Study of Quasi-Z-Source Cascaded H-Bridge Multilevel Inverter with Voltage-Lift Cell

G. Prem Sunder^{1*}, B. Shanthi², Alamelu Nachiappan³ and S.P. Natarajan⁴

¹Department of Electrical and Electronics Engineering, Mailam Engineering College, Mailam, Tindivanam – 604304, Villupuram, India; premgsunder@gmail.com. ²Centralized Instrumentation and Service Laboratory, Annamalai University, Annamalai Nagar – 608 002, Tamil Nadu, India; au_shan@yahoo.com ³Department of Electrical and Electronics Engineering, Pondicherry Engineering College, Puducherry – 605 014 India; nalam63@pec.edu ⁴Department of Instrumentation Engineering, Annamalai University, Annamalai Nagar –608001, Chidambaram, Tamil Nadu, India; spn_annamalai@rediffmail.com

Abstract

Background/Objectives: Quasi-Z-source based multilevel inverters have attracted much interest in recent research works due to its valuable merits when evaluated with conventional voltage source inverters and Z-source Inverters. The objectives of this research work is to provide lower power rating of power devices, continuous input current, higher boosted output voltage and reduced current stress for dc source. **Methods/Statistical analysis:** A new quasi-Z-source Cascaded H-Bridge multilevel inverter with voltage-lift cell (VL-qZS-CHB-MLI) is analysed in this research paper. The performance of the VL-qZS-CHB-MLI is verified through simulation results obtained using multicarrier PD-PWM technique with simple boost control strategy. Shoot-through states are introduced in generated pulses by utilizing the simple boost control technique. Extended boost operation of the proposed topology is provided by the shoot-through states. **Findings:** In this new proposed topology, the presence of voltage-lift cell significantly strengthens the boost capability for the equal shoot-through duty ratio as in traditional qZS-CHB-MLI. The proposed topology involves lower shoot-through duty ratio as in the qZS-CHB-MLI for achieving the same boost gain. This advantage of the proposed topology can be popularly utilized for high-power applications requiring good quality boosted output and low voltage stress. Also, the proposed topology offered abundant merits over traditional Cascaded H-Bridge (CHB) multilevel inverter in distributed power generation applications like PV power system and wind energy system.

Keywords: Cascaded H-Bridge (CHB) Multilevel Inverter, PD-PWM, Quasi-Z-Source, Simple Boost Control, Voltage-Lift Cell

1. Introduction

The Z-source based multilevel inverters created a centre of attention in modern research works owing to its fruitful advantages in contrast with conventional voltage source inverters and Z-source inverters (ZSI)¹. The ZSI has a one-stage power conversion capability that makes use of shoot-through and non-shoot-through states to provide boosted output voltage, thus achieving high immunity to the Electro-Magnetic

*Author for correspondence

Interference (EMI) noise^{2–5}. However, it has noticeable flaws including high voltage stress across the capacitors and switching devices, high incoming current and lower boosting capability. The major negative aspect of the ZSI is the irregular input current that may lead to rude operation and permanent failure of the dc source. To overcome the flaws associated with the ZSI, various improved circuit structures^{6–11} were presented in the literature.

A new extended-boost ZSI^{6} is presented with a capacitor/diode, which provides increased boost factor and continuous current, but it has complex circuit structure. The quasi-Z-Source Inverter (qZSI)^Z portrays the advantages of lower number of power devices with lower power rating. Also, in recent days multilevel inverters are popularly utilized for high-power applications with good quality output and low voltage stress¹². CHB multilevel inverter has more advantages over Diode clamped and Capacitor clamped multilevel inverters for a given number of levels¹³⁻¹⁶. The qZSI concept has been applied to CHB multilevel inverter, providing combined advantages of CHB multilevel inverter and qZSI17. The quasi-Z-Source Cascaded H-Bridge Multi-Level Inverter (qZS-CHB-MLI) offered abundant merits over traditional CHB multilevel inverter in distributed generation applications. A new Voltage-Lift quasi-Z-Source Cascaded H-Bridge Multilevel Inverter (VL-qZS-CHB-MLI) cell is presented in this paper to further increase the boosting capability. The new VL-qZS-CHB-MLI provides extended boosting capability for the equal shootthrough duty ratio as in the qZS-CHB-MLI.

The traditional qZS-CHB-MLI is explained in section II with circuit topology and characteristics of boost factor and shoot-through duty ratio. The VL-qZS-CHB-MLI is explained in section III. The PWM control strategy of the proposed VL-QZS-CHB-MLI is given in section IV. The simulation results of the VL-qZS-CHB-MLI are portrayed in section V. Lastly, the conclusion is specified in section VI.

2. Traditional qZS-CHB-MLI

Figure 1. shows the traditional qZS-CHB-MLI, which comprises a qZ-source-network with two inductors (L_1 , L_2), two capacitors (C_1 , C_2) and one diode (D_1).



Figure 1. Traditional qZS-CHB-MLI.

In this traditional topology, qZ source network shares the common ground with inverter. The boost factor (B) of the qZS-CHB-MLI is given in (1)

$$B = \frac{V_{dc}}{V_{in}} = \frac{1}{(1 - 2D_{sh})}$$
(1)

3. Proposed VL-qZS-CHB-MLI

To enhance the boost ability of the traditional qZS-CHB-MLI, a voltage-lift cell is incorporated by replacing inductor L_2 in that topology to form a new proposed topology VL-qZS-CHB-MLI which is shown in Figure 2.

3.1 Shoot-Through Control State

In shoot-through control state depicted in Figure 3, the inductors L_2 , L_3 and capacitor C_3 are in shunt connection, where the diodes D_2 and D_3 are on and D_1 is off. The capacitor C_3 is charged, while C_2 and C_1 are discharged.

All the inductors L_1 , L_2 and L_3 store energy during this state. Thus, we can state the inductor voltages (V_{L1} , V_{L2} , V_{L3}) and capacitor voltages (V_{C1} , V_{C2} , V_{C3}) as given below in (2).

$$\begin{cases} V_{L1} = V_{in} + V_{C2} \\ \Box \\ V_{L2} = V_{L3} = V_{C1} = V_{C3} \end{cases}$$
(2)



Figure 2. Proposed VL-qZS-CHB-MLI.



Figure 3. Equivalent circuit of the proposed VL-qZS-CHB-MLI under shoot-through.

3.2 Non-Shoot-Through Control State

In non-shoot-through control state depicted in Figure 4, the inductors L_3 , L_2 and C_3 are in series connection, where diodes D_2 and D_3 are off and D_1 is on. The capacitor C_3 is discharged, while C_1 and C_2 are charged. All inductors L_3 , L_2 and L_1 transmit energy from dc source to load. Thus, we can obtain the inductor voltages and capacitor voltages as given in (3).

$$\begin{cases} V_{C1} = V_{in} + V_{L1} \\ \Box \\ V_{C2} = V_{C2} + V_{L2} + V_{L3} \\ \Box \\ V_{dc} = V_{C1} + V_{C2} \end{cases}$$
(3)



Figure 4. Equivalent circuit of the proposed VL-qZS-CHB-MLI under non-shoot-through.





Figure 5 depicts the boosting capability of the VL-qZS-CHB-MLI, which is considerably superior when evaluated with traditional topology. Total harmonic

distortion is high for lower modulation index which results in significant degrade in the ac output voltage. In the most favourable design of the quasi-Z-source multilevel inverter, the value of the modulation index is chosen near to 1. Consequently, the boost factor of quasi-Zsource impedance network is limited by shoot-through duty ratio and modulation index. Simple boost control method is adopted for the proposed topology, which is well known for its easy implementation and reduced current stress across the components. Fig.6 illustrates the characteristics of voltage gain and the modulation index for the VL-qZS-CHB-MLI topology, and it is observed from the plot that the voltage gain rises as the modulation index reduces. Therefore, the proposed topology utilizes higher modulation index for the identical voltage conversion ratio when compared to convention qZS-MLI.



Figure 6. Voltage conversion ratios of the traditional and proposed topology.

4. PWM Control Strategy of the Proposed VL-qZS-CHB-MLI

The switching signals for the proposed topology are produced by Phase Disposition Pulse Width Modulation (PD-PWM) method. In PD-PWM, the triangular carriers are in phase with each other, having identical frequency f_c and identical amplitude A_c . In this technique, the reference signal with an amplitude A_m and frequency f_m is compared with each of the triangular carrier signals to create gate pulses. Shoot-through states can be generated by simple boost control, maximum boost control and constant boost control methods. For the VL-qZS-CHB-MLI, the shoot-through states are introduced in the generated pulses with PD-PWM technique utilizing simple boost control method. The shoot-through states provide extended boost operation of the proposed topology. The simple boost control strategy employs a constant line with amplitude identical to or larger than the crest value of the modulating signal to produce the shoot-through states.

For this case, the shoot-through duty ratio is given in (4).

$$D_{s\mathbf{h}} = \frac{T_{s\mathbf{h}}}{T} = 1 - M \tag{4}$$

Where, the correlation between modulation index M and shoot-through duty ratio is given in (5).

$$M < 1 - D_{sh} \tag{5}$$

The boost factor of VL-qZS-CHB-MLI is shown in (6).

Boost Factor,
$$B = \frac{2}{1 - 3D_{sh}}$$
 (6)

The proposed topology involves lower shoot-through duty ratio when compared with qZS-CHB-MLI for attaining the same boost gain. This improvement of the VL-qZS-CHB-MLI topology makes possible the larger improvement in the output voltage.

5. Simulation Results

To address the virtues of the VL-qZS-CHB-MLI topology shown in Figure 2, the simulation results obtained through Matlab is compared with that of the traditional topology. Figure 7 and 8 illustrate the simulation results of the VL-qZS-CHB-MLI and their simulation parameter are provided in Table 1.

 Table 1.
 Simulation parameters of the VL-qZS-CHB-MLI.

Input DC Voltage	Vin	100V
VL-qZS network	$L = L_1 = L_2 = L_3$	40 mH
	$C = C_1 = C_2 = C_3$	6000 <mark>µ</mark> F
Switching frequency	f _s	10 KHz
Resistive Load	R	50Ω

As exposed in Figure 9, in steady state, V_{dc} is increased to 300V for the given dc voltage of 100V. The capacitor voltages $V_{c1} & V_{c2}$ for the proposed topology are boosted to 160V and 140V approximately, which are same with analysis and shown in Figure 8.



Figure 7. Simulation results of the dc link voltages: (a) V_{dc1} , (b) V_{dc2} (c) V_{dc3} .



Figure 8. Capacitor voltages $(V_{C1} & V_{C2})$ of the proposed topology



Figure 9. Output voltage waveform of proposed topology.

6. Conclusion

A new voltage-lift quasi-Z-Source Cascaded MLI with higher boost ability is compared with traditional quasi-Z-source Cascaded MLI. The higher boost ability of the proposed topology improves the quality of the output voltage waveform. The study of the new proposed topology is verified by simulation results obtained with simple boost control method. This topology is appropriate for distributed power generation applications such as PV power system and wind energy system.

7. References

- Banaei MR, Dehghanzadeh AR, Salary E, Khounjahan H, Alizadeh R. Z-source-Based Multilevel Inverter with Reduction of Switches, IET Power Electronics. 2012 Oct; 5(3):385–92.
- Miaosen Shen, Joseph A, Jin Wang, Peng FZ, Adams, DJ. Comparison of Traditional Inverters and Z -Source Inverter for Fuel Cell Vehicles. IEEE Transactions on Power Electronics. 2007 Jul; 22(4):1453–63.
- Yi Huang, Miaosen Shen, Peng FZ, Jin Wang. Z-Source Inverter for Residential Photovoltaic Systems, IEEE Transactions on Power Electronics. 2006 Nov; 21(6): 1776–82.
- 4. Peng Fang zheng. Z-source Inverter. IEEE Transactions on Industry Applications, 2003 March; 3(2): 504–10.
- Fang Zheng Peng, Joseph A, Jin Wang, Miaosen Shen, Lihua Chen, Zhiguo Pan, Ortiz-Rivera E, Yi Huang. Z-source Inverter for Motor Drives. IEEE Transactions on Power Electronics. 2005 Jul; 20(4):857–63.
- Gajanayake CJ, Lin LF, Hoay G, Lam SP, Kian SL. Extended Boost Z-source Inverters. IEEE Transactions on Power Electronics. 2010 Oct; 25(10):2642–52.
- Anderson J, Peng F. Four Quasi-Z-Source Inverters. Power Electronics Specialists Conference. 2008 Jun; 2743–49.

- Wei Qian, Fang-Zheng Peng, Honnyong Cha. Trans-Z-Source Inverters. IEEE Transactions on Power Electronics. 2011 Dec; 26(12): 3453–63.
- Abdel R0, Orabi M, Abdelmarim E. Switched Inductor Boost Converter for PV Applications. Applied Power Electronics Conference and Exposition, 2012, p. 2100–06.
- Zhu M, Yu K, Luo FL. Switched Inductor Z-source Inverter, IEEE Transactions on Power Electronics. 2010 Aug; 25(8):2150–58.
- Minh-Khai Nguyen, Young-cheol Lim, Geum-Bae Cho. Switched Inductor Quasi-Z-Source Inverter, IEEE Transactions on Power Electronics. 2011 Nov; 26(11):3183–91.
- 12. Rodriguez J, Lai J.S, Peng F. Z. Multilevel Inverters: A Survey of Topologies, Controls, and Applications. IEEE Trans. Ind. Electron. 2002 Aug; 49(4):724–38.
- Rodriguez J, Bernet S, Wu B, Pontt JO, Kouro S. Multilevel Voltage-Source-Converter Topologies for Industrial Medium-Voltage Drives. IEEE Trans. Ind. Electron. 2007 Dec; 54(6):2930–45.

- Miao Chang-xin, Shi Li-ping, Wang Tai-xu, Cui Chengbao. Flying Capacitor Multilevel Inverters with Novel PWM Method, Procedia Earth and Planetary Science. 2009 Sep; 1(1):1554–60.
- 15. Kang DW, Lee BK, Jeon JH, Kim TJ, Hyun DS. A Symmetric Carrier Technique of CRPWM for Voltage Balance Method of Flying Capacitor Multilevel Inverter. IEEE Trans. Ind. Electron. 2005 Jun; 52(3):879–88.
- 16. Mosazade SY, Fathi SH, Radmanesh H. An Overview of High Frequency Switching Patterns of Cascaded Multilevel Inverters Suitable for PV Applications and Proposing a Modified Method, Indian Journal of Science and Technology. 2014 Jan; 7(9):33–36.
- Yushan Liu, Baoming Ge, Abu-Rub H, Peng FZ. An Effective Control Method for Quasi-Z-Source Cascade Multilevel Inverter-Based Grid-Tie Single-Phase Photovoltaic Power System, IEEE Transactions on Industrial Informatics. 2014 Feb; 10(1):399–407.