ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 7, July 2014

Design and Simulation of Cascaded H- Bridge Quasi Z-source Multilevel Inverter for Photovoltaic Applications

D.Umarani[1], Dr.R.Seyezhai[2]

PG scholar, Department of EEE, SSN College of Engineering, Chennai, India[1]

Associate professor, Department of EEE, SSN College of Engineering, Chennai, India[2]

Abstract: In this paper, a cascaded five level Quasi Z-Source inverter is proposed for photovoltaic applications. The proposed topology employs an LC network between the DC source and inverter circuitry to achieve boost as well as inversion operation. The output voltage of the proposed inverter is controlled by using modulation index and shoot through state. Various modulation strategies have been reported in the literature for the proposed topology. But this paper focuses on the implementation of simple boost, maximum boost and constant boost control strategies with third harmonic injected phase shift PWM. The performance parameters of the proposed topology are computed and comparison is provided for all the three control strategies. Simulations of the circuit configuration for the above mentioned control methods have been performed in MATLAB/Simulink and the results are verified.

Keywords: Quasi Z-Source inverter, Simple Boost, Maximum Boost, Constant Boost control, Pulse Width Modulation (PWM), Phase shifted pulse width modulation (PSPWM)

I. INTRODUCTION

In recent years, power generation from the renewable energy sources are becoming more and more popular as there is an increasing power demand and scarcity of conventional non renewable energy sources. Solar energy is the most promising and abundantly available renewable energy which could be absorbed easily with PV systems. So we are at the verge of trapping the solar energy with high efficiency, reduced cost and improved energy capture. Therefore to obtain the above mentioned features, a Cascaded H Bridge multilevel inverter with Quasi Z network can be implemented to obtain both inversion and boost capability in a single stage [7]. Multilevel inverter is widely used in high power applications such as large induction motor drives, UPS systems and Flexible AC Transmission Systems. Desired output can be obtained from several levels of input DC voltage sources and also the output levels depends on the number of input DC voltage sources. The multilevel inverters offer several advantages over a conventional two level inverters such as lower semiconductor voltage stress, better harmonic performance, low Electro Magnetic Interference (EMI) and lower switching losses [3]-[4]. Cascaded H Bridge type Quasi Z- Source multilevel inverter is proposed in this paper. QZSI are very suited for renewable energy systems. The important operating characteristic is that the QZSI is operated with continuous input current. This is a very important characteristic when dealing with PV systems, given that these systems are limited power sources and they are not able to handle sudden changes in their supplied current. Introducing a Quasi Z- Source network into the Cascaded H Bridge module, the system features several advantages, such as PV string voltage boost, independent tracking MPP of each PV string, and keeping an equal DC-link voltage for each H-bridge inverter module [7]-[10].

II. TOPOLOGY DESCRIPTION

The topology of the five- level Quasi Z-Source inverter is illustrated in the Figure 1.It consists of a series of single phase H bridge inverter units, Quasi Z Source impedance networks and DC voltage sources. DC sources can be obtained from batteries, fuel cells, solar cells.

III. QUASI Z-SOURCE INVERTER

Figure 2 shows the basic topology of QZSI. The QZSI extends several advantages over the ZSI such as continuous current from the input DC source, cut down component ratings, and enhanced reliability.

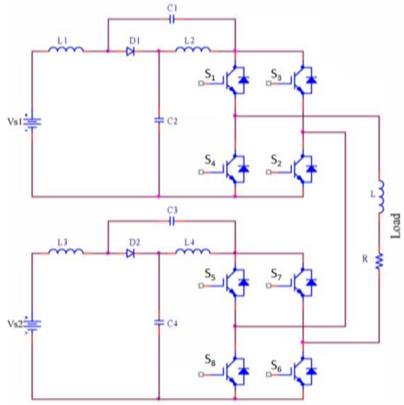

Fig 1. Five - level cascaded H Bridge Quasi Z-Source Inverter

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 7, July 2014

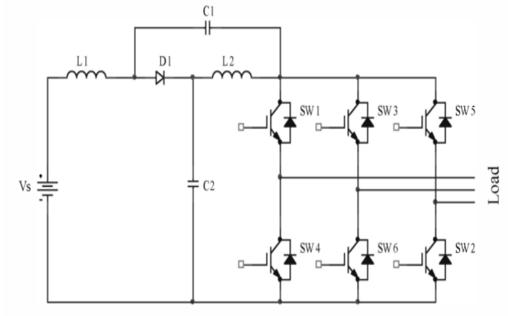

Fig 2 . Basic topology of QZSI

IV. MODES OF OPERATION AND CIRCUIT ANALYSIS

A. Active or Non-Shoot through state

In this state the load is directly connected to the supply through the switches, so the equivalent circuit of Quasi Z-Source Inverter Bridge becomes a current source.

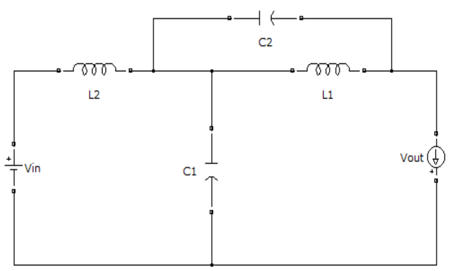

Fig 3.Equivalent circuit of QZSI in active state

By writing mesh equations for this circuit we get,

$$V_{L2} = V_{in} - V_{c1} \quad (1)$$

$$V_{L2} = -V_{c2} \quad (2)$$

$$V_{out} = V_{c1} - V_{L1} = V_{c1} + V_{c2} \quad (3)$$

Since the diode is turned on at this switching state

$$V_{diode} = 0 \quad (4)$$

B. Zero state

During one of the traditional zero state the load is shorted by the turning ON of upper devices or lower devices alone, so the inverter bridge is represented by a current source with zero value.

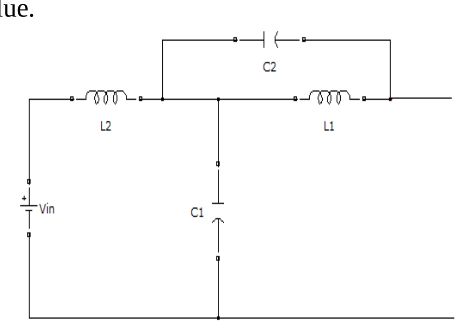

Fig 4. Equivalent circuit of QZSI in zero state

C. Shoot-through state

The special feature of QZSI is the shoot through state, during this state the devices in the same limb are triggered ON. Since there are inductors and capacitors available in the topology this switching that lasts for a very short duration does not damage the switches as in the case of VSI. The equivalent circuit of the inverter bridge is shown below.

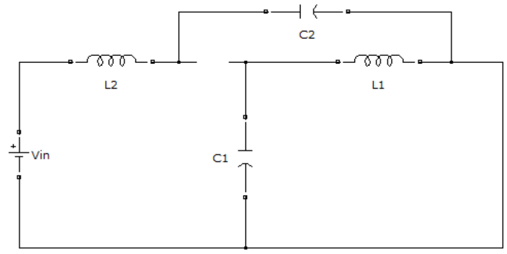

Fig 5.Equivalent circuit of QZSI in shoot through state

This state is switched either at the beginning or at the end of the zero state when the voltage across the load is zero to eliminate the damage of the switches. The analysis of the circuit is shown below

$$V_{out} = 0 \quad (6)$$

$$V_{L2} = V_{in} + V_{c2} \quad (7)$$

$$V_{L1} = V_{c1} \quad (8)$$

$$V_{diode} = -V_{c1} - V_{c2} \quad (9)$$

TABLE I. SWITCHING STATES

Output Voltage	State	ON Switches
2Vs	Active	S_1,S_2,S_5,S_6
Vs	Active	S_1,S_3,S_5,S_6
Vs	Shoot-through	S_1,S_2,S_3,S_4,S_5,S_6
Vs	Active	S_1,S_2,S_5,S_7
Vs	Shoot-through	S_1,S_2,S_5,S_6,S_7,S_8
0	Zero	S_1,S_3,S_5,S_7
0	Shoot-through	S_1,S_2,S_3,S_4,S_5,S_7
0	Shoot-through	S_1,S_3,S_5,S_6,S_7,S_8
-Vs	Active	S_1,S_3,S_7,S_8
-Vs	Shoot-through	S_1,S_2,S_3,S_4,S_7,S_8
-Vs	Active	S_3,S_4,S_5,S_7
-Vs	Shoot-through	S_3,S_4,S_5,S_6,S_7,S_8
-2Vs	Active	S_3,S_4,S_7,S_8

V. SWITCHING STATES

As compared to traditional cascaded multilevel inverter, the new topology has an additional switching state known as shoot-through state. During the shoot-through state, the DC link voltage of the inverter becomes zero. In boost mode some or all of the zero states are replaced by shoot-through states depending on the PWM technique used. In shoot-through states, the inductors in the impedance networks are charged by the capacitors while in the non-shoot-through states these inductors along with input DC source discharge through the load. Hence the output voltage is boosted. Table I shows details of the switching states and corresponding output voltage level of multi level QZSI.

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 7, July 2014

VI. PHASE SHIFTED CARRIER PWM STRATEGY

Several PWM strategies are available to generate pulses for the switches of multilevel inverters. In this paper, third harmonic injected Phase shift carrier PWM technique is applied to the five-level Quasi Z -Source multilevel inverter. In the phase-shifted multicarrier modulation, all the triangular carriers have the same frequency and the same peak-to-peak amplitude, but there is a phase shift between any two adjacent carrier waves, given by $\Phi_{cr} = 360°/(m - 1)$ where m is voltage level of multilevel inverter. In general, a multilevel inverter with m voltage levels requires (m – 1) triangular carriers.

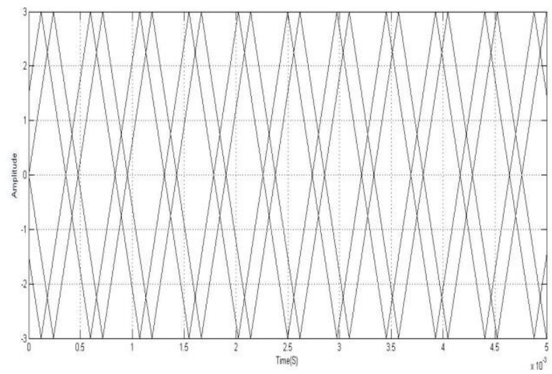

Fig 6. Phase shift carrier PWM

The gate signals are generated by comparing the modulating wave with the carrier waves. Four triangular carriers are needed for the five-level inverter with a 90° phase displacement between any two adjacent carriers. It is shown in Figure 6.

VII. INTRODUCTION OF SHOOT THROUGH IN THIRD HARMONIC INJECTED PHASE SHIFT PWM

The distribution of the shoot-through in the switching waveforms of the traditional pulse width modulation (PWM) concept is the key factor to control the Quasi Z-source inverter. Simple boost control (SBC), maximum boost control (MBC), constant boost control (CBC) are the control techniques that are implemented in this paper to introduce the shoot through in the pulses generated by third harmonic injected phase shifted carrier PWM. Table II provides the simulation parameters.

A .Simple Boost Control in PSPWM

Simple Boost control technique has been implemented with phase shifted carrier PWM to generate pulses to the proposed topology. In Simple Boost technique, the triangular carrier wave will be compared with a constant DC line to produce shoot through. The shoot through states will be produced if the carrier wave amplitude is greater than the DC line. Figure 7 shows the five-level Quasi Z-Source inverter with PSPWM and SBC.

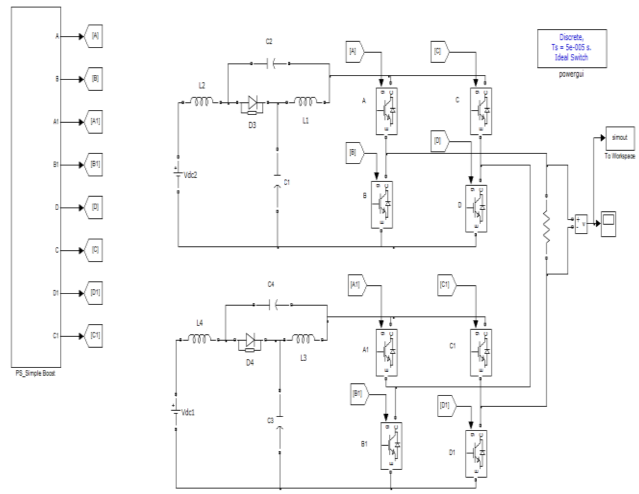

Fig 7. Five level Quasi Z-Source MLI with PSPWM and SBC

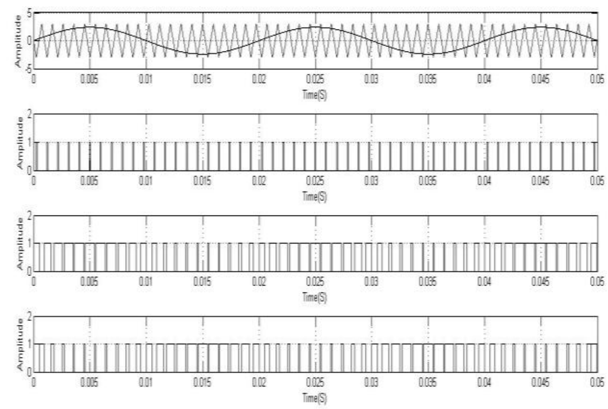

Fig 8. Pulse generation of PSPWM with SBC

Figure 8 shows the PSPWM along with shoot through generated using simple boost technique. The boosted output voltage obtained with the simple boost technique is shown in figure 9.

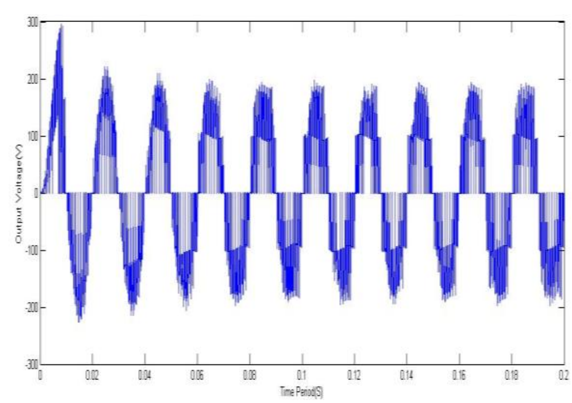

Fig 9.Output voltage of five- level QZMLI with PSPWM and SBC

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 7, July 2014

Modulation Index $M = \frac{V\sin}{Vtri}$

Voltage Gain $G = \frac{M}{2M - 1}$

Shoot-through duty ratio $Do = \frac{1}{2}[1 - \frac{M}{G}]$

Boost Factor $B = \frac{1}{1 - 2Do}$

Voltage Stress $Vs = B * Vo = (2G - 1)Vo$

Current ripple $r_o = \frac{MV_{in}T_o}{2I_{in}L}$

Voltage ripple $r_v = \frac{I_{in}T_o}{BV_{in}C}$

The performance parameters are calculated based on the above equations for simple boost control technique and tabulated in Table III.

B. Maximum Boost Control in Third Harmonic Injected PSPWM

Maximum Boost control technique has been implemented with third harmonic injected phase shifted carrier PWM to generate pulses to the proposed topology. In Maximum Boost technique, the triangular carrier wave will be compared at the maximum of the modulating wave to produce shoot through and all the traditional zero states are turned to the shoot through states. The shoot through states will be produced if the carrier wave amplitude is greater than the maximum of the modulating wave. Figure 10 shows the PSPWM along with shoot through generated using Maximum boost technique.

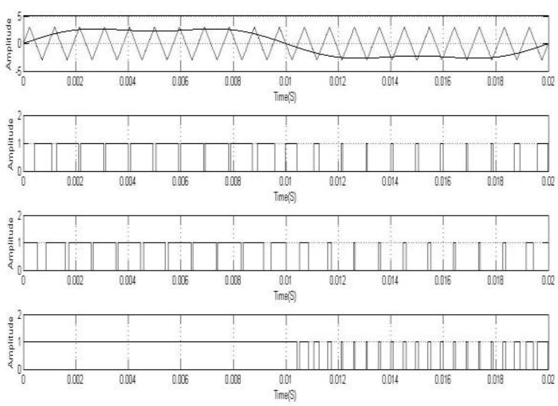

Fig 10. Pulse generation of PSPWM with MBC

Output voltage obtained is shown in the Figure 11.The performance parameters are calculated based on the following equations for the maximum boost control technique and tabulated in Table III.

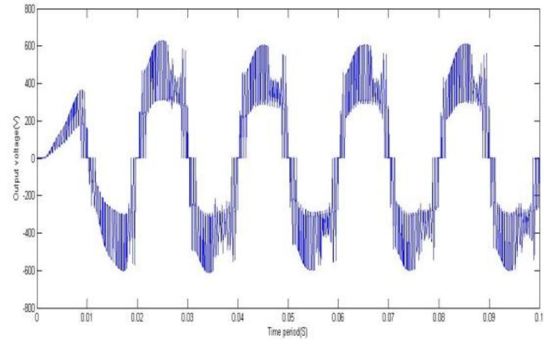

Fig 11.Output voltage of five- level QZMLI with PSPWM and MBC

Modulation Index $M = \frac{V\sin}{Vtri}$

Voltage Gain $G = \frac{M\prod}{3\sqrt{3}M - \prod}$

Boost Factor $B = \frac{3\sqrt{3}G - \prod}{\prod}$

Voltage Stress $Vs = B * Vo = (2G - 1)Vo$

Current ripple $r_o = \frac{MV_{in}T_o}{2I_{in}L}$

Voltage ripple $r_v = \frac{I_{in}T_o}{BV_{in}C}$

C.Constant Boost Control in Third Harmonic Injected PSPWM

In the constant boost control technique the shoot-through duty ratio is kept constant. At the same time, a greater voltage boost for any given modulation index is desired to reduce the voltage stress across the switches. Figure 12 shows the PSPWM along with shoot through generated using Maximum constant boost technique.

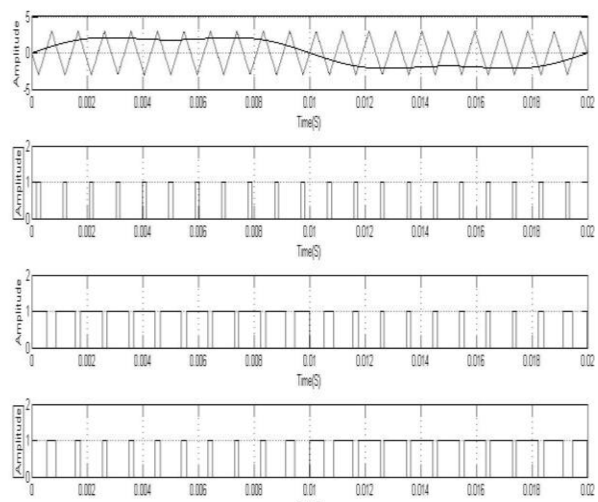

Fig 12. Pulse generation of PSPWM with CBC

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

IJIREEICE

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 7, July 2014

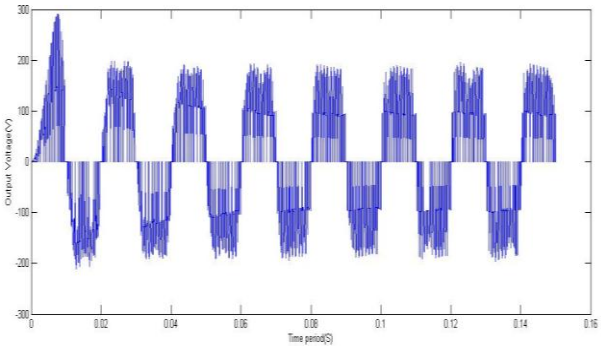

Fig 13.Output voltage of five level QZMLI with PSPWM and CBC

Modulation Index	$M = \frac{V\sin}{Vtri}$
Voltage Gain	$G = \frac{M}{\sqrt{3}M - 1}$
Boost Factor	$B = \frac{1}{\sqrt{3}M - 1}$
Voltage Stress	$Vs = B * Vo = (2G - 1)Vo$
Current ripple	$r_o = \frac{MV_{in}T_o}{2I_{in}L}$
Voltage ripple	$r_v = \frac{I_{in}T_o}{BV_{in}C}$

5. VIII. DESIGN EQUATIONS OF QUASI Z-SOURCE IMPEDANCE NETWORK

Inductance:

$$L_1 = L_2 = \frac{\Delta T . V_L}{\Delta I} = \frac{T_o . m . V_{in}}{2 . I_L . R_c} \quad (10)$$

Capacitance:

$$C_1 = C_2 = \frac{2 . \Delta T . I_c}{\Delta(V_{c1} + V_{c2})} = \frac{T_o . m . I_L}{2 . B . V_{in} . R_v} \quad (11)$$

Where, T_o - Shoot-through Interval, M - Modulation Index, R_c - Peak current ripple in %, R_v - Peak voltage ripple in %, I_L - Rated Load current, f_s - Switching frequency

TABLE II. SIMULATION PARAMETERS

Parameter	Rating
Input Voltage per bridge	75 V
Inductors L_1, L_2	5mH
Capacitors C_1, C_2	1150 µH
Inductor resistance r_L	0.0005 Ω
Capacitor resistance r_c	0.005 Ω
Boost Factor B	1.66
Switching frequency f_s	1050 Hz
Load resistance R_L	25Ω

Table II provides the parameters used to carry out the simulation in Matlab/Simulink for the proposed topology.

TABLE III . PERFORMANCE PARAMETERS

Table III provides the calculated performance parameters for the five-level cascaded Quasi Z-Source inverter implemented with Simple Boost, Maximum Boost and Maximum constant Boost control techniques.

Parameter	Simple Boost	Maximum Boost	Maximum Constant Boost
Modulation Index	0.8	0.8	0.8
Boost Factor	1.67	3.087	2.59
Voltage Gain	1.33	2.47	2.07
THD	52.04%	40.11%	54.49%
Voltage Stress	323.7 V	463.11 V	388.32 V
Inductor current ripple	11%	18.84%	17.53%
Capacitor voltage ripple	1.31%	1.16%	1.29%

Figure 14 shows Comparative graphs of various performance parameters.

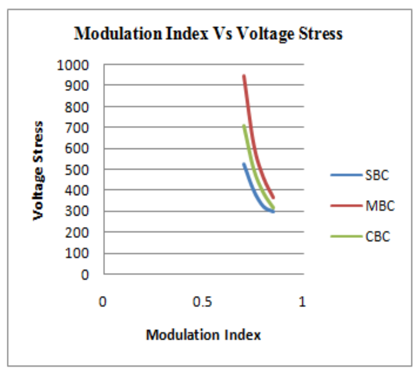

Fig 14(a) Modulation Index Vs Voltage stress

From the above graph it is clear that, the voltage stress of the power switching devices is decreased when the modulation index is increased.

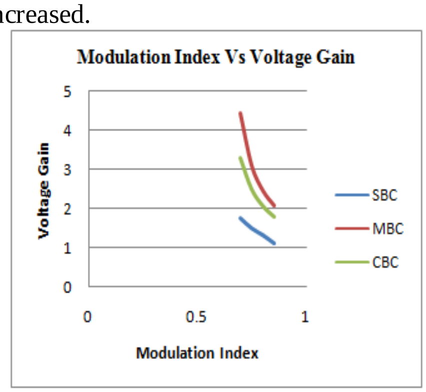

Fig 14 (b) Modulation Index Vs Voltage Gain

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 7, July 2014

The curve of voltage gain versus modulation index is shown in Figure 14 (b), from which we can see that the voltage gain is higher for lower modulation index.

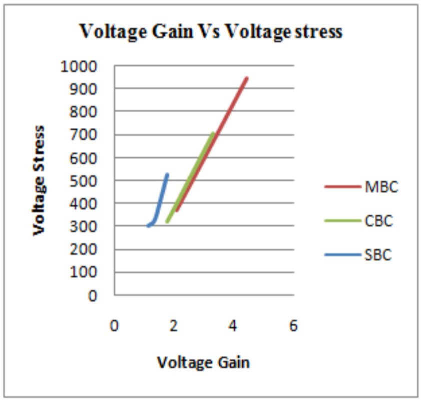

Fig 14 (c) Voltage gain Vs Voltage Stress

The relationship of voltage gain versus voltage stress shows that voltage stress is higher with increasing voltage gain for the MBC.

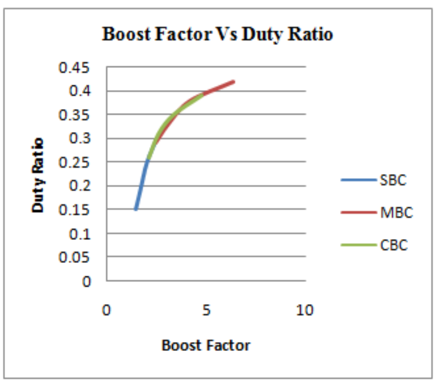

Fig 14(d) Boost Factor Vs Duty Ratio

VII. CONCLUSION

In this paper, the control techniques such as Simple Boost Control (SBC) is applied to for the five level Quasi Z-source inverter , Maximum Boost Control(MBC) and Constant Boost Control(CBC) are applied to third harmonic injected phase shift carrier pulse width modulation(PWM) for the five level Quasi Z-source inverter. The above mentioned control strategies have been reviewed and performance parameters are calculated. By comparing them, proper control method can be selected according to the requirement of different loads and demands. The simulations have been developed in Matlab/Simulink environment for five level Quasi Z-source inverter with R load. The comparison results shows that Constant Boost control with third harmonic injected phase shifted carrier pulse width modulation provides better voltage stress and voltage gain with effective dc boost and lowest harmonics compared to the other two control techniques.

ACKNOWLEDGMENT

The authors would like express their thanks to All India Council for Technical Education (AICTE) for funding the project "Development of Cascaded Z Source Inverter for photovoltaic applications " and to carry out the research work.

REFERENCES

[1] Peng, Fang Zheng. "Z-source inverter" ,IEEE Transactions on Industry Applications ,Volume 39,No.2,2010,pp. 504-510.
[2] S. Thangaprakash, A. Krishnan."Comparative evaluation of modified pulse width modulation schemes of Z-source inverter for various applications and demands", International Journal of Engineering, Science and Technology, Volume. 2, No. 1, 2010, pp. 103-115
[3] J.Rodriguez,J.-S. Lai, and F. Z. Peng, "Multilevel inverters: A survey of topologies, controls, and applications," IEEE Transactions on Industrial Electronics, vol. 49, no. 4, pp. 724–738, Aug. 2002.
[4] B. P. McGrath and D. G. Holmes, "Multicarrier PWM strategies for multilevel inverters," IEEE Transactions on Industrial Electronics., vol. 49, no. 4, pp. 858– 867, Aug. 2002.
[5] M.Calais, L. J. Borle and V.G. Agelidis, "Analysis of Multicarrier PWM Methods for a Single-phase Five Level Inverter", in Proceedings of 32nd IEEE Power Electronics Specialists Conference,PESC'01,July 2001,pp 1351-1356.
[6] F. Z. Peng, M. Shen, and Z. Qian, "Maximum boost control of the Z-source inverter" ,IEEE Transactions on Power Electronics., vol. 20, no. 4, pp. 833–838, 2006.
[7] Yuan Li Joel Anderson, F.Z.Peng and Dichen Liu, "Quasi Z-Source Inverter for Photovoltaic Power Generation System", 241h Annual IEEE Applied Power Electronics Conference, pp.918-924, 2009.
[8] Muhammad H.Rashid, Power Electronics circuits, devices and Applications, Prentice Hall, 2nd Edition.
[9] Baoming Ge ; Abu-Rub, H. ; Fang Zheng Peng ; Qin Lei ; de Almeida, A.T. ; Ferreira, F.J.T.E. ; Dongsen Sun ; Yushan Liu "An Energy Stored Quasi-Z-Source Inverter for Application to Photovoltaic Power System" IEEE Transactions on Industrial Electronics, Vol 60, Issue: 10 , Oct. 2013:4468 - 4481.

BIOGRAPHIES

D.Umarani received her B.E degree (Electrical and Electronics) in the year 2011 from Mepco Schlenk Engineering College, Sivakasi. Currently she is pursuing her Master of Engineering in Power Electronics and Drives from SSN College of Engineering, Chennai. Her areas of interest are Z-Source and Quasi Z-Source inverters, PV applications and AC Drives.

Dr.R.Seyezhai obtained her B.E. (Electronics & communication Engineering) from Noorul Islam College of Engineering, Nagercoil in 1996 and her M.E in Power Electronics & Drives from Shanmugha College of Engineering, Thanjavur in 1998 and Ph.D from Anna University, Chennai, in 2010 . She has been working in the teaching field for about 15 Years. She has published 120 papers in the area of Power Electronics & Drives. Her areas of interest include SiC Power Devices & Multilevel Inverters.