Study of Quasi-Z-Source CHB Multilevel Inverter with Switched-Inductor

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Abstract—This paper presents a new Switched-Inductor based Quasi-Z-Source Cascaded H-Bridge Multilevel Inverter (SL-qZS-CHB-MLI) with increased boost voltage applicable to PV power system. Each unit of the proposed SL-qZS-CHB-MLI is comprised of a Quasi-Z-Source (qZS) network with switched-inductor cell, and a full H-Bridge cell. The switched-inductor cell contains three diodes and two inductors. The qZS network enables the operation of shoot-through state control to provide boosted output voltage. The presence of switched-inductor increases the boost gain for the same shoot through duty ratio as compared with qZS-CHB-MLI. The performance analysis of the proposed topology in terms of THD for various output voltage levels under simple boost control with multicarrier PWM technique is presented with the simulated results using MATLAB. The simulation results obtained from the proposed topology provides extended boost output voltage with reduced THD.

Index Terms— Quasi -Z-Source, Switched-inductor, CHB-Multilevel Inverter, Simple boost control.

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1 INTRODUCTION

IN recent days, multilevel inverters are well-liked power-conversion systems for high-power applications requiring good quality output with low voltage stress [1]. The CHB inverter synthesizes output voltage with reduced THD using several dc voltage sources from renewable energy sources such as PV panel, windmill [2]. The CHB inverter has reduced number of switching components in its configuration as compared with Diode clamped and Capacitor clamped multilevel inverters for a given number of levels [3], [4]. Impedance-source (Z-source) networks are extensively used to provide boost ability [5-10]. The quasi-Z Source (q-ZS) network is the first improvement of Z Source network in terms of reliability. The ZSI and q-ZSI has tremendous applications in grid connected renewable energy sources. The q-ZSI uses the impedance network between DC source and the CHB inverter to attain buck-boost operation. This combination enables voltage boost and power conversion simultaneously in a single stage by utilizing shoot through states, thus increasing the reliability. A second improvement of the Z source network is the switched-inductor quasi-Z-source inverter (SL-QZSI), producing a high boost factor [11], [12]. The SL-ZSI overcomes the boost limitations of the conventional ZSI with size reduction and high power density [8], [13]. Also, the limitations allied with the ZSI such as high voltage stress on capacitors, discontinuous input current, and no common ground point between the CHB inverter and dc-source can be tackled with the development of the SL-qZSI inverters.

The switched-inductor increases the boost gain for the same shoot through duty ratio as compared with the ZSI and q-ZSI.

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The switched-inductor enables the operation of the proposed topology at higher modulation index, thus reducing the stress over the switching components. This paper presents a comparative analysis on the performance of SL-qZS-CHB-MLI with seven, nine and eleven level output voltages, accomplishing outstanding performance with combined advantages of the switched-inductor, qZS network and the H-Bridge cell. The SL-qZS-CHB-MLI is reliable, and has lower THD, higher efficiency and higher voltage boosting capability as compared with traditional inverters. The performance analysis of the SL-qZS-CHB-MLI in terms of the THD for different output voltage levels is presented with the simulated results using MATLAB. The simulation result reveals reduced THD for the eleven level output voltage obtained from the SL-qZS-CHB-MLI.

The SL-qZS-CHB-MLI topology is explained in section II. The PWM control of the proposed SL-qZS-CHB-MLI is given in section III. The simulation results are presented in section IV, which depicts various output voltages with THD. Finally the conclusion is given in section V.

2 SWITCHED-INDUCTOR BASED QUASI-Z- SOURCE CHB MULTILEVEL INVERTER

The proposed SL-qZS-CHB-MLI for generating 7-level output voltage is as shown in Fig.1. Here, the single unit of the proposed topology is considered for explaining the principle of operation. Each unit of the proposed topology consists of a SL-qZS network with switched-inductor cells, and an H-bridge inverter cell. The SL-qZS network is formed with two switched-inductor cells. Each switched-inductor cell consists of three diodes and two inductors. The SL-qZS network provides the common ground point with the CHB inverter. The inductors enable the proposed topology to draw the continuous current from the dc source. Also, the switched-inductor cells extend the voltage boosting capability of the proposed topology.

The operation of the proposed topology can be explained in two states such as shoot-through and non-shoot-through states. Fig.2 and Fig.3 depicts equivalent circuit of the non-shoot-through state and the shoot-through state of the proposed topology, respectively. During the non-shoot-through state, the diodes D_{in}, D_5 and D_6 are forward biased, and the diodes D_1, D_2, D_3 and D_4 are reverse biased. The pair of inductors L_1 and L_3 in first switched-inductor cell is connected in series, and also the pair of inductors L_2 and L_4 in second switched-inductor cell is connected in series. During this state, the capacitors C_1 and C_2 are charged, and the energy is transferred from the dc voltage sources to the main circuit through the inductors L_1, L_2, L_3 and L_4.

Fig. 1. Proposed 7-Level SL-qZS-CHB-MLI.

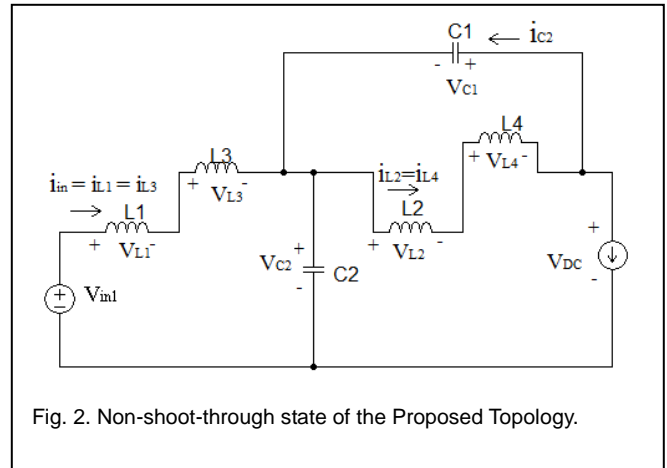average value of the voltage across capacitor C_1 is given in (1)

Fig. 2. Non-shoot-through state of the Proposed Topology.

$$V_{C1} = \frac{2D_{sh}}{1-3D_{sh}} V_{in} \qquad (1)$$

The average value of the voltage across capacitor C_2 is

$$V_{C2} = \frac{1-D_{sh}}{1-3D_{sh}} V_{in} \qquad (2)$$

The average value of DC link voltage is

$$V_{DC} = V_{C1} + V_{C2} = \frac{1+D_{sh}}{1-3D_{sh}} V_{in} = B V_{in} \qquad (3)$$

The average value of AC output voltage is

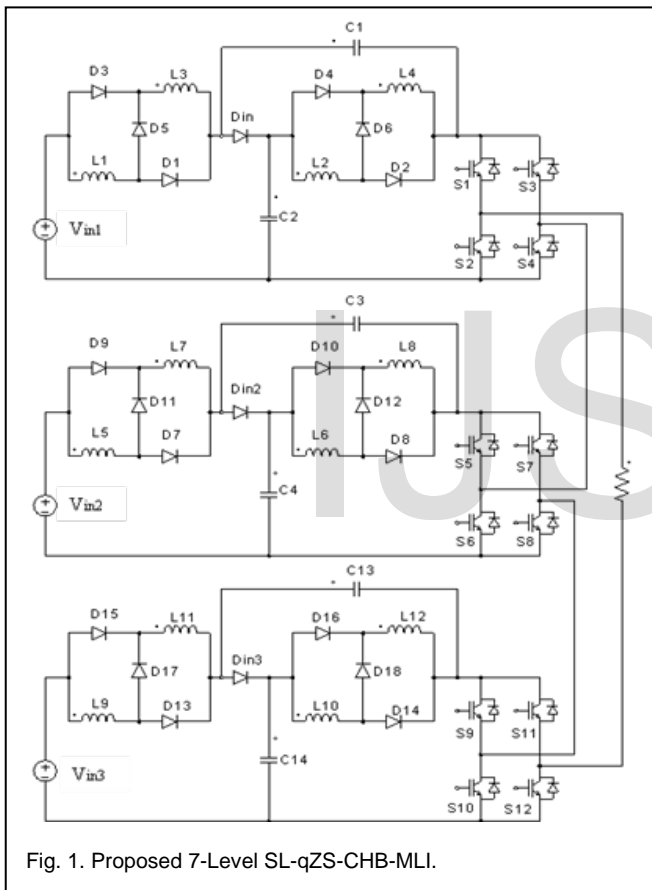$$V_o = MB\frac{V_{dc}}{2} \qquad (4)$$

During the shoot-through states, the H-bridge inverter cell is shorted by turning on both the upper and lower power switches in the same phase leg. During this state, the diodes D_{in}, D_5 and D_6 are reverse biased, and the diodes D_1, D_2, D_3 and D_4 are forward biased. The pair of inductors L_1 and L_3 in the first switched-inductor cell is connected in parallel, and the pair of inductors L_2 and L_4 in the second switched-inductor cell is connected in parallel.

The capacitors C_1 and C_2 are discharged, and the inductors L_1, L_2, L_3 and L_4 store the energy. The equations governing the operation of the proposed topology are given below. The
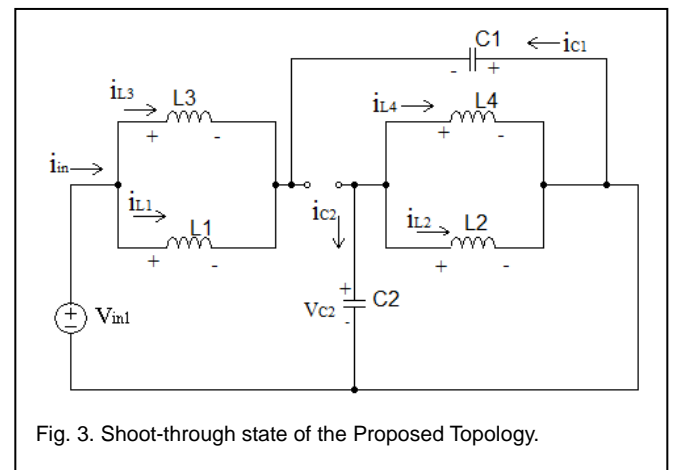

Fig. 3. Shoot-through state of the Proposed Topology.

3 PWM CONTROL OF THE PROPOSED SL-QZS-CHB-MLI

In this paper, the switching signals for the proposed topology are generated by phase disposition pulse width modulation (PD-PWM) technique [14], [15]. In PD-PWM, the triangular carriers are in phase with each other. Here, all the triangular carriers have same frequency f_c and same amplitude A_c. These carriers are placed in such a way that the areas they cover are contiguous. In this technique, harmonic energy is focused at a carrier frequency without emerging to the output voltage. The reference signal with an amplitude A_m and frequency f_m is compared with each of the triangular carrier signals to generate gate pulses. The modulating signal frequency is taken as 50 Hz. Shoot-through states are required for perfect operation and control of the proposed topology. The shoot-through states are introduced in the generated pulses from PD-PWM technique by varying shoot-through duty cycle. These shoot-through states can be generated by simple, maximum and constant boost control methods [8], [16]. The shoot-through states enable buck, boost and extended boost operations of the proposed topology.

The boost factor of SL-qZS-CHB-MLI is shown in (7)

$$B = \frac{1 + D_{sh}}{1 - 3D_{sh}} \qquad (7)$$

Where, B is the boost factor and D_{sh} is the shoot through duty ratio. The proposed topology requires lower shoot-through duty ratio when compared with qZS-MLI for attaining the same boost gain. This advantage of the proposed topology facilitates the larger improvement in the output voltage.

From equation (5) and (7), we get the voltage gain G as given in (8)

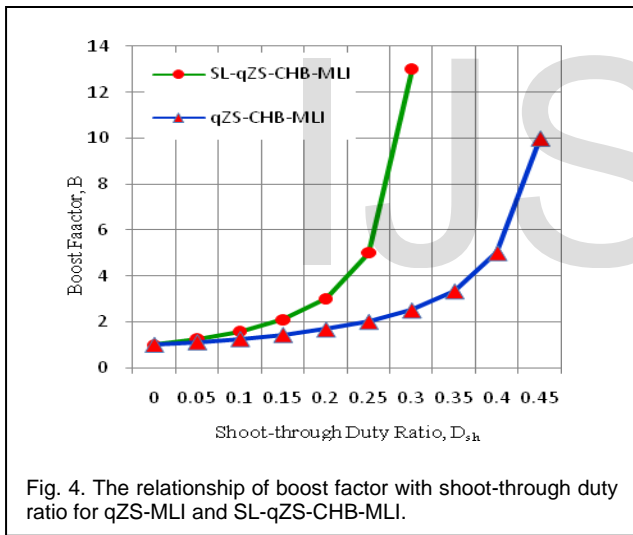$$G = \frac{1 - M}{3M - 2} \qquad (8)$$

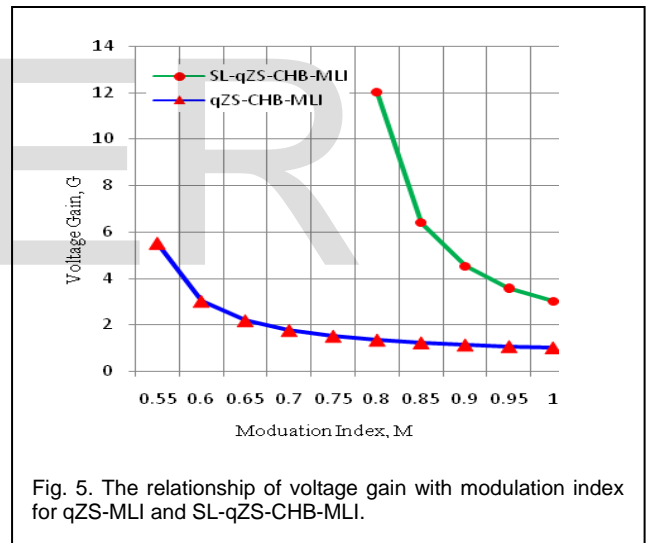Fig. 4. The relationship of boost factor with shoot-through duty ratio for qZS-MLI and SL-qZS-CHB-MLI.

Fig. 5. The relationship of voltage gain with modulation index for qZS-MLI and SL-qZS-CHB-MLI.

In this paper, the simple boost control method is applied for the performance analysis of the proposed topology. The simple boost control method employs a straight line, whose amplitude is equal to or greater than the peak value of the modulating signal in order to produce the shoot-through states. The shoot-through duty ratio D_{sh} can be modified as a constant value.

For this case, the shoot-through duty ratio is given in (5)

$$D_{sh} = \frac{T_{sh}}{T} = 1 - M \qquad (5)$$

where, the relationship between modulation index M and shoot-through duty ratio is given in (6)

$$M < 1 - D_{sh} \qquad (6)$$

Fig.5 shows the voltage gain versus the modulation index characteristics of the proposed topology, and it is observed from the plot that the voltage gain increases with a decrease in the modulation index. From the plot, it is depicted that the modulation index of the proposed topology is high for the same voltage conversion ratio when compared to conventional qZS-MLI [8], [9].

4 SIMULATION RESULTS

The proposed configuration of SL-qZS-CHB-MLI is simulated in Matlab. To analyze the performance of the proposed topology, the following simulation parameters are considered for each unit $L_1=L_2=L_3=L_4=2$mH, $C_1=C_2=2000$μF, ratio D=0.15, B=2, R=10Ω and the input voltage V_{in} =100V for each unit.

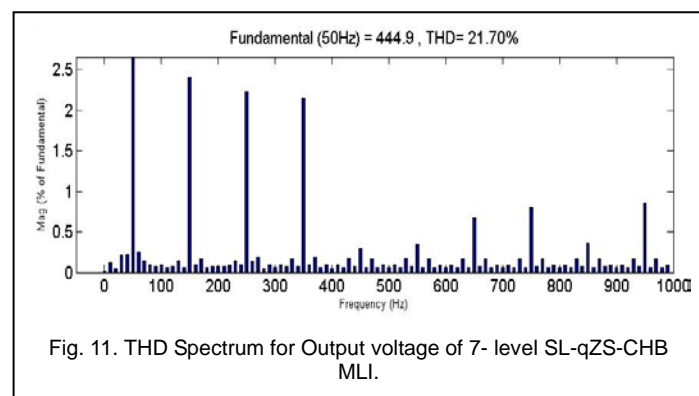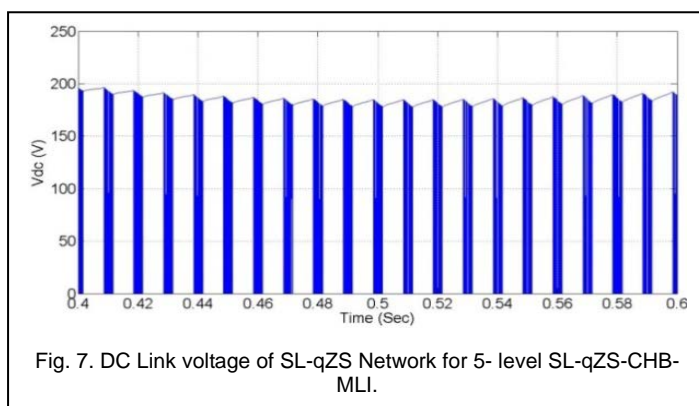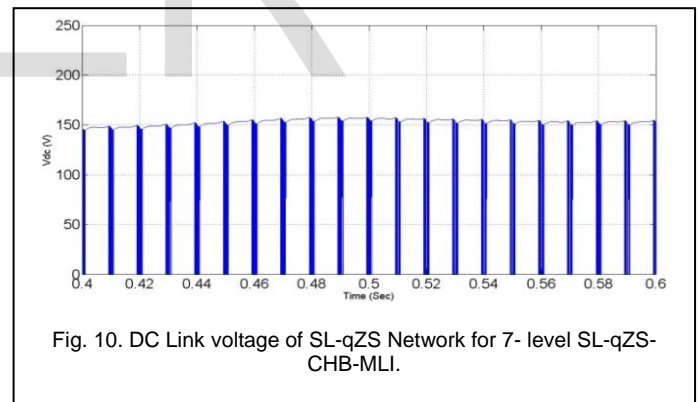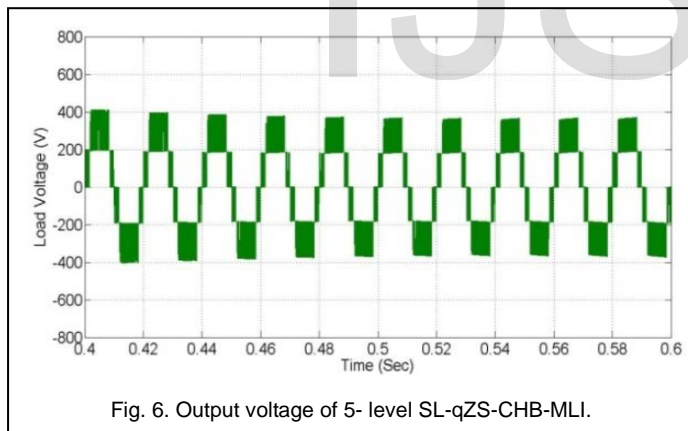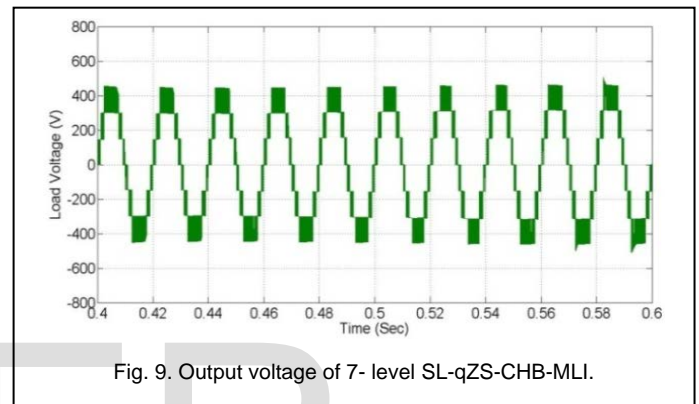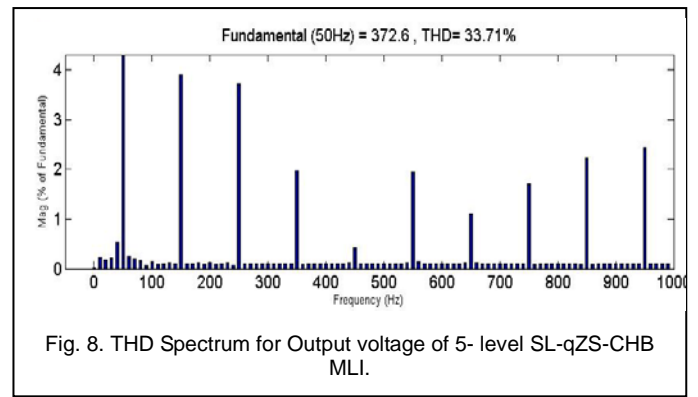The comparison of the RMS output voltage and THD is shown

in Table.1 for various levels. The output voltages for 5-level, 7-level, 9-level and 11-level of SL-qZS-CHB-MLI configurations are depicted in Fig.6, Fig.9, Fig.12 and Fig.15, respectively.

Table 1
Fundamental Value of Output Voltage and THD

No. of Output Voltage Levels	Input Voltage (Vin)	RMS Output Voltage (V)	THD in %
5	200	372.6	33.7
7	300	444.9	21.7
9	400	540.3	15.3
11	500	610.8	13.0

The THD spectrum from FFT analysis for the output voltages of 5-level, 7-level, 9-level and 11-level of SL-qZS-CHB-MLI are presented in Fig.8, Fig.11, Fig.14 and Fig.17, respectively. The DC link voltages for the 5-level, 7-level, 9-level and 11-level SL-qZS-CHB-MLI are provided in Fig.7, Fig.10, Fig.13 and Fig.16, respectively. As depicted in Fig.15, the RMS output voltage of the proposed topology is boosted to 610.8V when the input dc voltage is 500V. Similarly, the improvement in the output voltages for various level SL-qZS-CHB-MLI configurations has been consolidated and presented in Table.1.
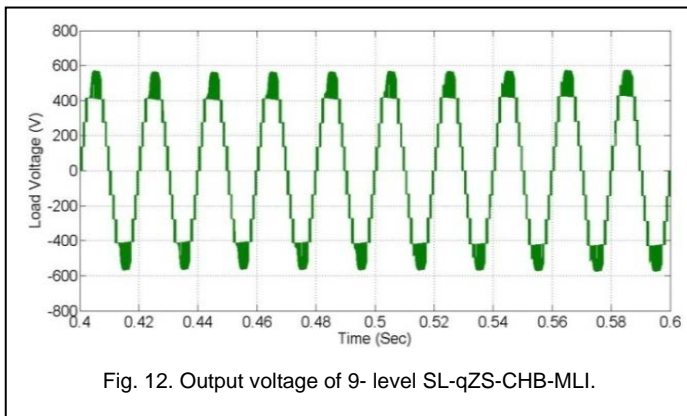

Fig. 8. THD Spectrum for Output voltage of 5- level SL-qZS-CHB MLI.

Fig. 9. Output voltage of 7- level SL-qZS-CHB-MLI.
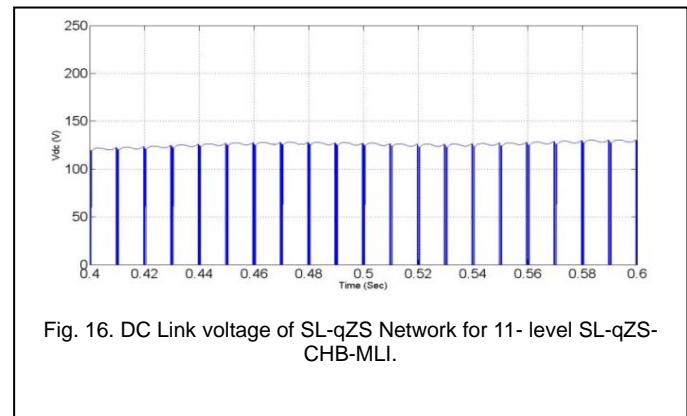

Fig. 6. Output voltage of 5- level SL-qZS-CHB-MLI.

Fig. 10. DC Link voltage of SL-qZS Network for 7- level SL-qZS-CHB-MLI.

Fig. 7. DC Link voltage of SL-qZS Network for 5- level SL-qZS-CHB-MLI.

Fig. 11. THD Spectrum for Output voltage of 7- level SL-qZS-CHB-MLI.

Fig. 12. Output voltage of 9- level SL-qZS-CHB-MLI.

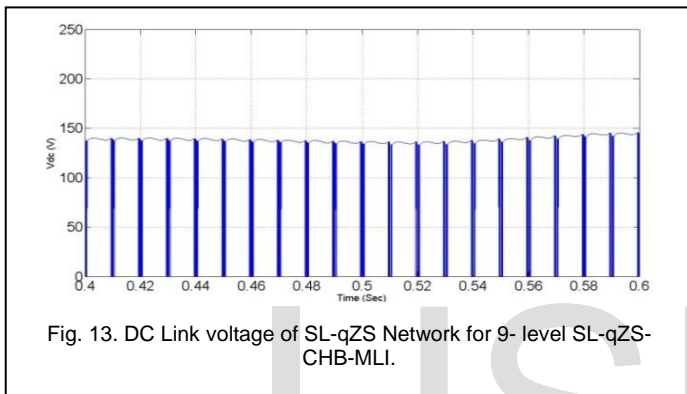Fig. 16. DC Link voltage of SL-qZS Network for 11- level SL-qZS-CHB-MLI.

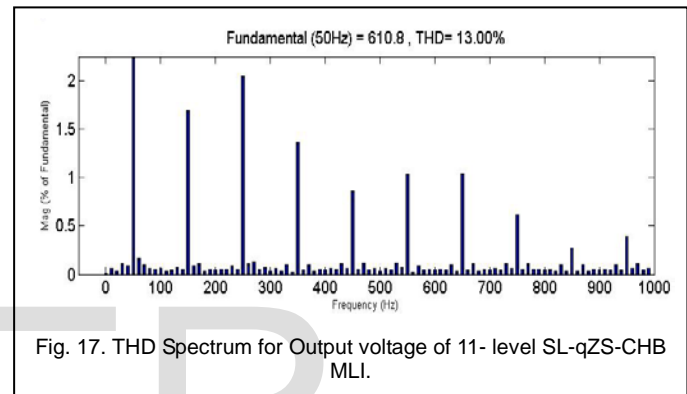Fig. 13. DC Link voltage of SL-qZS Network for 9- level SL-qZS-CHB-MLI.

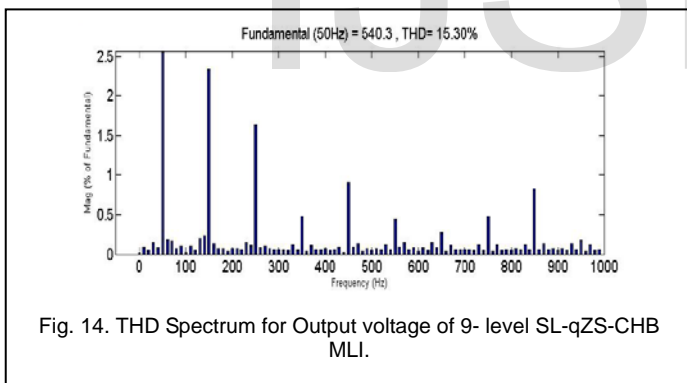Fig. 17. THD Spectrum for Output voltage of 11- level SL-qZS-CHB MLI.

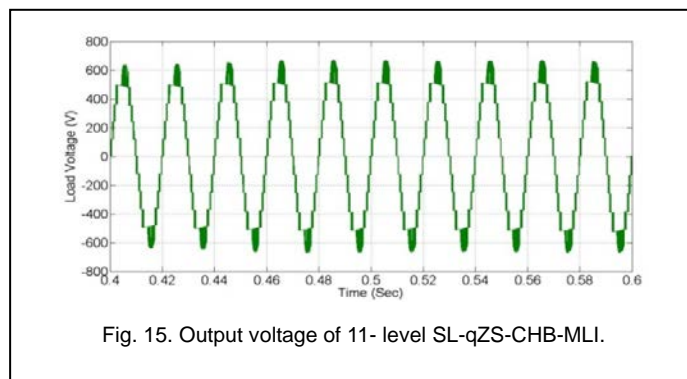Fig. 14. THD Spectrum for Output voltage of 9- level SL-qZS-CHB MLI.

5 CONCLUSION

In this paper, a new SL-qZS-CHB-MLI with extended boost capability is proposed. The performance analysis of the proposed topology in terms of THD for various output voltage levels are presented with the simulated results using MATLAB. The result ensures reduced THD for the new proposed topology output voltage with high boost gain.

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