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Quasi Z source inverter

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***Abstract*—** This study presents quasi z source inverter (QZSI) which is new topology derived from the traditional Z source inverter (ZSI). Quasi z source inverter (QZSI) with built in impedance network is an advanced compared to traditional voltage source inverter and current source inverter technology. QZSI can realize buck/boost of voltage and inversion in single stage which improves reliability. The quasi Z source inverter (QZSI) can be realize through unique control methods like simple boost control(SBC) and maximum boost control(MBC), which helps to produce wide range voltage gain. These control techniques are modification of simple PWM. The QZSI with its unique impedance network and wide range of voltage gain like features makes it most suitable for PV based power system application.

***Keywords*—**Quasi Z-source Inverter, Z-source Inverter, Simple boost control, Maximum boost control.

I. INTRODUCTION

The traditional inverters have a major disadvantage. The AC output can only be equivalent or less than the DC input values is one of the major disadvantage or conceptual barrier. This problem has limited the flexibility of the inverters which means that if one desires to produces AC output larger than the DC input, one must design a two stage converter which will consist of the boost converter and inverter and thus it will directly affect the overall efficiency and cost of the circuit [1].

A recent upsurge in the study of Z-source/quasi-Z-source inverters (ZSI/QZSI) Emerges since they present remarkable capability to cope with the wide DC source voltage variations in single-stage power conversion [3].The ZSI/QZSI embeds an LC impedance network, composed of two inductors and two capacitors, between the DC source and inverter. With different configurations of the LC network, both ZSI and QZSI introduce a shoot-through zero state, which can boost the DC source voltage when it is not high enough to the required DC-link voltage. Moreover, the reliability is greatly enhanced as the power devices will never suffer from the breakdown of shoot circuit between upper and lower switches in one bridge leg [6]. Compared with the DC–DC boost circuit-based two-stage inverter, the ZSI/ QZSI system can increase the efficiency and reduce the costs of the entire power conversion system [4].

There are two typical SPWM methods: simple boost control and maximum boost control [6]. They carry out the shoot-through states by performing different shoot-through references into the comparison of the triangle carrier and modulating waves' envelops of the traditional SPWM technique. The maximum boost control has the greatest modulation index and the highest voltage gain [2]; whereas, a low-frequency ripple is introduced into the Z-source/quasi-Z-source capacitor voltage and inductor current as the shoot-through duty ratio varies at six times output frequency.

This paper comprehensively looks at the boosting and DC–AC conversion section of the inverter system using the latest Quasi Z-source inverter (ZSI) bridge technology, as QZSI offer a simplified single-stage power conversion topology and an extra advantage because the shoot-through (ST) can no longer destroy the inverter. Section I of these presented the introduction and reason evaluation of QZSI. After that section II represented the Advantages of QZSI over ZSI.

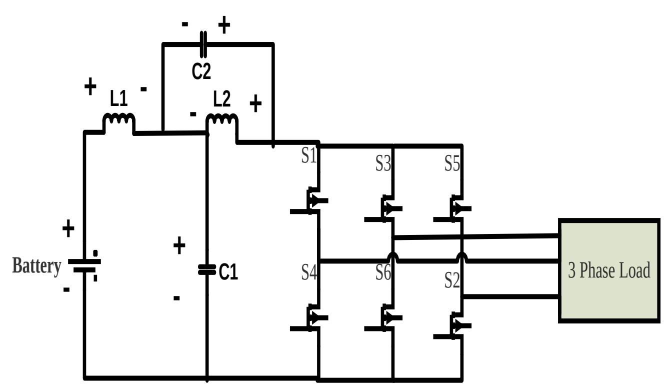

Figure1. Topology of QZSI

After presenting the Advantages of Quasi Z-source inverter over Z-source inverter in Section II, Working of quasi Z-source inverter with different modes of operation presented in section III. The Control strategies for QZSI and comparison of methods represented in section IV and V respectively. All proposed models are implemented in MATLAB/ Simul ink's results described in section VI.

II. ADVANTAGES OF QZSI OVER ZSI

1. In ZSI two capacitors have same voltage which is high; while QZSI the voltage ratings of C_2 is less than the voltage rating of C_1.

$$V_{C1} = V_{C2} = \frac{T_1}{T_1 - T_0} * V_{IN}$$

Where as in QZSI

$$V_{C1} = \frac{T_1}{T_1 - T_0} * V_{IN}$$

$$V_{C2} = \frac{T_0}{T_1 - T_0} * V_{IN}$$

2. In Shoot through state of the ZSI the diode is open circuited which cause the discontinues of the source current. This discontinues source current cause stress in ZSI. While in QZSI due to the inductor L_1, the source current is continues [3].
3. In QZSI there is common dc rail which is not presents in ZSI. It reduces the complication in design [3].

III. WORKING OF QUASI Z-SOURCE INVERTER

As shown in figure. 1 the basic circuit of Quasi Z-source inverter. Quasi Z-source inverter circuit contain two inductors L1 and L2 and two capacitors C1 and C2 and diode. With the help of this special configuration it can buck/boost the source voltage in single stage. In quasi Z-source inverter the both switch of single leg is turned on at a time, known as shoot through state, which is absent in the traditional inverters. In quasi Z-source inverter the combination of LC is work as low pass filter or second order filter, which is reduced the ripples in output voltage and current. In traditional inverter the Single capacitor and single inductor are less efficient to reduce the ripples in output.

1. Mode of operation

As per the switching state of the quasi Z-source inverter the mode of operation given below:

Mode 1: In this mode the inverter operates as normal switching modes of inverter as shown in figure 3.1. It's operated in the six active state of the inverter, which is known as non shoot through mode. In this mode of operation the Dc voltage appear across the capacitor and inductor. In this mode the capacitor is charged and energy flows to load via inductor.

Mode 2: In this mode the either upper or lower switches are short circuited. During this mode the circuit is open circuited. Here the system is operated in two zero states. In this mode due to open circuit no current is flow through the load.

Mode 3: In this mode of Inverter Bridge is operating in one of the seven different ways of ST. In this mode the switches of the same leg are short circuited. This mode of operation short circuited the load as shown figure 3.1. In this mode of operation the shoot through states are inserted in one of the zero states of the inverter. This mode of operation boost the capacitor voltage according to shoot through duty ratio (T0). These three modes of operation have shown in figure 3.1 and 3.2 of QZSI. The zero states may partially or entire used in this mode of operation by shoot through time [6].

As shown in Fig. 3.1, in shoot through state the same leg of QZSI is short circuited, which cause the DC link voltage is short circuited. In shoot through state the inductor and capacitor is charged and the diode is reversed biased. So, there is

$$V_{L1} = V_{C2} + V_{IN}, V_{L2} = V_{C2}, \; V_{PN} = 0 \tag{1}$$

Fig. 3.2 shows the Non shoot through state of the QZSI. In non shoot through mode QZSI operate as CSI, in which the DC source and inductors charge the capacitor and load. The diode is forward biased in non shoot through state.

So, there is

$$V_{L1} = V_{IN} - V_{C1}, V_{L2} = -V_{C2}, V_{PN} = V_{C1} + V_{C2} \tag{2}$$

The inductor voltages of QZSI over one cycle according to voltage-second balance principle are zero in steady state. There are

$$V_{L1} = \frac{\{T_0(V_{C1} + V_{IN}) + T_1(V_{IN} - V_{C1})\}}{T} = 0 \tag{3}$$

$$V_{L2} = \frac{\{T_0(V_{C1}) + T1(-V_{C2})\}}{T} = 0 \tag{4}$$

Thus, Capacitor voltage of the QZSI

$$V_{C1} = \frac{T_1}{T_1 - T_0} * V_{IN} \tag{5}$$

$$V_{C2} = \frac{T_0}{T_1 - T_0} * V_{IN} \tag{6}$$

The DC link voltage of the QZSI

$$V_{PN} = V_{C1} + V_{C2} = \frac{T}{T_1 - T_0} * V_{IN} = B * V_{IN} \tag{7}$$

$$V_{PN} = \frac{1}{1-2(\frac{T_0}{T})} * V_{IN} \quad (8)$$

So, boost factor and duty ratio

$$B = \frac{1}{1-2(\frac{T_0}{T})}, \qquad D = \frac{T_0}{T} = \frac{B-1}{2B} \quad (9)$$

$$V_{AC} = \frac{V_{PN}}{2} * M = M * B * \frac{V_{IN}}{2} \quad (10)$$

So final equation of the gain is

$$\frac{V_{AC}}{\frac{V_{IN}}{2}} = G \quad (11)$$

V_{IN} = Input voltage source, $V_L = V_{L1} = V_{L2}$ = Voltage across the inductors, $V_C = V_{C1} = V_{C2}$ = Voltage across the capacitors, V_{PN} = Voltage across the link, B = Boost factor of the QZSI.

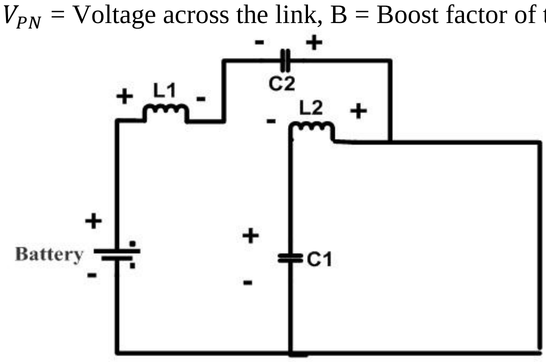

Figure3.1. Shoot through mode of QZSI

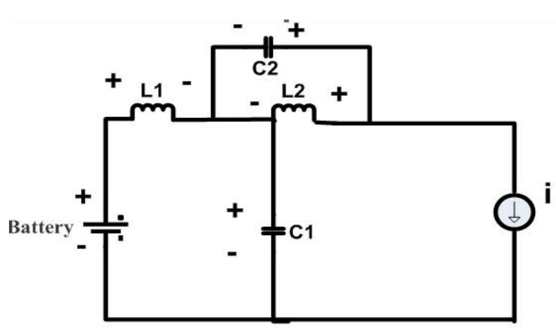

Figure3.2. Non-shoot through mode of QZSI

IV. CONTROL STRATEGIES

1. *Simple boost control (SBC)*

In this simple boost control method shown in Figure 4.1. The two straight line passes through the max contour of sinusoids and min contour of sinusoidal known as V_p and V_n, respectively. Now, whenever the triangle waveform is greater than the Vp. All switches of the upper legs are switched on whereas the lower leg switches is already on. These cause the shoot through of the QZSI. In same way when Vn is greater than the triangle wave all lower leg switches are on and it cause the ST in second half cycle of the triangle wave. In Simple boost control method the ST duty ratio decreases with increase in M (modulation index). In this control method two zero states are not fully utilised. Due to the low ST duty ratio the voltage stress across the link is high. [4, 6].

Important mathematical expressions are

Now, Duty ratio of this control method is given by

$$D_0 = 1 - M \quad (12)$$

$$G = M * B = \frac{M}{1-2D_0} \quad (13)$$

$$G = \frac{M}{1-2(1-M)} = \frac{M}{2M-1} \quad (14)$$

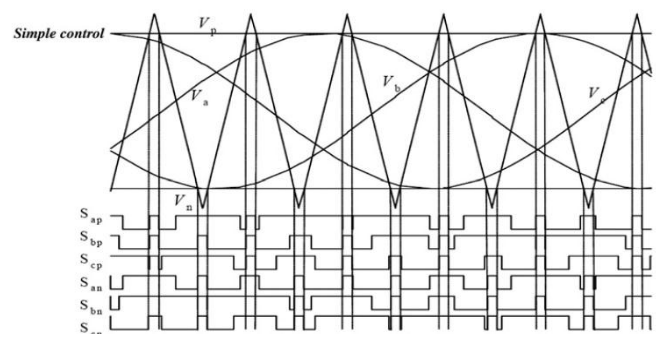

Figure 4.1 Simple boost control method (SBC)

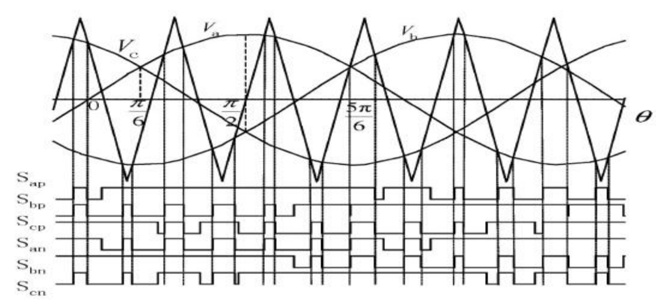

Figure 4.2 Maximum boost control method (MBC)

2. *Maximum Boost Control (MBC)*

Maximum boost control method is useful to obtain high voltage at lower ST duty ratio. MBC is utilised the zero states in shoot through mode of operation, cause the voltage stress across the Dc link is reduced. The Maximum contour of all three sinusoidal together and minimum three contours of all three sinusoidal together acts as the Vp and Vn ST references, respectively. These Vp and Vn are compared with the triangular waveform to obtain the ST as shown in figure 4.2. Due to varying Max min contours of the maximum boost control method, the shoot through duty ratio is varying over cycle. Because of varying shoot through duty ratio it produces the higher inductor ripples, which required high value of inductor to suppress the ripples [2, 4, 6].

For every π/3 radian the shoot through state is repeats. For interval of (π/6, π/2) the shoot through duty ratio over one switching cycle is given by

$$\frac{T_0}{T} = \frac{2-(M\sin\theta - M\sin(\theta - 2\Pi/3))}{2} \qquad (15)$$

By integrating the above equation we can get the average value of shoot through duty ratio

$$\frac{T_0}{T} = \int_{\frac{\Pi}{6}}^{\frac{\Pi}{2}} \frac{2-\left(M\sin\theta - M\sin\left(\theta - \frac{2\Pi}{3}\right)\right)}{2}\, d\theta$$

$$= \frac{2\Pi - 3\sqrt{3}M}{2\Pi} \qquad (16)$$

Now, thus from the above equations the boost factor of the QZSI is given by calculated as,

$$B = \frac{1}{1-2(\frac{T_0}{T})} = \frac{\Pi}{3\sqrt{3}M - \Pi} \qquad (17)$$

Now, The voltage gain of QZSI can be obtained by the modulating the modulation index with boost factor

$$\frac{V_{AC}}{\frac{V_{IN}}{2}} = G = MB = \frac{\Pi M}{3\sqrt{3}M - \Pi} \qquad (18)$$

V. COMPARISON OF CONTROL METHODS

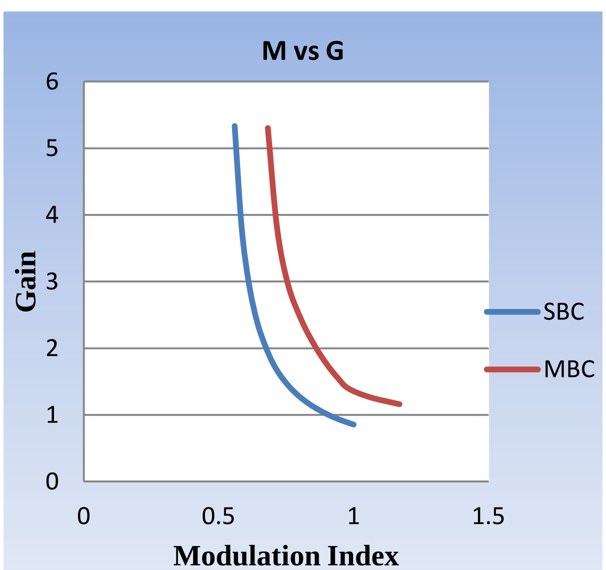

Figure 5.1 Graphical result of Modulation Index versus Gain

As shown in figure 5.1 the voltage gain versus modulation index graph of these two boost control methods. The maximum boost control method used zeros states effectively than simple boost control method, which cause the less voltage stress in the MBC compare to SBC[2, 3, 4].

As shown in figure 5.2 for (SBC) and (MBC), MBC has lower voltage stress than the SBC [2, 4]. These results are obtained from the simulation.

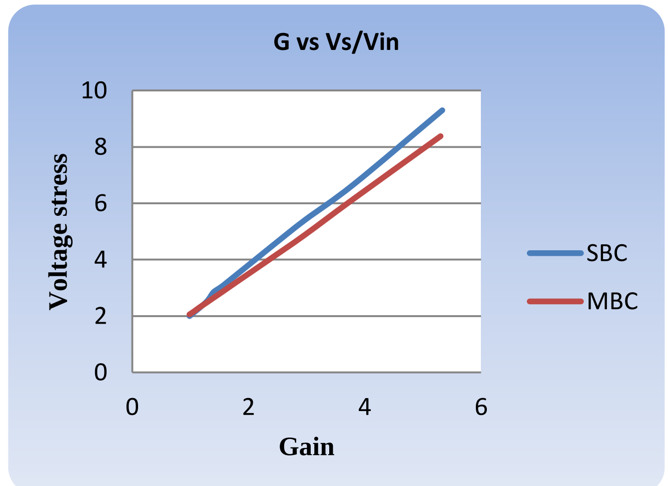

Figure 5.2 Graphical result of Gain versus Voltage Stress

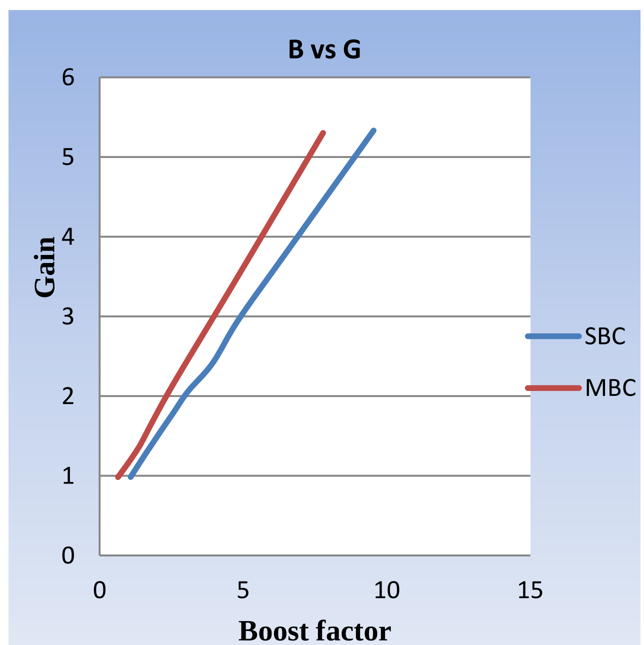

Figure 5.3 Graphical result of Boost factor versus Gain

Figure 5.3 shows the voltage gain of QZSI versus boost Factor B in any each of the control methods. At given voltage Gain, maximum boost control method has a lesser boost factor than the simple boost control method. Which indicate that because of lesser boost factor in MBC, The shoot through time is less for it [2, 4]. Therefore, the voltage stress is less in the maximum boost control method.

Figure 5.4 shows the relationship between shoot through period and modulation index for both methods. Among two methods for same modulation index the shoot through time is higher in maximum control than simple control.

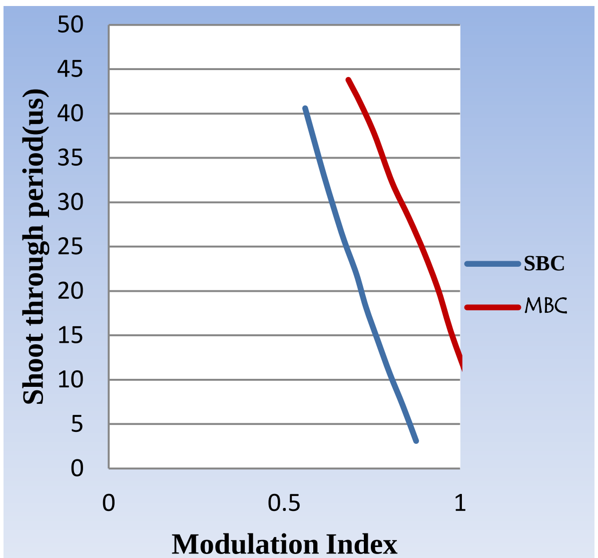

Figure 5.4 Graphical result of Modulation Index versus Shoot through period

From the above graphical comparisons of simple boost control and maximum boost control the results obtained given below.

1. Maximum boost control method has lesser voltage stress than simple boost control.
2. Maximum boost control method has wide range of modulation index than the simple boost control method.
3. Maximum boost control method can boost voltage up to higher value compare to Simple Boost control.
4. Less rating of switches required in the MBC as compared to SBC.

VI. RESULTS AND DISCUSSION

The elements used in simulation of the Quasi Z-inverter network are shown in figure 1. The parameters used in the QZSI network:$L_1 = L_2 = 2mH$, $C_1 = C_2 = 30\mu F$, switching frequency: 10kHz. Here the Quasi Z-source inverter is used with different input voltages have constant output three phase voltage of around 230v rms. The input voltage in this simulation is varying in between 150 to 250 as shown in table 4.1 and 4.2 for SBC and MBC respectively. The modulation index is varying from 0.7 to 0.95 for SBC and MBC. Where V_{IN} is the input voltage, V_{PN} is the DC link voltage, which is also voltage stress Vs, and V_L is the output line to line voltage. Based on the analysis above, the theoretical voltage stress and output line to line rms voltage are listed in tables 4.1 and 4.2 for SBC and MBC respectively.

Table 1. Simulation parameter of Quasi Z-source inverter

Parameter	Value
DC input V_{IN}	150-250 V
Inductance	2mH
Capacitance	30µF
Switching frequency	1kHz
R-L Load	R=53 Ω, L=55mH
Load Voltage (Line)	230 V

As we can observe that the line voltage phase voltage shown in figure 6.1 and 6.2 respectively. As shown in the figure 6.3 the capacitor voltage, the capacitir voltages is continusely charged and discharged during the shoot through and non-shoot through state. This capacitor is mainly used to boost the voltage in quasi z-source inverter. As per the capacitor voltage there is also DC link voltage shown in figure 6.4. As shown in figure The DC link voltage is Zero in the shoot through state, where as the some voltages appears across the link in the non-shoot through state. This average DC link voltage is the sum of the both capacitor voltages.
During the design of the L and C the % current ripples and % voltage ripples is 30% and 3% respectivel [6]. Than Inductance and capacitace of QZSI

$$L = \frac{V_C * T_0}{\Delta I} = 2mH$$

$$C = \frac{V_C * T_0}{\Delta V} = 30\mu F$$

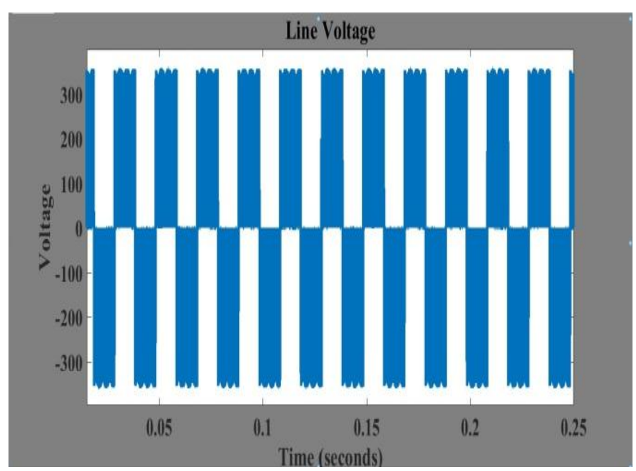

Figure 6.1 Line voltage of QZSI

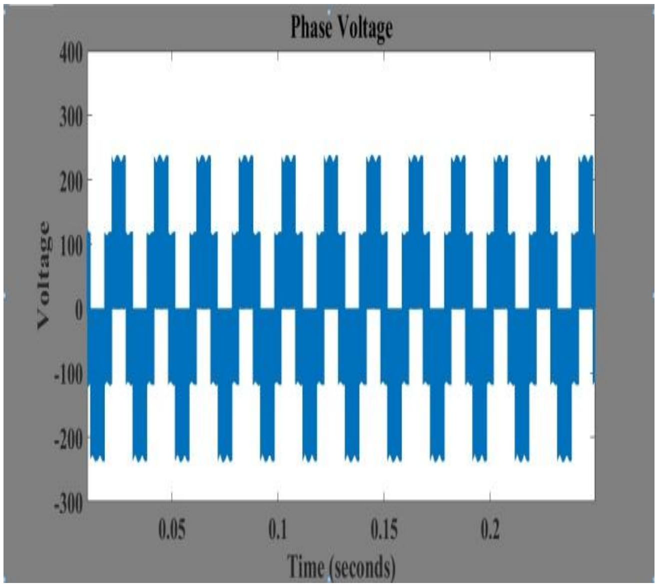

Figure 6.2 Phase voltage of QZSI

Table II. For Constant line output voltage (230V) and for 1kw load various results of SBC

Sr. No	Input Voltage (Vin)	Modulation Index (M)	DC Link Voltage (Vdc)	Gain (G)
1	250	0.875	290	1.06
2	230	0.838	285	1.16
3	210	0.8	279	1.27
4	190	0.766	272	1.4
5	170	0.732	269	1.57

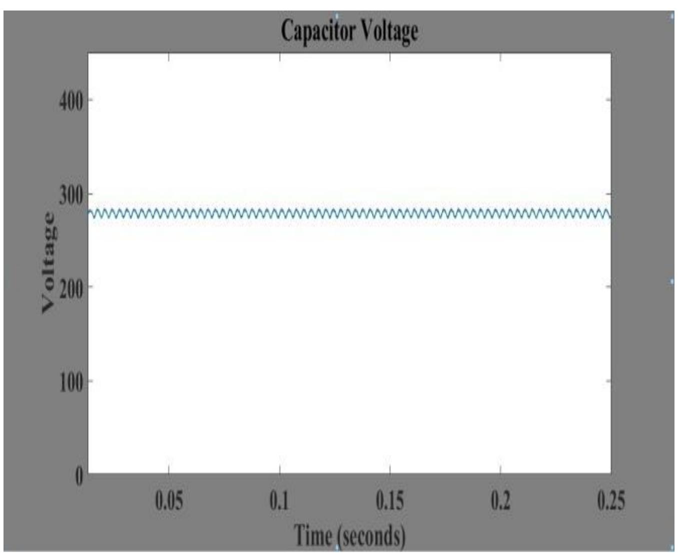

Figure 6.3 Capacitor voltage of QZSI

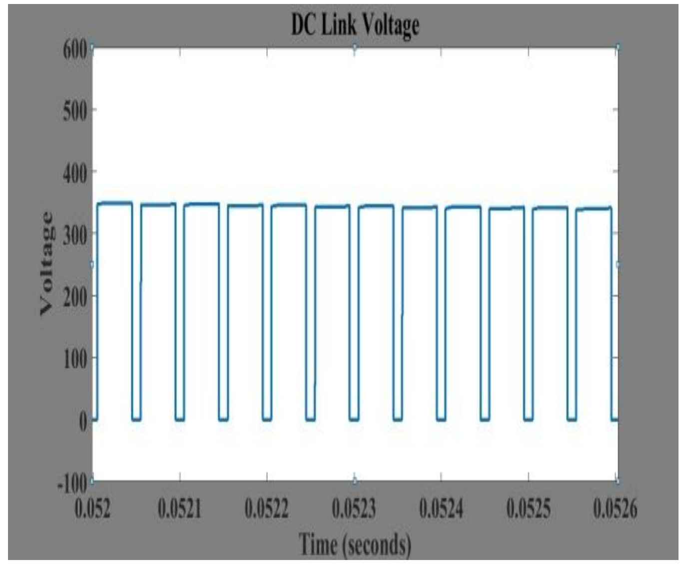

Figure 6.4 DC link voltage of QZSI

Table III. For Constant line output voltage (230V) and for 1kw load various results of MBC

Sr. No	Input Voltage (Vin)	Modulation Index (M)	DC Link Voltage (Vdc)	Gain (G)
1	230	1.17	266	1.16
2	210	1.06	258	1.26
3	1900	0.98	251	1.398
4	170	0.939	245	1.56
5	150	0.898	238	1.77

VII. Conclusion and Future Scope

This study presents quasi z source inverter (QZSI) which is new topology derived from the traditional Z source inverter (ZSI). Quasi z source inverter (QZSI) with built in impedance network is an advanced compared to traditional voltage source inverter and current source inverter technology. QZSI can realize buck/boost of voltage and inversion in single stage which improves reliability. The quasi Z source inverter (QZSI) can be realized through unique control method like simple boost control (SBC).which they briefly elaborated comparison of traditional inverters against the Z-source inverter in term of topology, performance advantage and limitations.

Furthermore, the proposed QZSI has advantages of continuous input current, reduced source stress, and lower component ratings when compared to the traditional ZSI. Theoretical analysis, control method, and system design guide are presented in this paper. Simulation results show that with a voltage range of DC input (from 150 V to 250 V), the QZSI can provide three Phase 50 Hz, 230 V Line ac voltage, which verifies the theoretical analysis. Two main shoot through control methods simple boost control and maximum boost control described in the paper. Also the comparison of the both methods with various quantities is described.

A grid-connected PV power generation system is one of the most promising applications of renewable energy sources. The proposed Quasi Z-Source Inverter is intended as a grid connected system and transfers the maximum power from the PV array to the grid by maximum power point tracking technology. In that case, the efficiency would be improved and the cost would be reduced with the proposed one stage power conversion system.

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