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Maximum Boost control of Cascaded MultiLevel Z-Source Inverter for Fuel Cell Applications

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Abstract—In this paper, a cascaded five level Z-Source inverter is proposed for fuel cell applications. The proposed topology employs Z network between the DC source and inverter circuitry to achieve boost operation. The output voltage of proposed inverter can be controlled 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 maximum boost control with third harmonic injection which turns all traditional zero states into shoot-through states. The performance parameters of Z-Source cascaded Multilevel inverter is computed and compare with simple boost method. Simulations of the circuit configuration of the control methods have been performed in MATLAB/Simulink and the results are verified.

Keywords—Cascaded Z-source Multilevel Inverter, Maximum boost control, voltage stress & voltage gain..

I. INTRODUCTION

In recent years, the multilevel voltage inverter is widely used in high power applications such as large induction motor drives, UPS systems and Flexible AC Transmission Systems (FACTS). Multilevel inverter obtains a desired output voltage from several levels of input DC voltage sources. With an increasing number of DC voltage sources, the inverter voltage output waveform level increases. As compared to traditional two level inverters, the multilevel inverters have more advantages which include lower semiconductor voltage stress, better harmonic performance, low Electro Magnetic Interference (EMI) and lower switching losses. Despite these advantages, multilevel inverters output voltage amplitude is limited to DC sources voltage summation. Occurring of short circuit can destroy multilevel inverters. To solve these problems, cascaded multilevel Z-source inverter [1-2] is proposed in this paper. The performance of the inverter is analyzed by employing a maximum boost control with third harmonic injection PWM technique. Maximum boost control converts all traditional zero states to shoot through while maintaining the active states. In this technique, the shoot through duty ratio varies during each cycle and maximum gain is obtained. Simple boost and maximum boost control methods for the proposed inverter topology are analyzed and compared .The effect of voltage gain and voltage stress for various modulation indices is studied for both the methods and the results are verified.

II. CASCADED MULTILEVEL Z-SOURCE INVERTER

The circuit diagram of cascaded Z-Source five-level inverter is shown in Fig.1. It consists of a series single phase H bridge inverter units, Z impedances and DC voltage sources. DC sources can be obtained from batteries, fuel cells, solar cells [1]. Each H-bridge Z-Source inverter can generate three different output voltage +Vin, 0, -Vin. Output voltage can be higher than the input voltage when boost factor, B>1.The number of output voltage levels, m in this topology is given by (n-1)/2, where n is the number of Z impedances or DC voltage sources. This topology has an extra switching state: shoot through state as compared to cascaded H-bridge inverters. During the shoot-through state, the output voltages of Z networks are zero [3].

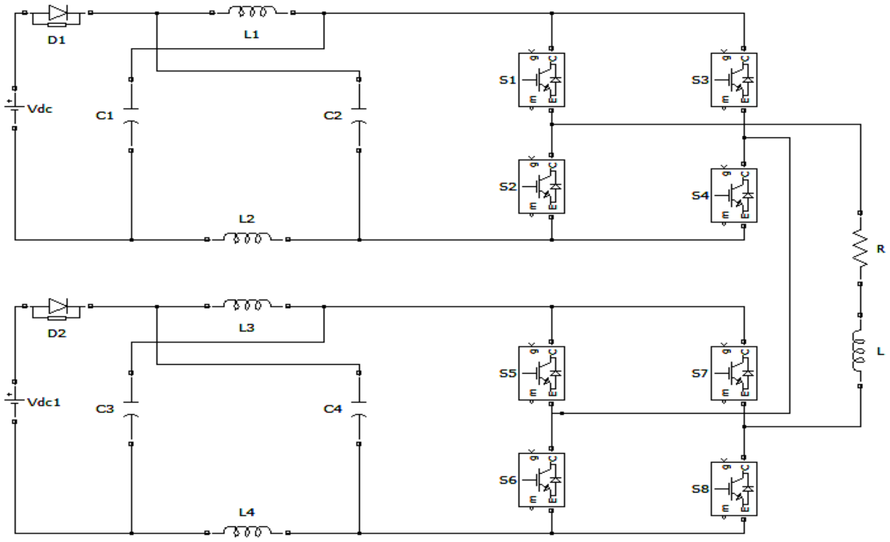

Fig.1.Five-level cascaded Z-source Multilevel Inverter

Circuit operation consists of two modes namely shoot -through and non shoot-through states [2]. In Shoot-Through (ST) switching state of Z-Source MLI, upper and lower bridges of the same leg is turned on having the output voltage of zero .During non shoot-through state opposite pairs of legs of both the bridge conducts. In ST state the two inductors are being charged by the capacitors and in Non-Shoot-Through (NST) states the inductors and input DC source transfer energy to the capacitors and load. This process is similar to the boost converter. Output voltage depends on the boost factor. The conduction table is shown in table –I

Table –I **Conduction Table for Cascaded Multilevel Z-source Inverter**

VOLTAGE LEVEL OUTPUT	**VOLTAGE**	**ON SWITCHES**
Level 2 (non shoot-through)	$2V_{in}$	S_3,S_4,S_5 ,S_6
Level 1 (non shoot-through)	V_{in}	S_1,S_3,S_5 ,S_6
Level 1 (shoot-through)	V_{in}	S_1,S_2, S_3, S_4, S_5, S_6
Level 1 (non shoot-through)	V_{in}	S_3,S_4,S_5 ,S_7
Level 1 (shoot-through)	V_{in}	S_3,S_4,S_5 ,S_6, S_7, S_8
Level 0 (zero state)	0 (V)	S_1,S_3,S_5 ,S_7
Level 0 (shoot-through)	0 (V)	S_1,S_2,S_3 ,S_4,S_5,S_7
Level 0 (shoot-through)	0 (V)	S_1,S_3,S_5 ,S_6,S_7,S_8
Level -1 (non shoot-through)	$-V_{in}$	S_1,S_3,S_7 ,S_8
Level -1 (shoot-through)	$-V_{in}$	S_1, S_2, S_3, S_4, S_7,S_8
Level -1 (non shoot-through)	$-V_{in}$	S_1,S_2,S_5 ,S_7
Level -1 (shoot-through)	$-V_{in}$	S_1, S_2, S_5, S_6, S_7,S_8
Level -2 (non shoot-through)	$-2V_{in}$	S_1,S_2,S_7,S_8

III. MAXIMUM BOOST CONTROL WITH THIRD HARMONIC INJECTION

A simple third harmonic injection method is therefore presented to provide the waveform with high quality . the reference waveform consists of both fundamental component and third harmonic component. The sinusoidal reference signal can be injected by a third harmonic with a magnitude equal to 25% of the fundamental. As a result, the peak-to-peak amplitude of the resulting reference function does not exceed the DC supply voltage Vs, but the fundamental component is higher than the available supply Vs. This eliminates third and multiples of third order harmonics which leads to reduction in Total Harmonic Distortion it is observed that Third harmonic injection PWM technique gives high voltage gain and reduced THD. Inductor current ripple and capacitor voltage ripple of Z-Source cascaded inverter are also reduced. Therefore, third harmonic injection PWM technique. Maximum boost control with third harmonic injection turns all traditional zero states

into shoot-through state [4-6]. The voltage stress across the switching devices is greatly reduced by fully utilizing the zero states. Turning all zero states into shoot-through state can minimize the voltage stress and this causes a shoot-through duty ratio varying in a line cycle, which causes inductor current ripple.
Maximum shoot-through boost factor can be written as,

$$B = \frac{1}{1-2D} \qquad (1)$$

Where B is boost factor and D is duty ratio which is given by

$$D = \frac{2\prod - 3\sqrt{3}\prod}{2\prod} \qquad (2)$$

The circuit is in shoot through state when the triangular carrier wave is either greater than the maximum curve of the reference signals or smaller than the minimum of the references [7,8]. The shoot-through duty cycle varies each cycle. The shoot-through state repeats periodically in every *n/3* degrees. Fig.2 shows the reference and carrier waveforms for maximum boost control with third harmonic injection PWM technique. The circuit is in shoot through state when the triangular carrier wave is either greater than the maximum curve of the reference signals or smaller than the minimum of the references. The shoot-through duty cycle varies each cycle.

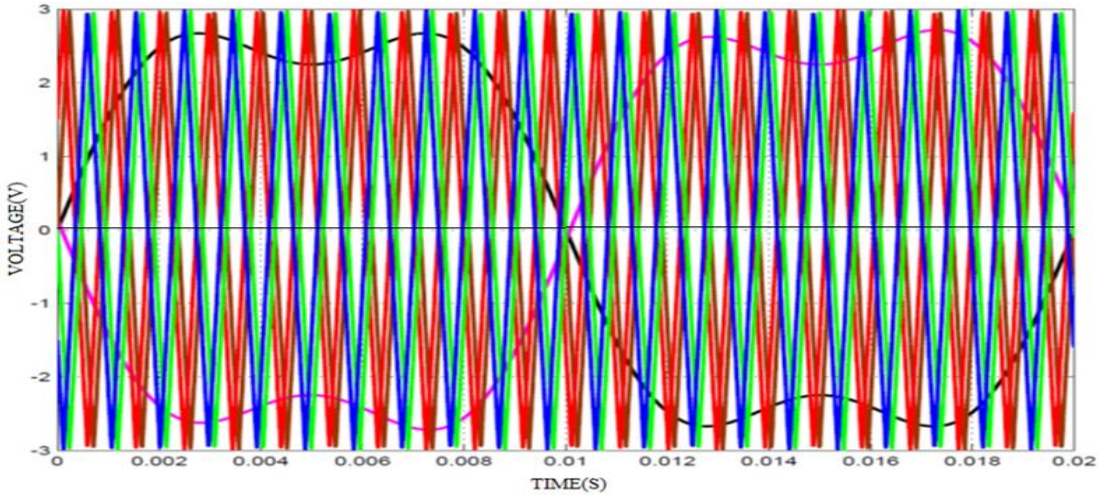

Fig.2 Maximum Boost control with **t**hird harmonic injection

Fig.3 shows Matlab/ Simulink of Z-Source cascaded MLI using Unipolar PWM with Boost factor = 1.25, $m_a = 0.8$, RL Load where R=50Ω and L=24mH, Input voltage V_{dc}=75V, Z impedances, $L_1 = L_2 = L_3 = L_4 = L$ = 40mH and $C_1 = C_2 = C_3 = C_4$ = 6600μF. Simulink circuit is shown with LC filter having L=30mH and C=150μF.

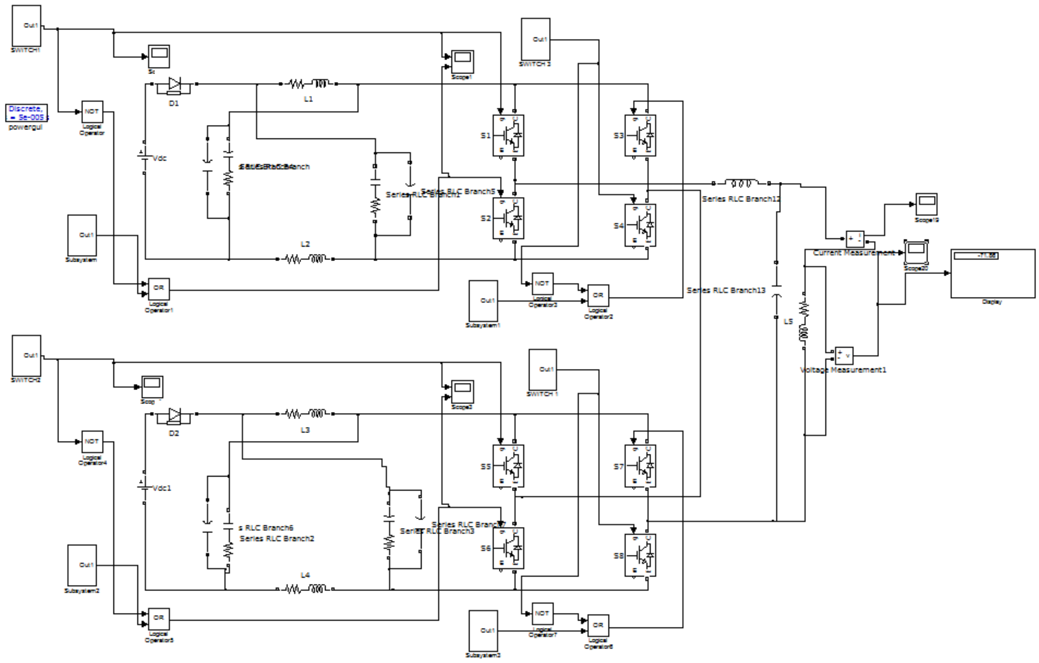

Fig 3 MATLAB/ SIMULINK circuit of Z-Source cascaded MLI using Maximum Boost control

IV. SIMULATION OF CASCADED Z-SOURCE INVERTER USING MAXIMUM BOOST CONTROL WITH THIRD HARMONIC INJECTION

The simulation results for the Z-source MLI with maximum boost control is shown in Figs.4,5 &6.

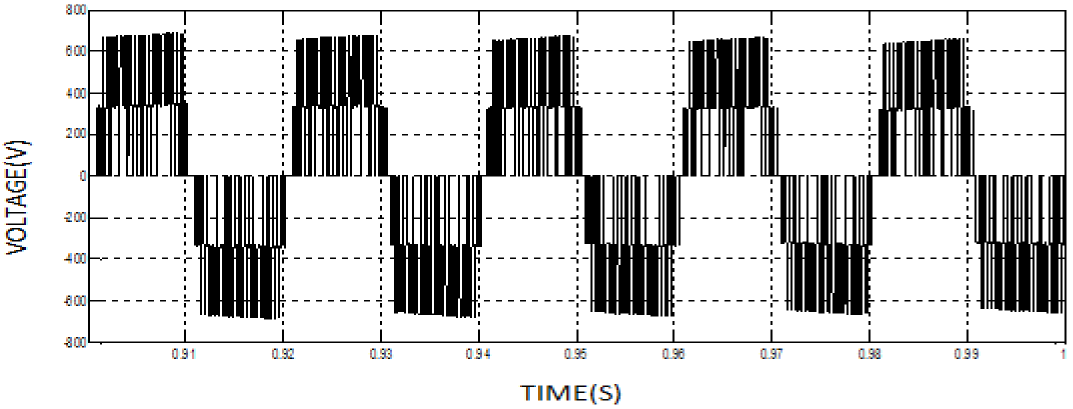

Fig.4 Load voltage waveform for maximum boost control with Third Harmonic injection PWM without filter (Boost factor: 3.09, m_a= 0.8, RL Load)

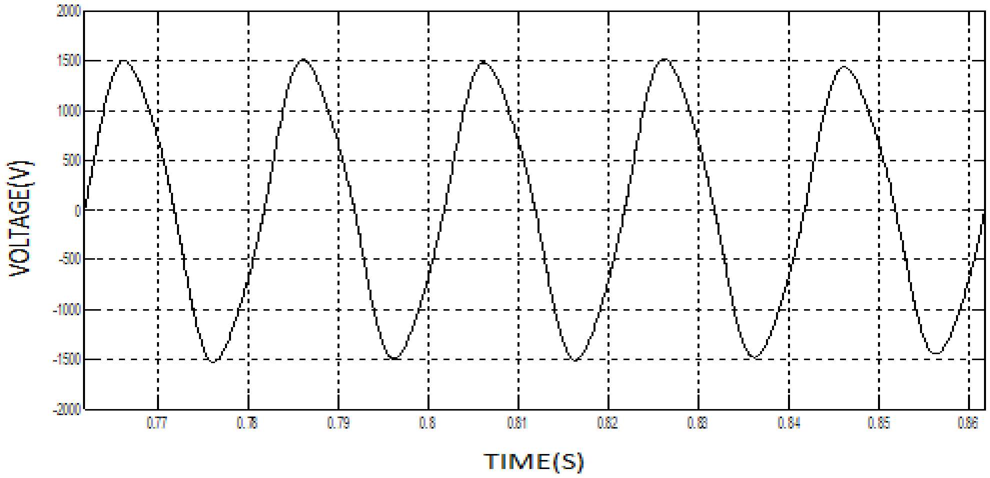

Fig 5. Filtered output voltage waveform for Z-Source MLI

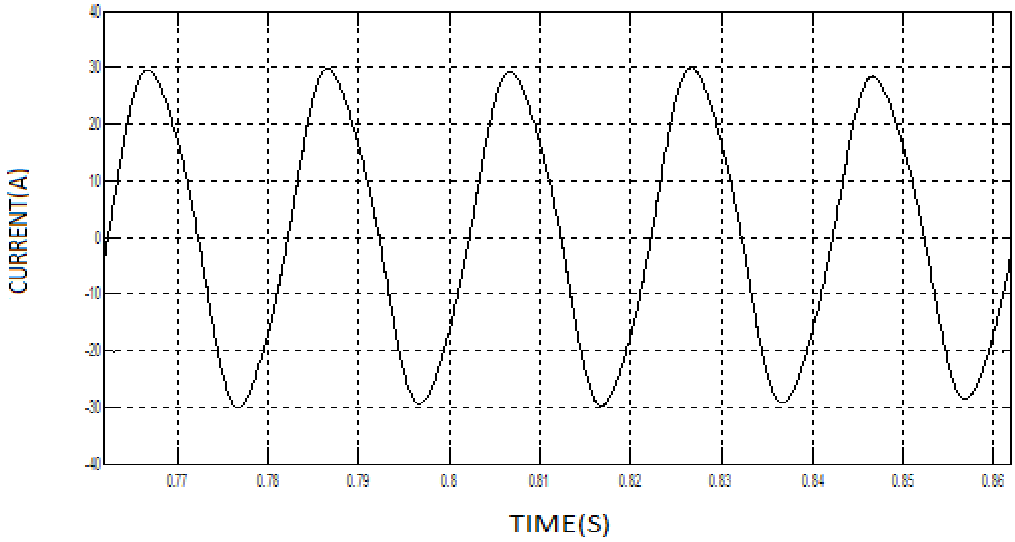

Fig .6 Filtered output current waveform for Z-Source MLI

Performance parameters of Z -Source multilevel Inverter are analyzed for various control methods which are implemented using third harmonic injection PWM technique [9-12]. Performance parameters are Total Harmonic Distortion, inductor current ripple of Z-Source inverter, capacitor voltage ripple of Z-Source inverter, voltage gain and voltage stress. Total Harmonic Distortion of five level Z-Source inverter is analyzed and compared for control methods- -simple boost control and maximum boost control. THD is calculated for various modulation index values and the comparison is shown in Fig.7.

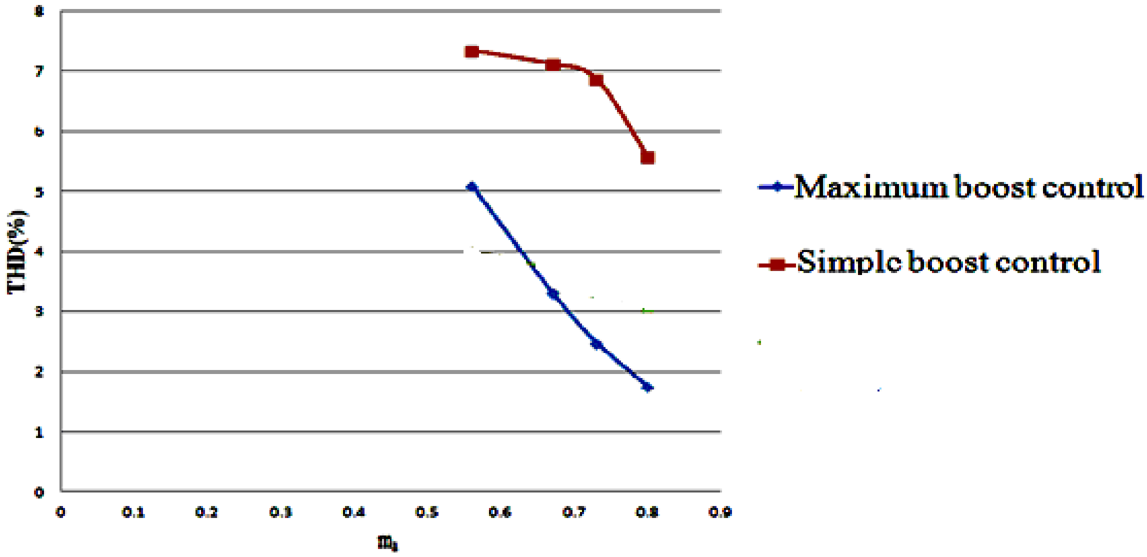

Fig .7 Effect of modulation index on Total Harmonic Distortion for three control techniques

From Fig .7, it can be concluded that the maximum boost control technique has reduced THD_v compared to simple boost for ma=0.8. Inductor current ripple is calculated across the inductor of z impedance of Z-Source inverter. Inductor current ripple is shown in table for various modulation strategies that changes with variation in modulation indices.

Table I **Effect of modulation index on inductor current ripple for three control techniques**

S.N0	m_a	SIMPLE BOOST CONTROL METHOD	MAXIMUM BOOST CONTROL METHOD
1	0.8	0.5	0.0598
2	0.73	0.6191	0.0680
3	0.67	0.7	0.0796

From the Table I, it is clear that maximum boost control has less inductor current ripple than simple boost control method. Capacitor voltage ripple is calculated across the capacitor of z impedance of Z-Source inverter. Capacitor voltage ripple is shown in table -II for various modulation strategies that changes with variation in modulation indices.

Table II **Effect of modulation index on Capacitor voltage ripple for three control techniques**

S.N0	m_a	SIMPLE BOOST CONTROL METHOD	MAXIMUM BOOST CONTROL METHOD
1	0.8	0.0414	0.1138
2	0.73	0.0362	0.8718
3	0.67	0.0230	0.8571

From the Table II, maximum boost control has the least capacitor voltage ripple which reduces the cost of the capacitor used. Voltage gain, G is calculated for various modulation strategies. In Fig.8, voltage gain in compared with different modulation indices for all modulation techniques. Voltage gain, G is given by [13,14],

$$G = \frac{2V_{ac}}{V_{in}} \quad (3)$$

where, V_{ac}=RMS value of output voltage
V_{in}=Input voltage

From the Fig 8 , maximum boost control technique has higher voltage gain compared to simple boost control method for ma=0.8.

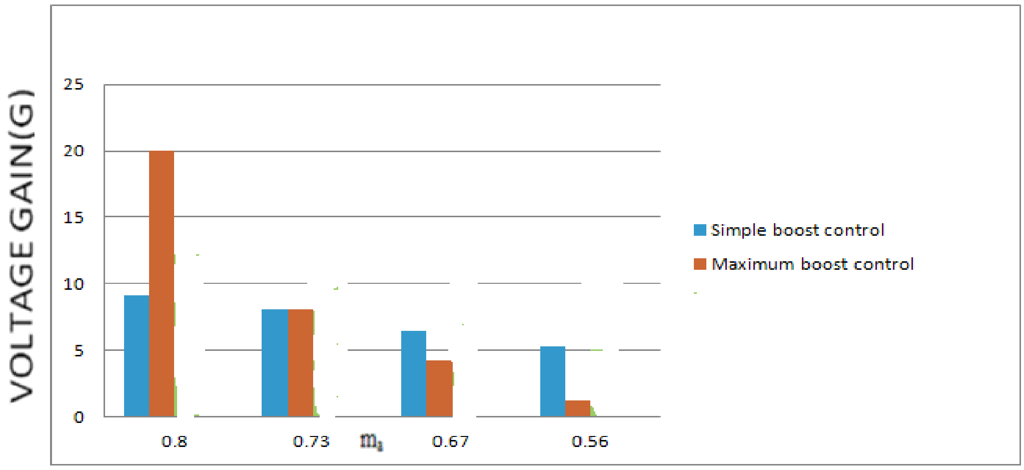

Fig 8 Effect of modulation index on voltage gain for three control techniques

In Figures 8, 9 and 10, voltage stress in compared with voltage gain for various modulation techniques. Voltage Stress is calculated from voltage gain as shown in equations (4-6). Voltage stress is given by [15],

Simple boost control: - $$V_S = 2 - \frac{1}{G} \quad (4)$$

Maximum boost control: - $$V_S = \sqrt{3} - \frac{1}{G} \quad (5)$$

Maximum constant boost control: - $$V_S = \frac{\Pi}{3\sqrt{3}G - \Pi} \quad (6)$$

Where, G=Voltage gain

Fig.9 to Fig.10 shows variation of voltage stress with voltage gain(G) for all three techniques.

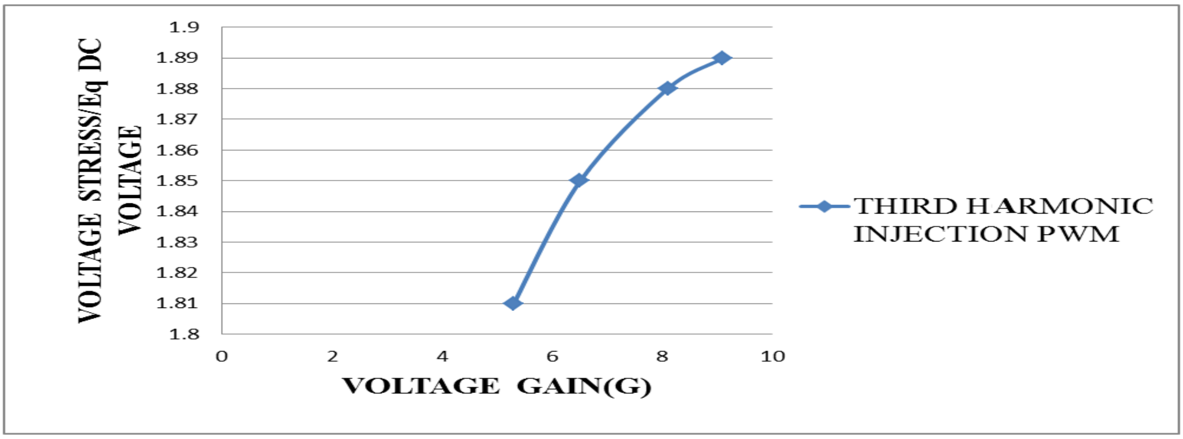

Fig 9 Effect of voltage gain on voltage stress for simple boost control method

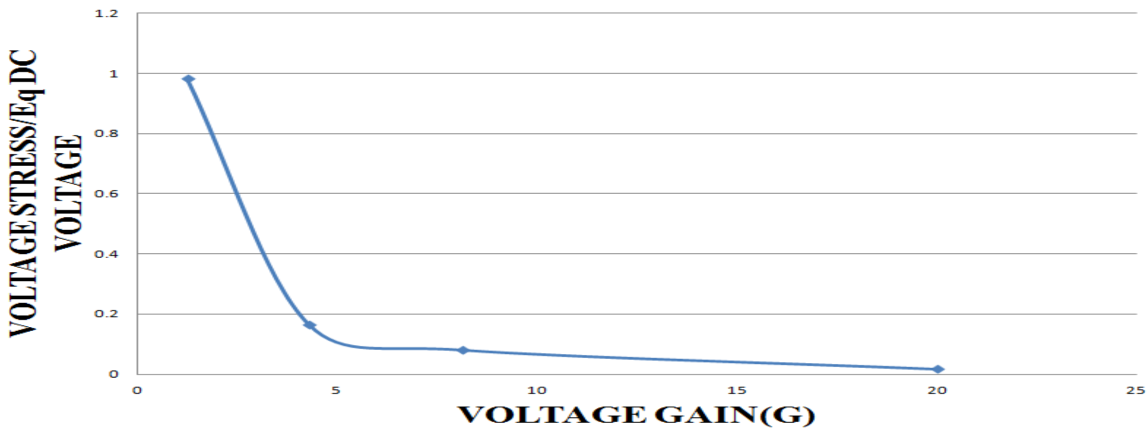

Fig 10 Effect of voltage gain on voltage stress for maximum boost control method

Table –III **COMPARISON TABLE FOR THE CONTROL METHODS**

S. NO	**PARAMETERS**	**SIMPLE BOOST CONTROL METHOD**	**MAXIMUM BOOST CONTROL METHOD**
1	THD_v	6.78	5.58
2	THD_i	6.62	5.16
3	Ripple in capacitor voltage	0.0414	0.1138
4	Ripple in inductor current	0.5	0.0598
5	Voltage gain(G)	9.107	20
6	Voltage stress	1.89	2.03
7	Boost factor(B)	1.25	3.09

From the Table III, it is observed that the maximum boost control method has less Capacitor voltage ripple which reduces the cost of the capacitor used and gives high voltage gain (G) and reduced voltage stress (V_S) compared to simple boost control.Inductor rating of maximum boost control method is reduced with third harmonic injection PWM technique and also ripple in the output current reduces thus reducing the cost of the filter. With this maximum boost control method, THD of the output voltage waveform has been reduced. Therefore maximum boost control method is preferred for the proposed topology.

V. CONCLUSION

This paper provides a clear overview on control techniques used in z-source multilevel inverters. It has been found that the maximum boost control method yields better results when compared to maximum boost control method. By employing the maximum boost control technique THD of the output voltage is reduced , inductor rating is reduced with third harmonic injection PWM technique, capacitor voltage ripple is less which reduces the cost of the capacitor used, ripple in the output current reduces thus reducing the cost of the filter , high voltage gain (G) and reduced voltage stress V_S. The impact of third harmonic injection has eliminated 3^{rd} order harmonic and multiples of 3^{rd} order harmonics there by reducing the output voltage THD (THD_v) and output current THD (THD_i).

REFERENCES

[1]. M. Reza Banaei and A.R. Dehghanzadeh, "A Z-Source novel based multilevel inverter for renewable sources fed DVR", *IEEE International Conference, Power Quality Conference (PQC)*, pp.1-6, 2011.

[2]. M.R. Mohamad Reza Banaei and A.R. Ali Reza Dehghanzadeh, "DVR based cascaded multilevel Z-source inverter", *IEEE International Conference, Power and Energy (PECon)*, pp.51-56, 2010.

[3]. Y. Tang, S. Xie, C. Zhang and Z. Xu, "Improved Z-source inverter with educed Z-source capacitor voltage stress and soft-start capability", IEEE Trans. Power Electron., vol. 24, pp. 409-415, Feb. 2009.

[4]. J. Holtz, "Pulse width modulation – a survey", *IEEE Trans. Ind. Electron.*, vol. 39, pp. 410-420, 2009.

[5]. Miaosen Shen and F.Z. Peng, "Modulation methods and characteristics of the Z-Source inverter with small inductance", *Industry Applications Conference, Fortieth IAS Annual Meeting*, Vol. 2, pp. 1253 – 1260, 2009.

[6]. P. C. Loh, F. Gao, F. Blaabjerg, and S. W. Lim, "Operational analysis and modulation control of three-level Z-source inverters with enhanced output waveform quality, " *IEEE Trans. Power Electron.*, vol. 24, no. pp. 1767–1775, Jul. 2009.
[7]. P. C. Loh, D. M. Vilathgamuwa, Y. S. Lai, G. T. Chua and Y. W. Li ," Pulse width modulation of Z-source inverters" , *IEEE Trans. Power Electronics*, Vol. 19, NO.3, pp.732-738, 2006.
[8]. P. C. Loh, D. M. Vilathgamuwa, C. J. Gajanayake, L. T. Wong and C. P. Ang, "Z-source current-type inverters: digital modulation and logic implementation", *IEEE Trans. Power Electron.*, vol. 22, pp. 169-177, 2007.
[9]. P. C. Loh, F. Gao, F. Blaabjerg and S. W. Lim, "Operational analysis and modulation control of three-level Z-source inverters with enhanced output waveform quality", in *Proc. EPE'07*, pp. 1-10,2007.
[10]. F. Z. Peng, M. Shen, and Z. Qian, "Maximum boost control of the Z- source inverter," *IEEE Trans. Power Electron.*, vol. 20, no. 4, pp. 833–838, 2006.
[11]. P. C. Loh, B. Flaabjerg, S. Y. Feng and K.N. Soon, "Pulse-width modulated Z-source neutral-point clamped inverter," *in Proc.IEEE. APEC'05*, pp.431–437, 2005.
[12]. F. Z. Peng, A. Joseph, J. Wang, M. Shen, L.Chen, Z. Pan, E. Oritz-River and Y. Huang, "Z-source inverter for motor drives," *IEEE Trans. Power Electron*., Vol. 20, No. 4, pp. 857-863, 2005.
[13]. A. Keith Corzine, W. Mike Wielebski, Fang Z. Peng and Jin Wang, "Control of Cascaded Multilevel Inverters", *IEEE Trans. Power Electronics*, Vol. 19, NO. 3, pp.732-738, 2005.
[14]. F. Z. Peng, "Z-source inverter", *IEEE Trans. Ind. Appl.*, vol. 39, pp. 504-510, 2005.
[15]. M. S. Shen , J. Wang and F. Z. Peng , "Maximum constant boost control of the Z-source inverter", IEEE Industry Applications Society Annual Meeting,pp.142-147,2003.

Biography

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