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A Simple Boost Shoot through Control for Single phase Quasi ZSI DC-DC Converters Based on Voltage Doubler Rectifier

***Abstract**. The Z-source inverters are recent topological options proposed for buck–boost energy conversion with a number of possible voltage- and current-type circuit. This paper presents new step-up DC-DC converter topologies with improved efficiency, nearly twofold increased gain, over twofold boost factor and reduced ripple free output. The topology contains quasi ZSI (Impedance Source Inverter) which has one diode, two capacitors, two inductors are used to maintain continuous current on the primary side for reducing energy losses in the output, a single phase isolation transformer, and a voltage doubler rectifier (VDR). There are two operating modes shoot-through (ST) and non-shoot through (NST) modes. For controlling quasi ZSI (impedance source inverter), Pulse Width Modulation (PWM) with duty cycle ratio control method is used. By implementing the Simple boost control method of shoot- through technique is achieved in quasi ZSI (impedance source inverter), voltage boost factor and component stresses are considerably reduced when compared to the conventional method.*

***Streszczenie.** W artykule zaprezentowano nową topologię przekształtnika DC-DC o zwiększonej skuteczności, zmniejszonych tętnieniach. Zastosowano dwa tryby pracy: shoot-through ST i non shoo through (NST). W układzie zastosowano podwójny układ prostowania VDR. Do sterowania przekształtnika ZSI wykorzystano układ PWM. **Proste sterowanie przekształtnika DC-DC typu ZSI bazujące na podwójnym prostowaniu napięcia**.*

Keywords: Impedance Source Inverter (ZSI), Shoot through technique, High efficiency, Pulse Width Modulation (PWM), Full-bridge converter.
Słowa kluczowe: przekształtnik ZSI, układ PWM, podwójne prostowanie\

Introduction

Due to demand in high efficiency and reduced losses, the input LC circuit is employed to reduce harmonic pollution and thus efficiency of the converter is improved. The quasi ZSI (Impedance Source Inverter) is capable of operating in both modes such as voltage or current fed mode. It can be used in buck or boost operation depending upon the mode of operation. The reliability of qZSI (quasi Impedance Source Inverter) is high due to shoot-through capability and low inrush current. These inverters are widely used in high voltage gain such as motor controllers or renewable energy systems. By using shoot through technique, it is possible to made conduction of phase switches of same leg. To overcome the problems in the conventional inverters, the Z source inverter was emerged in which bridge type inverter has been successfully combined with dc – dc converter. In addition it provides high efficiency, reliability and low cost for its buck –boost power conversion ability [1]-[3].

Magnetic energy can be increased by use of inductor at input terminals, without short circuiting the capacitors. Thus, improved inductive energy in turn increases the input voltage and ZSI (Impedance Source Inverter) operates as a conventional VSI (Voltage Source Inverter). The capacitors and inductors acts as a filter circuit which reduces input ripple and so efficiency can be improved. The MOSFET switches can conduct in a cross conduction so that switching losses will be greatly reduced.

The advantage of shoot through state was utilized by gating focused, for the same component rating; shoot through duty cycle is greatly reduced at the same voltage boost ability. In other hand, for the same component rating, shoot through voltage conversion is greatly increased nearly fourfold boost of the DC input voltage due to the presence of VDR in the back end output side. As a modification of popular voltage fed Z source inverter (ZSI), voltage fed quasi Z source (qZSI) with continuous input current are discussed [4-6]. Dmitri vinnikov [7], provides two fold voltage boost of the DC input voltage with the overlapping of the active states control technique.

In [10] Dmitri Vinnikov has dealt with an input voltage V_{in}= 40V, the duty cycle of active states and the maximum shoot through duty cycle was set at D_A= 0.5 and D_S= 0.5 per switching period in order to achieve the increased power density of the single stage converter. And also VDR implemented at its output side for its voltage doubling effect of the peak voltage of the secondary winding of isolation transformer.

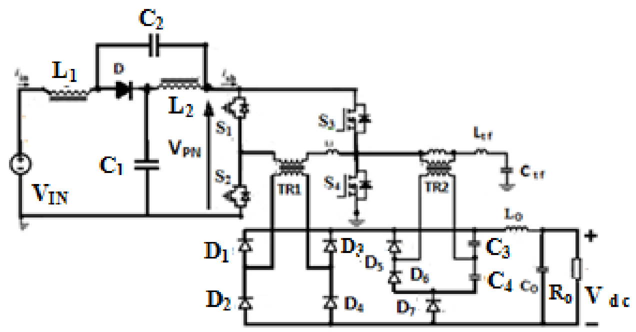

Fig.1. Proposed Converter.

To obtain a higher voltage gain with the same shoot through duty ratio D_S =0.2 and the modulation index in the voltage fed Z source inverter compares with the traditional Z source inverter with input voltage of V_{in}= 230V to the output voltage of V_{out}= 295 (peakV) [11]. The resonant period match with the switching period of converter due to the large variance of the leakage inductance TR2 and resonant capacitor C_3 in order to achieve the highest efficiency. Due to the reduced conduction losses of active states and output diodes with the lower current stresses, the converter provide higher output voltage and to get higher efficiency [12].

Trinh et.al [13], dealt with addition of more capacitors and inductors with the conventional ZSI (Impedance Source Inverter) system. By doing this, voltage stress and voltage level can be improved. Even though there is addition of capacitor and inductor to the conventional system, the cost and shoot through ratio is maintained same as that of conventional one. Further, voltage boost ratio can be improved. In order to improve the voltage boost level, concept of switched inductor is used. The reduced shoot through ratio produces increase in the voltage boost level. To realising the voltage boost level, Pulse Width Modulation (PWM) control method is used and also the design of passive components is explained. The SL and SC Z Source inverters are proved much higher gain and to keep their component stress on both lower and upper switch of phase leg to boost the dc bus voltage.

The shoot through states are eliminated when the DC input voltage is high and the qZS network based DC to DC converter starts to operate i.e. in the buck mode and in the conventional voltage source inverter when the front end DC voltage begins to reduce some below predefined value, qZS converter starts to working in the shoot through operating mode in order to achieve boost operating function. Hence qZS network based dc to dc converter working in the both operating condition i.e. buck-boost mode [14]. For renewable and alternate energy source qZSI is an attractive converter for its unique advantage of lower component rating s and constant dc Current from the source [15].

The improved inverter has a higher modulation index M with reduced Voltage stress on the dc link and current stress flow to the diode and transformer winding also lower input current ripple for the same transformer turn ratio and input and output voltage for the fixed modulation index M with reduced size Depends of problem and application under consideration on which select the controlling techniques because each technique has its own advantages and disadvantages and weight of the modulation index. For renewable and alternate energy source qZSI is an attractive converter for its unique advantage of lower component ratings and constant dc Current from the source [16]. As in [17] the combines the behaviour of two different converter topologies: LLC half-bridge converter operating at the load independent resonant frequency and the constant frequency phase-shifted full-bridge converter. The circuit diagram as in [17] has been modified i.e. introduce quasi impedance source network in between the DC input and single phase inverter which has one diode, two capacitors, two inductors are used to maintain continuous current on the primary side for reducing energy losses in the output source inverter). By implementing the Simple boost control method of shoot-through technique is achieved in quasi ZSI (impedance source inverter), voltage boost factor and element stresses are noticeably reduced when compared to the conventional method.

Basic Structure of Hybrid System

In Fig.1 the proposed novel diagram of hybrid dc-dc converter with qZSI is shown. Here, DC supply is given to impedance source network in order to provide wide range of voltage than the traditional voltage or current source inverter. The output from impedance network is given to leading or lagging leg of single phase inverter depending on type of output from network. The fundamental voltage and current can be controlled through use of single phase inverter. In many applications, a constant or adjustable voltage is required. So, in order to meet those requirements, a single phase inverter is used. The controllable AC output from inverter is stepped up by isolation transformers. Isolation transformers provide isolation of power device from power source and also it protects devices from electric shock or electric stress.

The primary rectifier is used to convert AC to DC and given to filter circuit in order to eliminate ripples in output. The voltage doubler rectifier is used to produce twice as that of input voltage at output terminals. The filter circuit consists of combination LC circuit or output capacitors. It is used to select desired range of frequencies. The voltage doubler is used to improve the level of voltage to a required level and get filtered to reduce the ripples. Ripple free pulse is given to load circuit. So, it results improved quality of output. Thus, efficiency of system gets improved than the conventional method.

In above figure.1 input current flows I_{in} through the coil L_1 and shunt current Ish flows through the switches. Based on the boosting factor, the level of input voltage can be increased or decreased by the use of impedance network. This network requires capacitance and inductance in small size and also it acts as a second order filter.

Assuming that quasi impedance network inductors L_{i1} and L_{i2} and capacitors C_{i1} and C_{i2} have same inductance (L) and capacitor (C) respectively, the quasi impedance source network becomes symmetrical.

Using symmetry condition

(1) $$V_{Ci1} = V_{Ci2} = V_C \ ; \ V_{Li1} = V_{Li2} = V_L$$

By observation of quasi impedance source dc-dc converter, the shoot through zero state for an interval of shoot through state interval T_{ST} during a switching cycle T_S can be reduces to the equivalent circuit, Fig .2 has

(2) $$V_L = V_C ; V_d = 2V_C \ ; \ V_i = 0$$

Consider that the quasi Z source Inverter Bridge in any one of non shoot through states for an interval of T_{NST}. Hence from the equivalent circuit, Fig. 2 has

$$V_L + V_C = V_{in} \ ; \ V_L = V_{in} - V_C \ ; \ V_d = V_{in}$$

(3) $$V_i = V_C - V_L = 2V_C - V_{in}$$

Where V_{in} is input dc voltage.

The average inductor over one switching period (T_S) should be zero, from equation (2) and (3), we get

(4) $$V_L = \frac{T_{ST}V_C + T_{NST}\left(V_{in} - V_C\right)}{T_S} = 0$$

or

(5) $$\frac{V_C}{V_{in}} = \frac{T_{NST}}{T_{NST} - T_{ST}}$$

Across the inverter bridge, average dc link voltage can be found as follows,

(6) $$V_i = \frac{T_{NST}}{T_{NST} - T_{ST}} V_{in} = V_C$$

Similarly, from (3), the maximum dc link voltage across Inverter Bridge can be rewritten as,

(7) $$V_i = V_C - V_L = 2V_C - V_{in} = \frac{T_S}{T_{NST} - T_{ST}} V_{in} = BV_{in}$$

where T_{ST} = Duration of shoot through state, T_{NST} = Duration of non shoot through state, T_S = operating period i.e. switching cycle.

(8) $$T_S = T_{ST} + T_{NST}$$

(9) $$B = \frac{T_S}{T_{NST} - T_{ST}} = \frac{1}{1 - \frac{T_{ST}}{T_S}(1+n)} = \frac{1}{1 - D_{ST}(1+n)} \geq 1$$

where n is number of stages.

If n=1 for traditional qZSI that is for single stage qZSI

(10) $$B = \frac{1}{1 - 2D_{ST}} \geq 1$$

D_{ST} is duty cycle of the shoot through state

(11) $$D_{ST} = \frac{T_{ST}}{T_S}$$

The modulation index of qZS main circuit will be decreased to a very low level and it can be expressed as,

$$M \leq 1 - D_{ST}$$

where M is modulation index

$$M = \frac{Amplitude\ of\ Modulation\ waveform}{Amplitude\ of\ carrier\ Waveform}$$

From (7),

$$(12)\ V_i = B.V_{in}$$

The equivalent dc link voltage of inverter is the maximum dc link voltage. Hence, the phase voltage of qZS inverter can be expressed as,

(13) $$V_{dc} = V_i$$

(14) $$V_{dc} = B.V_{in}$$

Resulting from shoot through state B is the boost factor. The equivalent dc link voltage of inverter is the maximum dc link voltage. Hence, phase voltage of qZS inverter can be expressed as,

(15) $$V_{ac} = M\frac{V_i}{2}$$

Using equation (7) & (12), equivalent dc link of inverter can be further expressed as,

(16) $$V_{ac} = M.B.\frac{V_{in}}{2}$$

Above equation further expressed as in terms of buck-boost factor

(17) $$V_{ac} = B_{BB}.\frac{V_{in}}{2}$$

where B_{BB} is buck boost factor.

(18) $$B_{BB} = M.B = (0 \approx \propto)$$

The qZSI based dc-dc converter starts to function as traditional VS based dc- dc converter without shoot through condition, when input voltage is high enough, thus performing only buck function of the input voltage. From (1), (5) & (10), the capacitor voltage can expressed as,

(19) $$V_{C1} = V_{C2} = V_C = \frac{1 - D_{ST}}{1 - 2D_{ST}}.V_{in}$$

Note that the Boost factor B in (10) can be controlled by shoot through duty cycle D_{ST} which can be decided by interval of shoot through time T_{ST}. Also, buck boost factor B_{BB} is determined by the modulation index M and boost factor B. In the simple boost method Pulse Width Modulation (PWM) techniques the modulation index M can be determined by the ratio of the amplitude of the modulation waveform to amplitude of the carrier waveform.

The voltage conversion ratio of qZS inverter can be expressed as,

(20) $$G = V_{ac} = M.B.\frac{V_{in}}{2}$$

Hence From (1) & (14), the quasi impendence network can perform the step-up dc–dc conversion from V_{in} to V_{dc}, thus the numerical condition D_{ST} is limited to,

(21) $$0 \leq D_{ST} \leq 0.5$$

Simulation Result and Discussion

In fig.2 the block diagram of gating signal generator is shown. The various input pulses such as sinusoidal and ramp is compared with relational operator. The Pulse Width Modulation (PWM) signals are generated and part of output is inverted through logic gates to perform the control process of active and zero states. Thus, inverted output signal is given to thyristor switches S_1 and S_3 to turn ON. The relational operators used to analysis and compare the amplitude of various signals given as an input. The Pulse Width Modulation (PWM) with logic gates and comparator provides the control circuit for active and zero states.

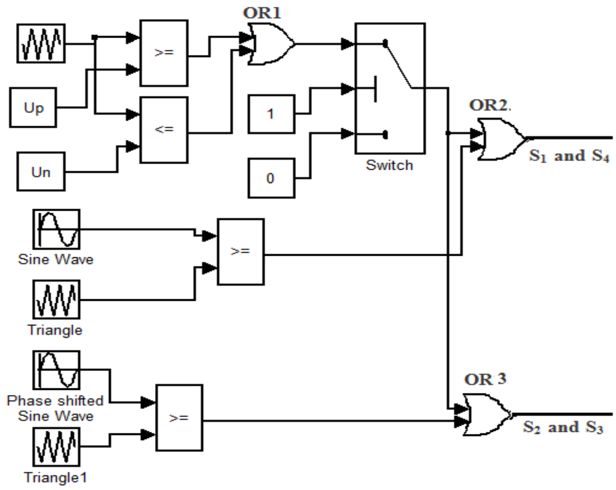

Fig .2 Generalized block diagram of gating signal generator

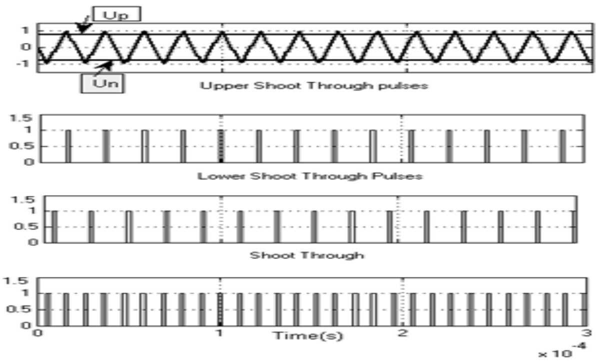

Fig.3 Generation of upper and lower shoot through pulses

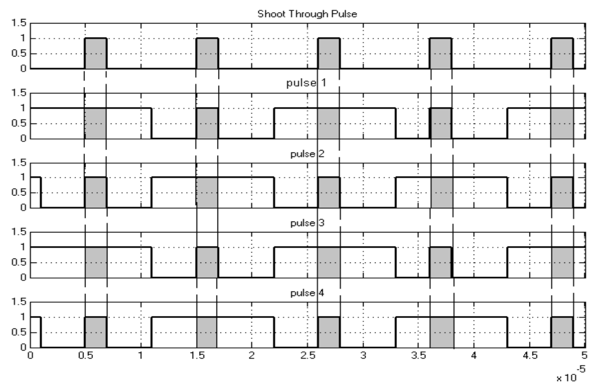

Fig.4 Pulses of various switches

The OR gates are used to perform addition of active and shoot-through states. Therefore, switches S_2 and S_4 get operated according to the gating signals. The shoot through states is controlled by comparator signals. The upper and lower level signals output are compared with the help of comparator. The output from comparator is given to logic

OR3 and given as one of the input to OR1 and OR2. The resultant is used to operate switches S_2 and S_4.The generation of shoot through pulses are given by Fig.3.The upper and lower shoot through pulses generated are shown in figure. The peak of pulses is produced with reference DC line voltages. The lower and upper shoots through pulses are generated by comparing with the reference signal. The lower shoot through pulses is produced as inter-mediate pulses of upper shoot through pulses. These waves are modified and combined in order to reduce cost and reliability. Thus, the efficiency of power conversion can be greatly increased. In Fig.4; various pulses are generated based on input given by the gate signal. At any instant two pulses starts at same time period and remaining two pulse remains in zero position for small interval of time.

The analog output signals can be generated with combination of Pulse Width Modulation (PWM) and filter circuit. In order to generate different levels of analog signals, the duty cycle and pulse width of digital signal is varied. In Fig.5 & 6 the voltage and current waveforms of transformer 1 & 2 respectively are clearly shown and when compared to transformer 1, the time duration of pulse generation is less and distortion is also reduced. The distortion in current waveform is more than that of voltage waveform. The transformer 1 produces output with ripple rich current. This distortion can be reduced by use of filters or capacitive circuits

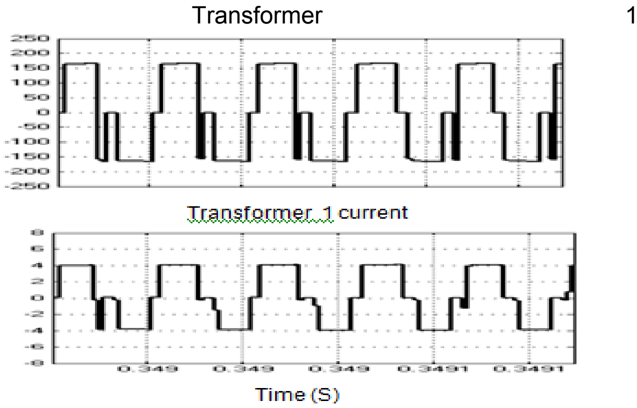

Fig.5 Zoom in view of voltage and current waveforms for transformer 1

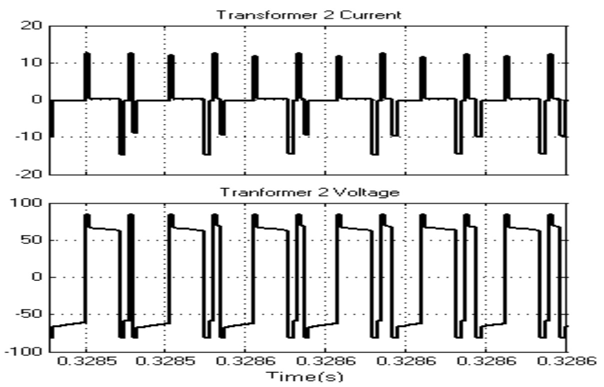

Fig.6 Voltage and current waveforms of transformer 2

Zoom in view of current waveform in the inductor 1 and 2 are shown in Fig.7. The current waveform of capacitor 1 & 2 waveforms during charging and discharging is shown in Fig.8. Fig.9 Output voltage and current waveforms when Up=0.7. The Fig.10 shows the boost control ability for proposed converter and compared with the existing system. The boost control ability for proposed system gets increased for rapidly for different shoot through condition i.e. for each duty cycle the boost factor gets increased rapidly. The current waveform gets distorted more than that of voltage. Thus, distortion can be reduced by use of filters. The current waveform is almost close to dc output and voltage waveform of inductor 2 is inverted output of inductor 1. The width of pulses is same for both voltage waveforms of inductors.

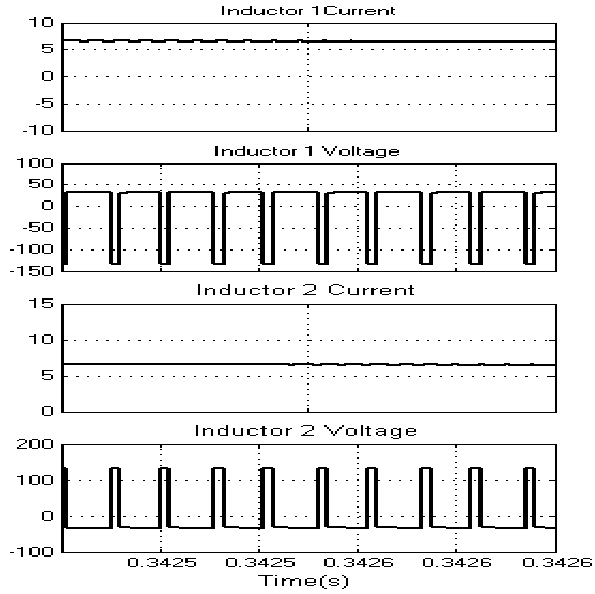

Fig.7 Zoom in view of Voltage and current waveforms of inductors

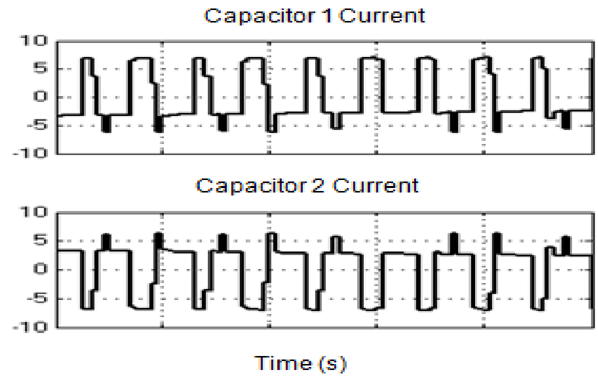

Fig.8 Current waveforms of capacitor

Table.1 Simulation Results of Boost Factor and Voltage Gain in various operating conditions

V_{in}	D_{ST}	M	B	G	V_{dc} across Load	
					Simu	Calc.
100V	0.1	0.9	1.25	1.125	112.5	112.5
	0.2	0.8	1.67	1.33	163	163
	0.3	0.7	2.5	1.75	250	250
	0.4	0.6	5	3.0	500	500
	0.45	0.55	10	5.5	1000	1000

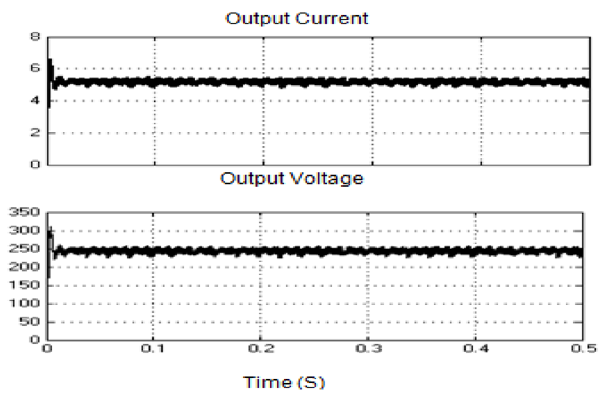

Fig.9 Output voltage and current waveforms when Up=0.7

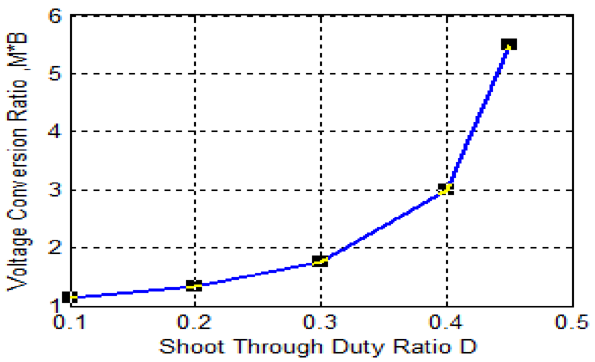

Fig.10. Maximum voltage conversion ratios of the proposed inverter, under the simple boost control condition for various Duty ratios.

Performance Analysis for Lossy System

The results are taken for various operating condition of boost factor and voltage gain. The simulation results are shown in the Table 1. The calculated value and simulated measured value of dc output voltages are under lossy system. Because the dc output voltage are including the voltage drop across the 47 ohm resistor. By using various duty cycle and modulation index condition, the results are taken for simple boost control condition. By varying duty cycle ratio, the output level of analogy signal can be increased and vice versa. In Fig.10 the output voltage can be improved with the aid of modulation index. The voltage conversion ratio gets increased with decrease in modulation index. To produce same 100V dc output voltage with the SB control of proposed control of cascaded converters with input Voltage V_{in} = 100, shoot through duty ratio D_{ST} = 0.3, modulation index M = 0.7 with voltage gain G = 3 and the boost factor B = 2.5 in the simulation with the simulation parameter of L_1 & L_2 = 3mH, C_1 & C_2= 10 μF and the switching frequency f_S = 47.6 KHz.

It can be explained with waveforms having different values of modulation index. The maximum voltage conversion ratio occurs at value of approximately 0.55. In Fig.10 the duty cycle ratio can be varied to improve the voltage conversion ratio. As voltage level is proportional to duty cycle ratio, the value of voltage conversion capability is also getting improved.

Conclusion

By using quasi ZSI, the energy losses can be greatly reduced in the output. While converting dc-dc, energy gets reduced by the use of quasi ZSI. During the energy conversion process, the loss of energy will be more and reduced by using proposed system. While converting ac-dc, it contains energy loss that also reduced in this method. The voltage boost factor can be improved with reduced voltage stress due to the use of shoot-through technique. When compared to the conventional method of DC-DC conversion, this method provides more efficient output. Further, the output ripples can be reduced by use capacitors to improve the efficiency of output. The value of Up can be adjusted to improve the performance of system.

REFERENCES

[1] F.Z.Peng, "Z source Inverter", IEEE Trans. On Industrial Power Electronics., vol. 39, no.2, pp. 501–510, Mar/Apr 2003.

[2] F.Z.peng and Miaosen Shen Zhaoming, "Maximum Boost Control of the Z Source Inverter", in the proc. of IEEE PSEC 2004.

[3] P.C. Loh; D.M.Vilathgamu; Y.S. Lai : G.T. Chua; Y.W.Li, " Pulse Width Modulation of Z source Inverter" , IEEE Trans. on Power Electronics., vol. 21, no.6, pp. 1346–1355, Nov2005.

[4] Anderson, J.; Peng, F.Z; Dichen Liu, "Four quasi – Z source inverters", in Proc. of IEEE power Electronics Specialists Conferences PESC'2008, pp.2743-2749, 15-19 June 2008.

[5] Yuan Li; Anderson, J.; Peng, F.Z; Dichen Liu, " Quasi Z source inverter for photovoltaic power generation", in Proc. of IEEE Applied power Electronics Conferences and Exposition APEC'2009,pp.918-924,15-19 Feb 2009.

[6] Jong-Hyoung Park; Heung-Geun kim; Eui-cheol Nho; Tae-Won Chun; jaeo Choi, "Grid connected PV system Using a Quasi – Z source inverters", in Proc. of IEEE Applied Power Electronics Conferences and Exposition APEC'2009, pp.925-929,15-19 Feb 2009.

[7] Ditri Vinnikov; Indrek Roasto; Ryszard Strzelecki, Marek Adamowicz "Two Stage Network Based Step Up DC/DC Converter", in Proc of IEEE, PP.1143-1148, 2010.

[8] Indrek Roasto; Dmitri Vinnikov; Tanel Jalakas; Janish Zakis; Silver Ott, "Experimental Study of Shoot Through Control Methods for qZSI Based DC/DC Converters", in Proc of IEE International symposium on Power Electronics SPEEDAM 2010 ,PP.29-34,2010

[9] Dmitri Vinnikov; Ryszard Strzelecki; Marek Adamowicz , "Performance Improvement Method for the Voltage-Fed qZSI with Continuous Input current", in Proc of IEEE PP.1459-1464, 2010.

[10] Dmitri vinnikov; Indrek Roasto, " Quasi –Z-Source – Based isolated DC/DC Converters for Distributed Power Generation" IEEE Trans. on Power Electronics., vol. 58, No.1, pp. 192–201, Jan 2011.

[11] Wei Qian; Fang Zheng peng; Honnyong , "Trans-Z-Source Inverters" , IEEE Trans. Power Electronics., vol. 26, No.12, pp. 3453–3463, Dec 2011.

[12] Wensong Yu; Jih Sheng Lai; Wei –Han Lai; Hongmei wan, " Hybrid Resonant and PWM Converters with High Efficiency and Full Soft switching Range" , IEEE Trans. On Power Electronics. vol. 27, No.12, pp. 4925–4933, Dec 2012.

[13] Quoc-Nam Trinh and Hong-Hee Lee, A New Z-Source Inverter Topology with High Voltage Boost Ability", Journal of Electrical Engineering & Technology Vol. 7, No. 5, pp. 714~723, 2012

[14] Ding Li; Poh Chiang; Miao Zhu; Feng Gao; Frede Blaabjerg, " Generalized Multicell Switched- Inductor and Switched Capacitor Z Source Inverters" , IEEE Trans. On Power Electronics. vol. 28, No.2, pp. 837–848, Feb-2013.

[15] H.bu-Rub; A.Iqbal; S.K.Moin Ahmes, F.Z.Peng; Y.Li ; G.Baoming," Quasi Z source inverter based photovoltaic Generation with maximum power tracking control using ANFIS", IEEE Trans. On Sustainable Energy2012.

[16] Minh-Khai Nguyen; Young-Cheol; Sung-Jun Park, "Improved Trans Z Source Inverter with Continuous Input Current and Boost Inversion Capacity", IEEE Trans. on Power Electronics. vol. 28, No.10, pp. 4500–4510, Oct-2013.

[17] N.Shobanadevi, Dr.V.Krishnamurty, Dr. N. Stalin, " A FB Hybrid Resonant Boost DC-DC Converter with ZVC Switching", International Journal of Scientific and Research Publications, Volume 3, Issue 6, pp.1-6 , June 2013.

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