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A Review Of Extended Boost Quasi Z-Source Inverter Topologies For PV Applications

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Abstract

The quasi Z-source Inverter (q-ZSI) is an effective topology that provides a single stage conversion for PV systems by providing low component ratings, reduced component count and simplified control strategies. It is a very attractive topology because of its unique capability of voltage boost and buck functions in a single stage. But its voltage boost property could be a limiting feature in some applications where very high input voltage gain is required. The input voltage gain could be extended by the implementation of the extended boost quasi-impedance network. This paper discusses four novel extended boost quasi-ZSI. Theoretical analysis of voltage boost, control methods and a system design guide for the four topologies of extended boost q-ZSI are investigated in this paper. Steady state analysis of topologies operating in continuous conduction mode is presented. Performances of topologies were compared. A simulation model of the extended boost q-ZSI has been built in MATLAB/SIMULINK for all the topologies.

Keywords-Boost Factor, Quasi Z source inverter (q-ZSI), Modified Diode Assisted (MDAEB), Modified Capacitor Assisted(MCAEB), Simple Boost, Shoot-through, THD, Voltage Gain, Voltage Stress.

1.INTRODUCTION

Photovoltaic (PV) power generation systems have always been considered as an alternative energy source that can lighten the rapid consumption of fossil fuels.. The quasi Z source inverter is a new promising power conversion technology perfectly suitable for interfacing of renewable energy sources [1]. It has single-stage boost-buck converter approach for the different renewable power applications. The q-ZSI has several advantages including lower component ratings, reduced source stress, reduced component count and simplified control strategies. It can buck and boost DC link voltage in a single stage without additional switches. The impedance network of q-ZSI couples the source and the inverter to achieve voltage boost and inversion in a single stage. But the efficiency and voltage gain of the q-ZSI are limited and comparable with the conventional system of a voltage source inverter with the auxiliary step-up DC/DC converter in the input stage[2]. The concept of extending the quasi ZSI gain without increasing the number of active switches was recently proposed [3] [4]

These new converter topologies are known as extended boost q-ZSI and could be generally classified as capacitor assisted and diode assisted topologies [5].

The PWM strategy like simple boost control is used for the proposed topologies of extended boost quasi ZSI. In the simple boost control method, a new carrier based pulse width modulation strategy for the extended boost q-ZSI which gives a significantly high voltage gain compared to the traditional PWM techniques is implemented [6].

In this paper four different topologies of Extended Boost q-ZSI with continuous input current will be presented, analyzed and compared for the simple boost control technique. The performance of the proposed topologies has been analyzed for simple boost modulation strategy to identify the preferred topology for the PV applications.

2.CIRCUIT ANALYSIS OF THE EXTENDED BOOST q-ZSI

The proposed topologies of extended boost q-ZSI are diode assisted (DAEB), modified diode assisted (MDAEB), capacitor assisted (CAEB) and modified capacitor assisted (MCAEB). All the topologies have a common property of the continuous input current conduction. The input inductor *L1* buffers the source current. It means that during the continuous conduction mode the input current never drops to zero. Another property of the presented topologies is their expandability. The higher stage boost circuit can be designed[4].

The topologies of DAEB & MDAEB q-ZSI are presented in Fig.1 and 2. The basic topology of the DAEB q-ZSI could be derived by the adding of one capacitor (*C3*), one inductor (L3) and two diodes (D2 and D3) to the traditional q-ZSI with continuous input current. The modified topology of a diode assisted extended boost q-ZSI (MDAEB q-ZSI) could be derived from the DAEB q-ZSI simply by the changing of the connection points of the capacitor C3, as shown in Fig. 2. The topologies of CAEB & MCAEB q-ZSI are presented in Fig.3 and 4. The basic topology of the CAEB q-ZSI could be derived by the adding of one diode (D2), one inductor (L3) and two capacitors (C3 and C4) to the traditional q-ZSI [6-8].The modified topology of a capacitor assisted extended boost q-ZSI (MCAEB q-ZSI) could be derived from the CAEB q-ZSI by the changing of the connection points of the capacitor C2 and C3, as shown in Fig. 4.

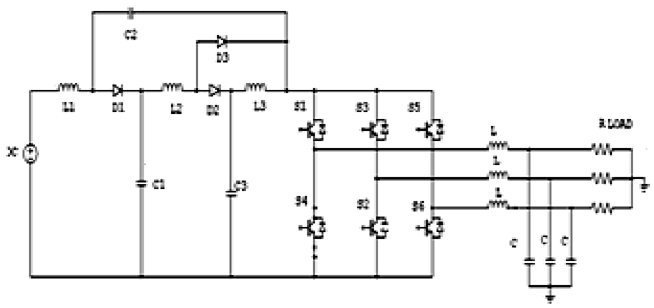

Fig.1.Basic Diode Assisted q-ZSI

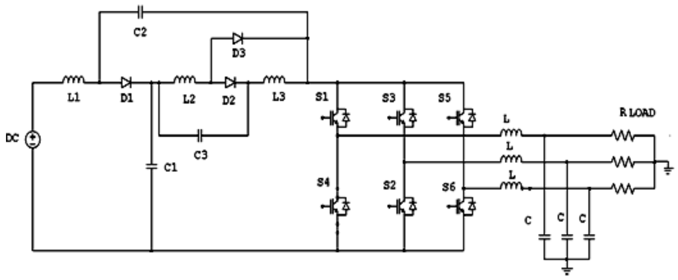

Fig.2. Modified Diode Assisted Extended Boost q-ZSI

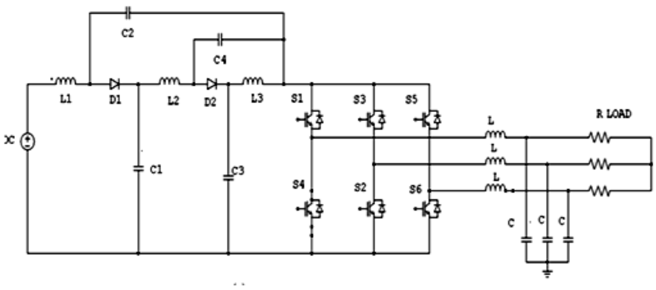

Fig.3. Capacitor Assisted Extended Boost q-ZSI

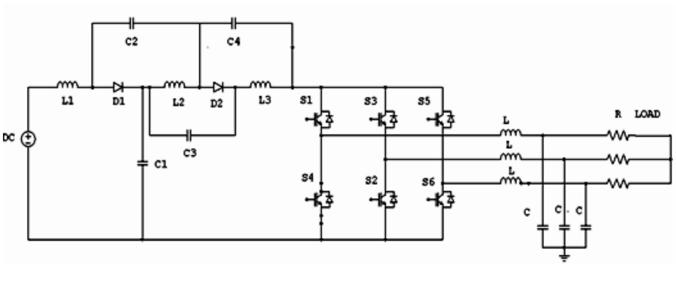

Fig.4. Modified Capacitor Assisted Extended Boost q-ZSI

2.1. Steady State Analysis of DAEB q-ZSI

The extended boost q-ZSI has two types of operational states at the dc side, the active state or non-shoot-through states (i.e. the six active states and two conventional zero states of the traditional VSI) and the shoot-through state. [7-9].

Let

T = Operating period of the q-ZSI

TA = Active state

TS = Shoot through state

DA = the duty cycles of an active state

DS = the duty cycles of shoot-through state

$$T = TA + Ts \quad (1)$$

$$DA + Ds = 1 \quad (2)$$

Fig.5 and 6, shows the equivalent circuits of the DAEB q-ZSI for the shoot-through and the active states.

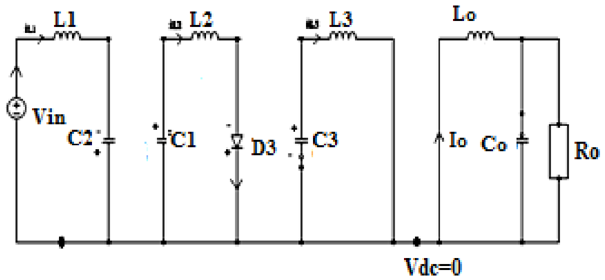

Fig.5.Equivalent Circuit of DAEB during shoot through state

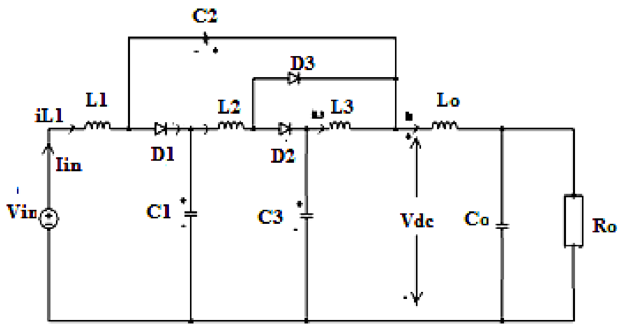

Fig.6.Equivalent Circuit of DAEB during active state

2.1.1 Shoot Through Mode

From the equivalent circuit of the DAEB q-ZSI during the shoot-through state (Fig. 5), the voltage of the inductors can be represented as

$$VL1 = Vin + Vc2 \quad (3)$$

$$VL2 = Vc1 \quad (4)$$

$$VL3 = Vc3 \quad (5)$$

2.1.2 Active Mode

During the active state (Fig. 6) the voltage of the inductors can be represented as

$$VL1 = Vin - VC1 \quad (6)$$

$$VL2 = VC1 - VC3 \quad (7)$$

$$VL3 = -VC3 - VC1 - VC2 \quad (8)$$

The voltages of the capacitors can be given as

$$Vc1 = Vin * \frac{(Ds^2 - 2Ds + 1)}{(Ds2 - 3Ds + 1)} \quad (9)$$

$$Vc2 = Vin * \frac{2Ds - Ds^2}{(Ds^2 - 3Ds + 1)} \quad (10)$$

$$Vc3 = Vin * \frac{1 - Ds}{(Ds^2 - 3Ds + 1)} \quad (11)$$

The peak DC –link Voltage is

$$Vdc = Vc1 + Vc2$$

$$= Vin * \frac{1}{(Ds^2 - 3Ds + 1)} \quad (12)$$

The boost ratio of the input voltage is

$$B = \frac{Vdc}{Vin} = \frac{1}{(Ds2 - 3Ds + 1)} \quad (13)$$

2.2Steady State Analysis of Modified DAEB q-ZSI

Fig.7 and 8. shows the equivalent circuits of the modified DAEB q-ZSI for the shoot-through and the active states.

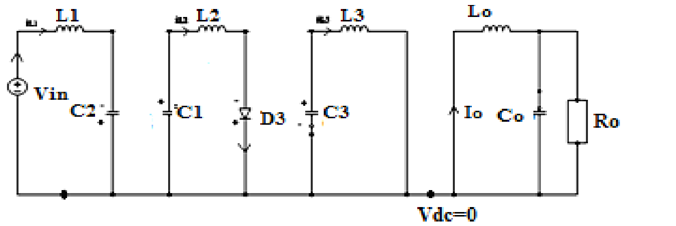

Fig.7.Equivalent circuit of MDAEB (shoot-through state)

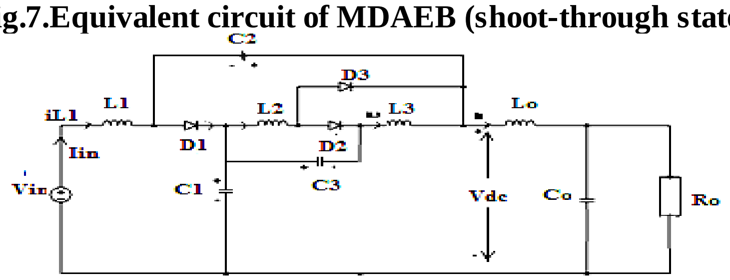

Fig.8.Equivalent circuit of MDAEB q-ZSI (active state).

2.2.1 Shoot Through Mode

From the equivalent circuit of the MDAEB q-ZSI during the shoot-through state (Fig.7.), the voltage of the inductors can be represented as

$$VL1 = Vin + Vc2 \quad (14)$$

$$VL2 = Vc1 \quad (15)$$

$$VL3 = Vc3 + Vc1 \quad (16)$$

2.2.2 Active Mode

During the active state (Fig. 8.) the voltage of the inductors can be represented as

$$VL1 = Vin - VC1 \quad (17)$$

$$VL2 = -VC3 \quad (18)$$

$$VL3 = VC3 - VC2 \quad (19)$$

The voltages of the capacitors can be given as

$$Vc1 = Vin * \frac{(Ds^2 - 2Ds + 1)}{(Ds2 - 3Ds + 1)} \quad (20)$$

$$Vc2 = Vin * \frac{2Ds - Ds^2}{(Ds^2 - 3Ds + 1)} \quad (21)$$

$$Vc3 = Vin * \frac{Ds - Ds^2}{(Ds^2 - 3Ds + 1)} \quad (22)$$

The peak DC –link Voltage is

$$Vdc = Vc1 + Vc2$$

$$= Vin * \frac{1}{(Ds^2 - 3Ds + 1)} \quad (23)$$

The boost ratio of the input voltage is

$$B = \frac{Vdc}{Vin} = \frac{1}{(Ds2 - 3Ds + 1)} \quad (24)$$

From the steady state analysis of the DAEB and MDAEB q-ZSI, both the topologies have the same boost voltage with the same boost factor except the operating voltage Vc3 of MDAEB q-ZSI is reduced when compared with the DAEB q-ZSI.

2.3. Steady State Analysis of CAEB q-ZSI

Fig.9 and 10, shows the equivalent circuits of the CAEB q-ZSI operating in the CCM for the shoot-through and the active states.

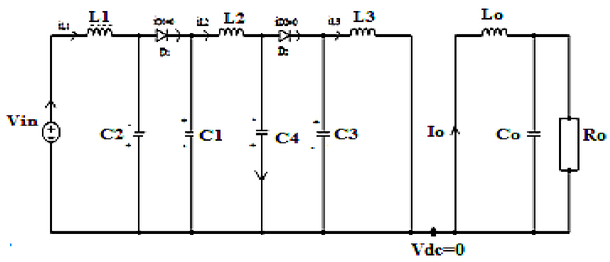

Fig.9.Equivalent circuit of CAEB q-ZSI-shoot-through state

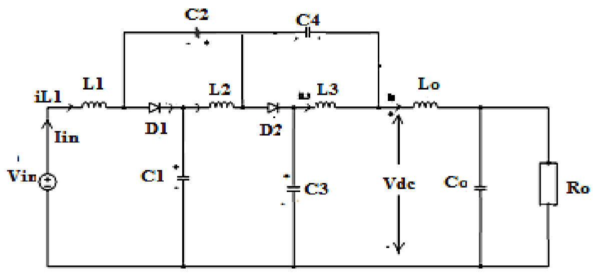

Fig.10.Equivalent circuits of the CAEB q-ZSI-active state

2.3.1 Shoot Through Mode

From the equivalent circuit of the CAEB q-ZSI during the shoot-through state (Fig.9.), the voltage of the inductors can be represented as

$$VL1 = Vin + VC2 \quad (25)$$

$$VL2 = VC1 \quad (26)$$

$$VL3 = Vc3 \quad (27)$$

2.3.2 Active Mode

During the active state(Fig.3b) the voltage of the inductors can be represented as

$$VL1 = Vin - VC1 \quad (28)$$

$$VL2 = VC1 - VC3 \quad (29)$$

$$VL3 = -VC4 \quad (30)$$

The voltages of the capacitors can be given as

$$Vc1 = \frac{Vin * 1 - 2Ds}{(1 - 3Ds)} \quad (31)$$

$$Vc2 = \frac{Vin * 2Ds}{(1 - 3Ds)} \quad (32)$$

$$Vc3 = Vc4 = \frac{Vin * Ds}{(1 - 3Ds)} \quad (33)$$

The peak DC –link Voltage is

$$Vdc = Vc1 + Vc2 = Vc1 + Vc4 = Vin * \frac{1}{(1-3Ds)} \quad (34)$$

The boost ratio of the input voltage is

$$B = \frac{1}{(1-3Ds)} \quad (35)$$

2.4. Steady State Analysis of MCAEB q-ZSI

Fig.11 and 12, shows the equivalent circuits of the MCAEB q-ZSI operating in the CCM for the shoot-through and the active states.

2.4.1 Shoot Through Mode

From the equivalent circuit of the CAEB q-ZSI during the shoot-through state (Fig.9.), the voltage of the inductors can be represented as

$$VL1 = Vin + VC2 + VC4 \quad (36)$$

$$VL2 = VC1 + VC2 \quad (37)$$

$$VL3 = Vc3 + VC1 \quad (38)$$

2.4.2 Active Mode

During the active state(Fig.3b) the voltage of the inductors can be represented as

$$VL1 = Vin - VC1 \quad (39)$$

$$VL2 = -VC3 = -VC2 \quad (40)$$

$$VL3 = -VC4 \quad (41)$$

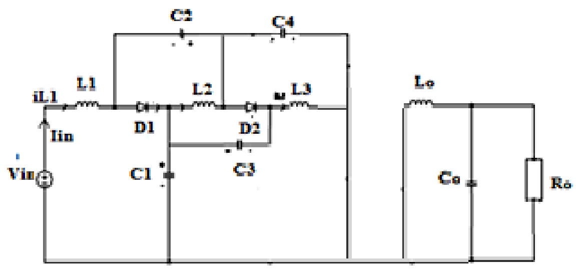

Fig.11.Equivalent circuit of MCAEB q-ZSI during the shoot-through state

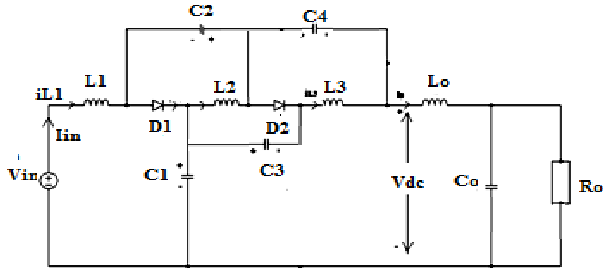

Fig.12.Equivalent circuit of the MCAEB q-ZSI during the active state

The peak DC –link Voltage is

$$Vdc = Vc1 + Vc2 + Vc4 = Vin * \frac{1}{(1 - 3Ds)} \quad (42)$$

The boost ratio of the input voltage is

$$B = \frac{1}{(1 - 3Ds)} \quad (43)$$

From the steady state analysis of the CAEB and MCAEB q-ZSI, both the topologies have the same boost voltage with the same boost factor except the operating voltage Vc3 of MCAEB q-ZSI is reduced when compared with the CAEB q-ZSI.

3. SIMULATION RESULTS

Fig.13.shows the Matlab/ Simulink circuit of PV connected extended boost q-ZSI using simple boost modulation technique with boost factor B=2.

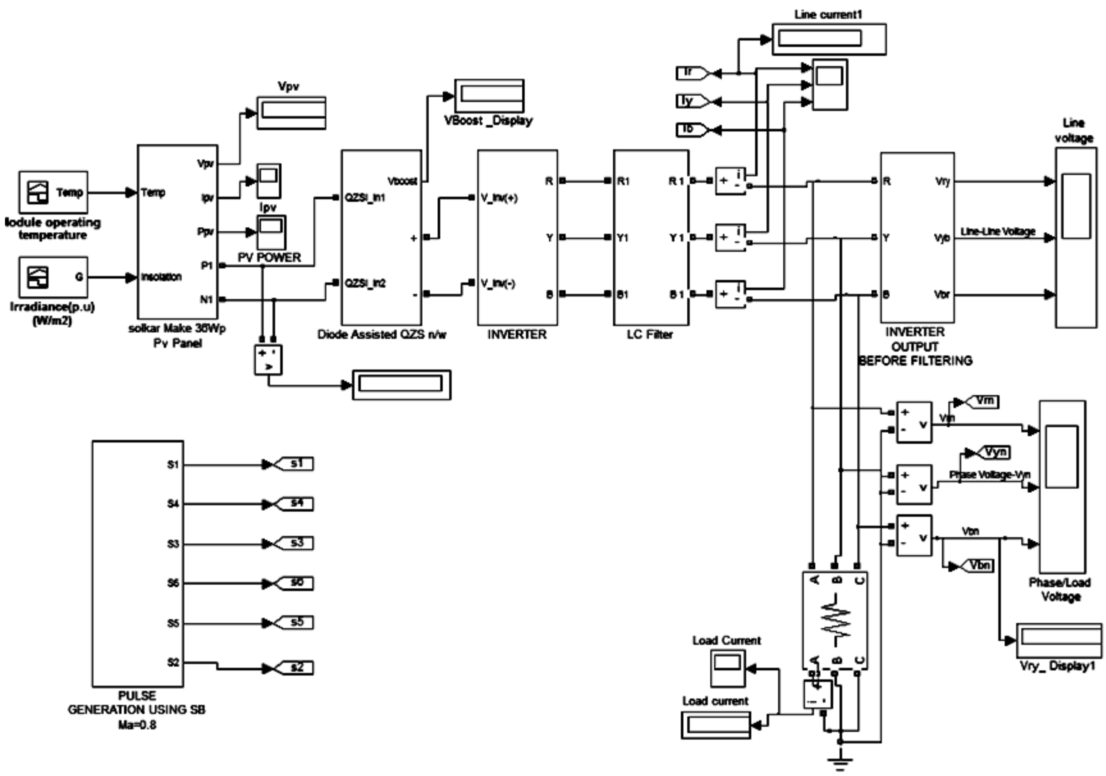

Fig.13.Matlab/ Simulink Circuit of PV connected extended boost q-ZSI.

TABLE:I shows the simulation parameters for simple boost modulation technique.

Input Voltage Vin	21V
Inductors L1, L2, L3 & r L	65µH, 0.005µH
Capacitors C1, C2, C3 & rC	185µF, 0.0005µF
Resistance load Rload	25 Ω
Boost Factor B	2
Shoot through duty cycle Ds	0.178
Modulation Index	0.822
Switching frequency fs	10 kHz
Output Inverter Frequency	50 Hz
Filter Inductance	20mH
Filter Capacitance	220µF

3.1 Simulation results of DAEB & MDAEB q-ZSI

The simulation results of the output line voltage, load voltage waveforms of DAEB & MDAEB q-ZSI for the simple boost modulation technique without filter are shown in Figs.14, 15. and the load voltage with filter is shown in Figs.16.

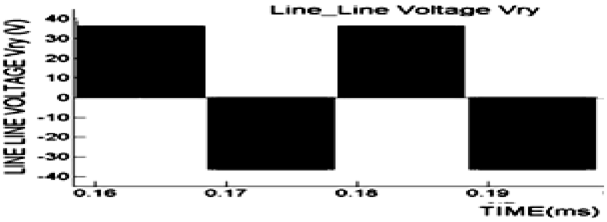

Fig.14.Line voltage waveform for DAEB & MDAEB q-ZSI

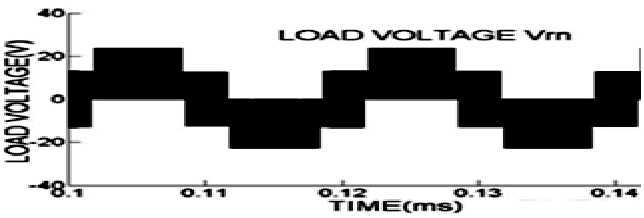

Fig.15.Load Voltage Waveform for MDAEB q-ZSI

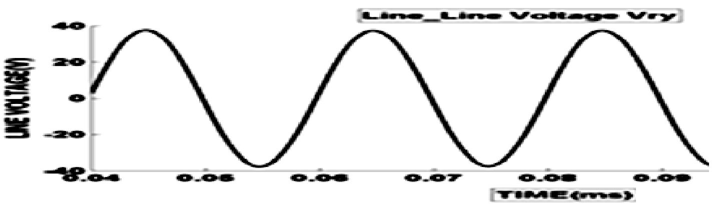

Fig.16.Filtered Output Line voltage waveform for MDAEB

From the simulation results of DAEB and MDAEB q-ZSI, both the topologies produce the same boost voltage of 39V for the boost factor of B=2.

The difference between the two topologies can be understood by comparing the operating voltages of the capacitors in the impedance network.

3.1.1 Comparison of the Operating Voltages of the Capacitors in DAEB and MDAEB q-ZSI

The average values of the capacitor voltages were calculated across the capacitors of the cascaded impedance network of DAEB and MDAEB q-ZSI. The theoretical and simulated results of the capacitor voltages for the proposed topologies are compared in Table II.

TABLE:II Theoretical and Simulated Results comparison of the average voltages of the capacitors in DAEB and MDAEB q-ZSI for B=2.

	Basic DAEB QZSI			MDAEB QZSI		
	Theoretical Values (V)		Simulation Results(V)	Theoretical Values (V)		Simulation Results(V))
V_{C1}	$V_{IN}*\frac{(Ds^2 2Ds+1)}{(Ds^2 3Ds+1)}$	28	26	$V_{IN}*\frac{(Ds^2 2Ds+1)}{(Ds^2 3Ds+1)}$	28	2 26
V_{C2}	$V_{IN}*\frac{2Ds-Ds^2}{(Ds^2 3Ds+1)}$	14	13	$V_{IN}*\frac{2Ds-Ds^2}{(Ds^2 3Ds+1)}$	14	13
V_{C3}	$V_{IN}*\frac{(1-D_S)}{(Ds^2-3Ds+1)}$	35	33	$V_{IN}*\frac{(D_S-Ds^2)}{(Ds^2-3Ds+1)}$	6	5

Table II shows that the operating voltage of the capacitor C3 of MDAEB q-ZSI was reduced when compared to the basic DAEB q-ZSI.

Fig.18.and Fig.19. it shows that the effect of modulation index on capacitor voltages of DAEB and MDAEB q-ZSI.

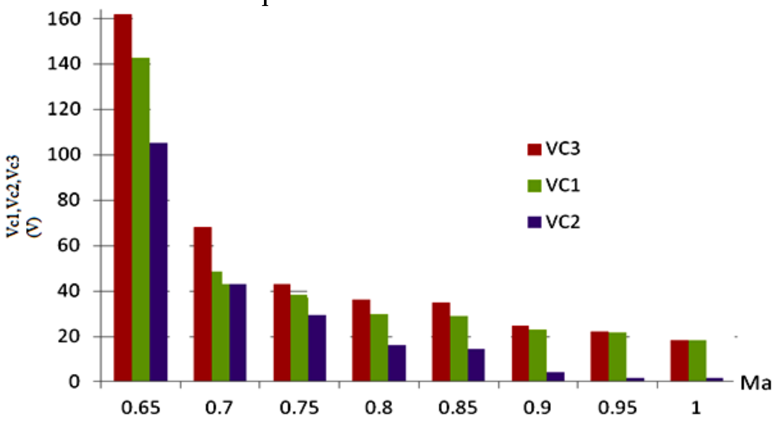

Fig.18.Effect of modulation index on Capacitor Voltage of DAEB q-ZSI.

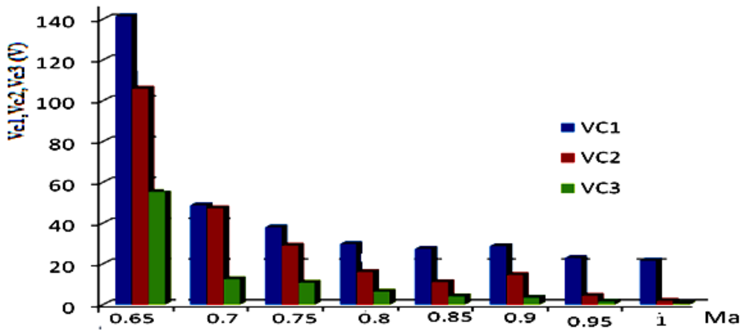

Fig.19.Effect of modulation index on Capacitor Voltage of MDAEB q-ZSI.

From the Fig.19.and Fig.20. it shows that the average value of voltage across the capacitor C3 of MDAEB q-ZSI was reduced with the increasing modulation index when compared to the DAEB q-ZSI.

3.2 Simulation results of CAEB & MCAEB q-ZSI

The simulation results of the output line voltage, load voltage waveforms of CAEB & MCAEB q-ZSI for the simple boost modulation technique without filter are shown in Figs.20, 21. and the load voltage with filter are shown in Figs.22.

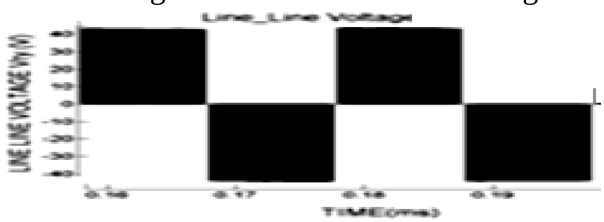

Fig.20.Line voltage waveform for CAEB & MCAEB q-ZSI

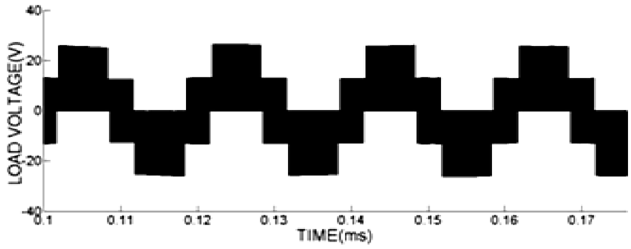

Fig.21.Load Voltage Waveform for CAEB & MCAEB q-ZSI

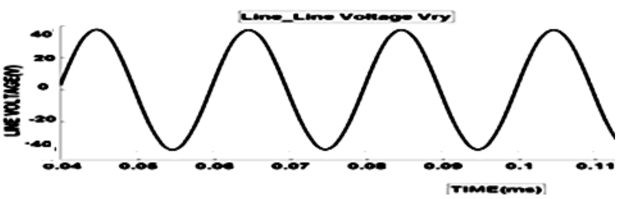

Fig.22.Filtered Output Line voltage waveform for CAEB & MCAEB q-ZSI.

From the simulation results of CAEB and MCAEB q-ZSI, both the topologies produce the same boost voltage of nearly 41V for the boost factor of B=2.

3.2.1 Comparison of the Operating Voltages of the Capacitors in CAEB and MCAEB q-ZSI

The average values of the capacitor voltages were calculated across capacitors of the cascaded impedance network of CAEB and MCAEB q-ZSI as shown in Fig.23 & 24.

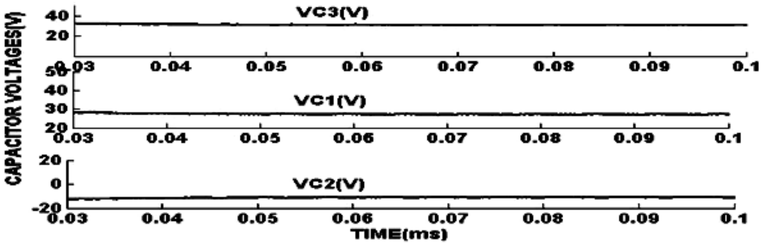

Fig.23.Capacitor Voltages: CAEB q-ZSI

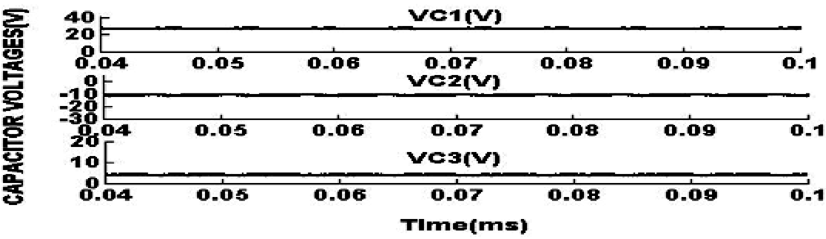

Fig.24.Capacitor Voltages: MCAEB q-ZSI

The theoretical and simulated results of the capacitor voltages for the proposed topologies are compared in Table III. for the simple boost modulation technique.

TABLE:III Theoretical and Simulated Results comparison of the average voltages of the capacitors in CAEB and MCAEB q-ZSI for B=2.

	Basic CAEB QZSI			MCAEB QZSI		
	Theoretical Values (V)	Simulation Results(V)		Theoretical Values (V)	Simulation Results(V)	
V_{C1}	V_{IN}*(1-2D_S)/ (1-3D_S)	28	26	V_{IN}*(1-2D_S) /(1-3D_S)	28	27.4
V_{C2}	V_{IN} * 2$D_{S/}$ (1-3D_S)	14	13.3	V_{IN} * D_{S} /(1-3D_S)	7	7.07
V_{C3}	V_{IN} * (1-D_S) /(1-3D_S)	35	33.5	V_{IN} * D_{S} /(1-3D_S)	7	7.07
V_{C4}	V_{IN} * $D_{S/}$ (1-3D_S)	7	7.23	V_{IN} * D_{S} /(1-3D_S)	7	7.22

From the Table III it shows that the operating voltage of the capacitor C3 of MCAEB q-ZSI was reduced when compared to the basic CAEB q-ZSI. It shows that by changing the interconnection points of the capacitors C2 and C3 the capacitor voltage of the capacitor C3 of MCAEB q-ZSI was reduced by more than five times as compared to the basic CAEB q-ZSI. It also shows that the voltages of the capacitors C2 and C4 are equalized to the same voltage.

4. PERFORMANCE PARAMETERS COMPARISON OF TOPOLOGIES OF EXTENDED BOOST Q-ZSI

Performance parameters of all the topologies of extended boost q-ZSI are analyzed to find the preferred topology for the PV applications. The boost factor, THD and the voltage gain of the proposed topologies are compared with the q-ZSI.

4.1 Boost Factor (B)

The boost factor is calculated for the simple boost modulation technique. In Fig.25, the boost factor B is compared with different values of modulation indices.

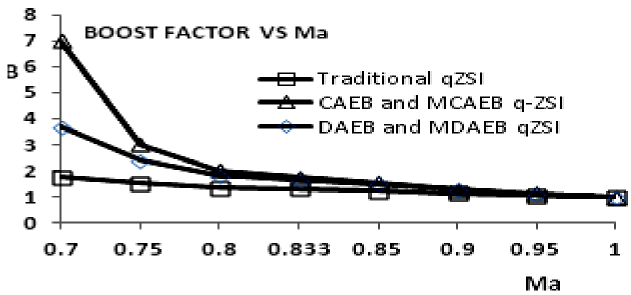

Fig.25. Boost Factor Comparison

From the Fig.25. it shows that the boost factor of CAEB & MCAEB topologies are high for the same value of the modulation indices when compared with the DAEB topologies.

4.2. Voltage Gain (G)

Voltage Gain, G is calculated for the simple boost modulation technique. In Fig.26. the voltage gain G is compared with different values of modulation indices for the simple boost modulation technique.

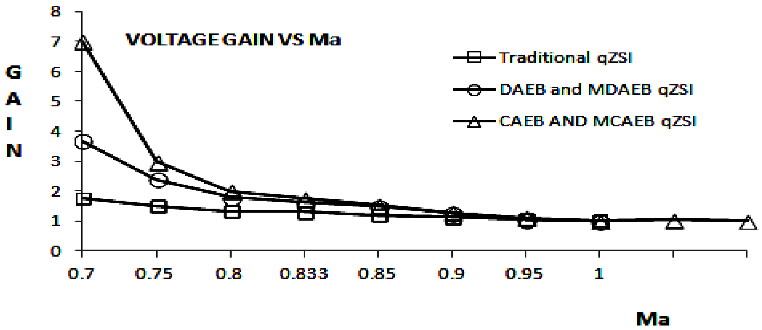

Fig.26. Voltage Gain Comparison

From the Fig.26.it is clear that the CAEB & MCAEB topologies have increased voltage gain for the same value of the modulation index(Ma).

4.3 Total Harmonic Distortion (THD)

Total Harmonic Distortion of MCAEB q-ZSI were analyzed for simple Boost modulation technique.THD is calculated for various modulation index values and the effect of the modulation indices on THD is shown in Fig.26.

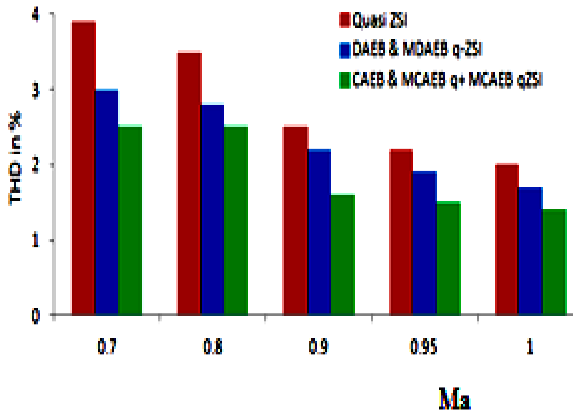

Fig.26. Effect of modulation index on THD

From the Fig.26., THD increase with the decrease in the modulation index and the MCAEB q-ZSI has reduced THD when compared to the quasi ZSI.

From the simulation results it is observed that the capacitor assisted extended boost topologies(CAEB & MCAEB) gives higher RMS value of the output voltage. From the performance measures the CAEB topologies have higher voltage gain, increased boost factor, reduced voltage stress and reduced THD when compared with the other topology of extended boost q-ZSI. Along with the above features, the MCAEB topology also provides reduced operating voltages of the capacitor C3 and also equalizes the capacitor voltage C2 and C4.So MCAEB q-ZSI is the preferred topology for the photovoltaic applications when compared to the other topologies of extended boost q-ZSI.

5. CONCLUSION

In this paper four types of extended boost q-ZSI topologies were proposed, discussed and compared for the simple boost modulation control strategy. A steady state analysis of topologies operating in the continuous conduction mode was performed. Theoretical study was validated by the simulated results. It was analyzed from the simulated results that the modified capacitor assisted topology provide high boost voltage, boost factor voltage gain, reduced operating voltage of capacitor C3 and thus it features reduced stress of the input voltage source when compared with other topologies of extended boost quasi ZSI.

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