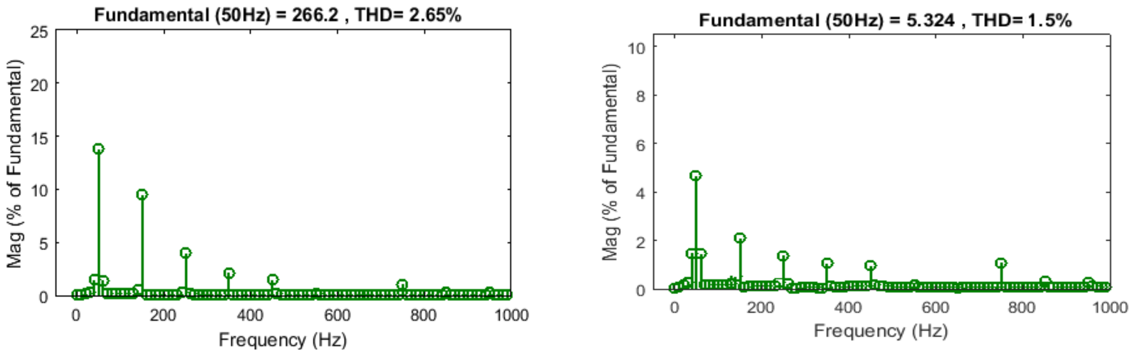


Figure 10. Voltage across the inductors L1 & L2



(a) (b)

Figure 11. FFT analysis for (a) stepped voltage and (b) stepped current

5. CONCLUSION

This paper gave an idea about implementation of MC-PWM for 7-level Z-source cascaded H-bridge inverter. MC-PWM technique is developed to generate switching pulses for Z-source inverter; it leads to boost the inverter output voltage with help of shoot through mode of operation. The output of Z-source network is connected to 7-level cascaded H-bridge inverter, Z-source network boosts the inverter output voltage of 2.5 times input DC voltage. This proposed system improves the inverter output voltage and current, reduces the THD to 2.65% for stepped voltage and 1.5% for stepped current. This proposed is developed and analysed using MATLAB/Simulink.

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