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PISB Control of Single Phase Quasi Impedance Source DC-DC Converter

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Abstract

The objective of the proposed topology for buck boosts energy conversion with a reduced ripple in the output voltage and current. The proposed topology contains quasi impedance source network which has one diode, two capacitors, two inductors are used to maintain continues current on the primary side by implementing simple boost PWM technique with PI controller. By PISB (Proportional Integral Simple Boost) control method, the proposed DC-DC converter gets high efficiency, nearly twofold increased gain, over twofold boost factor and reduced ripple in the output voltage compared with the conventional method.

Keywords: Pulse Width Modulation, Proportional Integral Controller, Quasi Impedance Source Inverter, Simple Boost Control, Voltage Double Rectifier

1. Introduction

Due to demand in high efficiency and reduced losses, the input LC circuit is employed to reduce harmonic pollution, thus the 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 depends upon the mode of operation. Due to shoot-through capability and low inrush current the reliability of qZSI (Quasi Impedance Source Inverter) is high. 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 have 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].

In Figure1, 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 act as a filter circuit which reduces input its ripple, so that the 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 was greatly reduced for 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), voltages fed quasi Z Source (qZSI) with continuous input current are discussed[4–6]. Dmitri Vinnikov[7], provides two fold voltage boost of the DC

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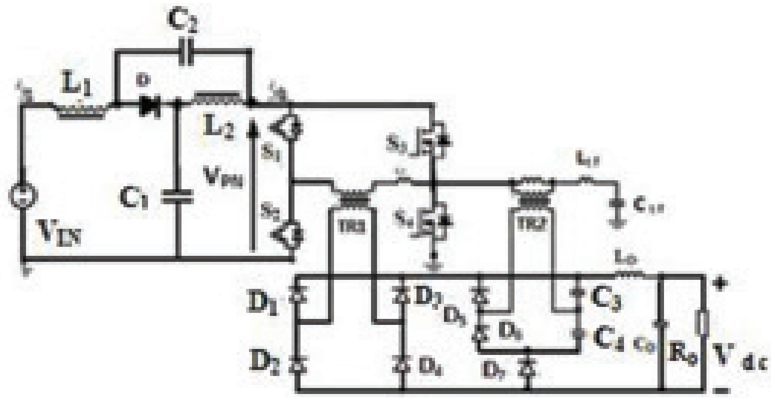

Figure 1. Proposed converter.

input voltage with the overlapping of the active states control technique.

Three dissimilar shoot through control methods are discussed in[8], by comparing all three methods Indrek Roasto accomplished that the shoot through control by the overlap of active states has the lowest switching frequencies. As in[9] vinnikov proved that the two stage qZS-network ensures continuous input current of the converter during shoot through mode. Moreover two stage qZS-network features over the 30 percent shoot through duty cycle reduction for the same voltage boost factor[10] are implemented with the an input voltage Vin = 40V the active duty cycle of active states ant 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 also VDR implemented at its output side for its voltage doubling effect of the peak voltage of the secondary winding of isolation transformer.

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 $V_{out} = 295$(peak)[11]. The resonant period has to match with the switching period of converter due to the large variance of the leakage inductance TR2 and resonant capacitor C3 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 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 through ratio produces increase in voltage boost level. To realizing 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 in[14].

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. 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 V 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 upon 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 rating s and constant dc Current from the source[16].

In[17,18], two inductors in the impedance Z network are replaced by a transformer with a turn ratio of 2:1 in order to attain a high voltage gain with the least component count. The trans Z source/quasi Z source inverter is extended to various structures in cascade topologies[19] and parallel operation for high power conversion system[20]. A proposed SMC is explained and implemented in a full-bridge converter using state averaging model. The study investigates two aspects of the proposed sliding mode; firstly, the effects of the controller parameters on the output and tracking performance. Secondly, the responses of the converter to sudden load and source changes are analyzed. The simulation results are demonstrates the robustness and accuracy of the proposed method[21].The new Single-stage solar based controlled full-bridge DC-DC converter is implemented. Solar model is connected to the input side. Using solar energy with less switching loss some constant voltage is given to the inductive load. Thus, efficiency of the converter is also increased. Compared with normal voltage source cost is less because in this work input side solar panel is used. The circuit diagram, operation of the converter and output waveforms has been explained and experimental results that confirmed the feasibility have been presented. The proposed circuit is got by integrating two boost PFCs resonant converter[22].

In Boost converter Small Signal Model (SSM), complete analysis is done for both ideal and non-ideal case. From the SSM of boost converter, transfer function of the both converters derived. Based on small signal output to controlled input (d), transfer functions root locus are plotted using MATLAB editor and script. Loop iterations are done to check the best step response and to obtain proper gain values of the PI control structure. After designing the controller parameters both ideal and Non-ideal cases are simulated using MATLAB Simulink and voltage response for both cases are compared[23]. The proposed paper of large signals improved one cycle control-technique shows the source side disturbance rejection and load side disturbance rejection in excellence. An improved one cycle control-technique is designed to control the duty-ratio (d) of the switch dynamically; therefore the control reference in each cycle is precisely equivalent to the switched variable's average value. The effective output signal is capable to trace the control reference within switching period of one cycle. The error correction of switching is done automatically within the switching period of one cycle. Thus, there is no possibility of getting the steady state error and dynamic error. i.e., both are zero[24].

2. Analysis of Proposed System

In Figure 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 L1 and shunt current I_{sh} 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 Li1 and Li2 and capacitors Ci1 and Ci2 have same inductance (L) and capacitor (C) respectively, the quasi impedance source network becomes symmetrical.

Using symmetry condition and equivalent circuit, we have

$$V_{Ci1} = V_{Ci2} = V_C \,;\, V_{Li1} = V_{Li2} = V_L \tag{1}$$

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, Figure 2 has

$$V_L = V_C\,;\; V_d = 2V_C\,;\; V_i = 0 \tag{2}$$

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, Figure 2 has

$$\begin{aligned} &V_L + V_C = V_{in}\,;\; V_L = V_{in} - V_C\,;\; V_d = V_{in} \\ &V_i = V_C - V_L = 2V_C - V_{in} \end{aligned} \tag{3}$$

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

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

Or,

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

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

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

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

$$\begin{aligned} V_i &= V_C - V_L = 2V_C - V_{in} \\ &= \frac{T_S}{T_{NST} - T_{ST}} V_{in} = BV_{in} \end{aligned} \tag{7}$$

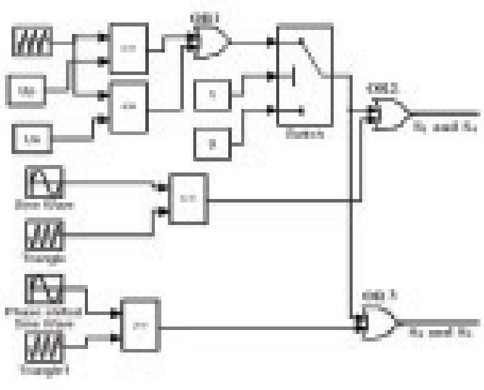

Figure 2. Generalized block diagram of gating signal generator for open loop.

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

$$T_S = T_{NST} + T_{ST} \tag{8}$$

$$\begin{aligned} B &= \frac{T_S}{T_{NST} - T_{ST}} = \frac{1}{1 - \frac{T_{ST}}{T_S}\left(1+n\right)} \\ &= \frac{1}{1 - D_{ST}\left(1+n\right)} \geq 1 \end{aligned} \tag{9}$$

Where n is number of stages
If n = 1 for traditional qZSI that is for single stage qZSI

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

DST is duty cycle of the shoot through state

$$D_{ST} = \frac{T_{ST}}{T_S} \tag{11}$$

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

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

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

Where M is modulation index
From (7),

$$V_i = B.V_{in} \tag{12}$$

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

$$V_{dc} = V_i \tag{13}$$

$$V_{dc} = B.V_{in} \tag{14}$$

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,

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

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

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

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

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

Where B_{BB} is buck boost factor.

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

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) and (10), the capacitor voltage can expressed as,

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

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 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,

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

Hence From (1) and (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,

$$0 \le D_{ST} \le 0.5 \quad (21)$$

3. Open Loop Control using Simple Boost Method

In Figure 2 the block diagram of gating signal generator is shown for open loop system. The pulses of active state for the switch S1 and S4 was generated by the interaction of the various input pulses such as sinusoidal and ramp is compared with relational operator. Similarly the pulses of active state for the switch S_2 and S3 was generated by the interaction of the phase shifted input sinusoidal pulse and ramps were compared with relational operator. In order to generate the shoot through states, two reference signals U_p and U_n were introduced. If the triangle waveform is greater than U_p, upper shoot through pulse was generated and lower than U_n, lower shoot through pulse was generated with the help of comparator. The output from comparator is given to logic OR1 and the shoot through pulses was generated by the upper and lower shoot through pulses logically added in the OR1. Thus the lower shoot through pulses was produced as intermediate 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. The output of OR1 is given as one of the input to OR2 and OR3. The OR2 and OR3 gates are used to perform addition of active and shoot-through states. According to the gating signals the ac link inverter switches turn in to shoot through state. During this operating condition the current through switches S_1 to S_4 reaches highest. The voltage across the ac link inverter during shoot through states drops to zero. The generations of shoot through pulses are given by Figure 3. In Figure 4 various pulses are generated based on input given by the gate signal. At any instant two pulses starts

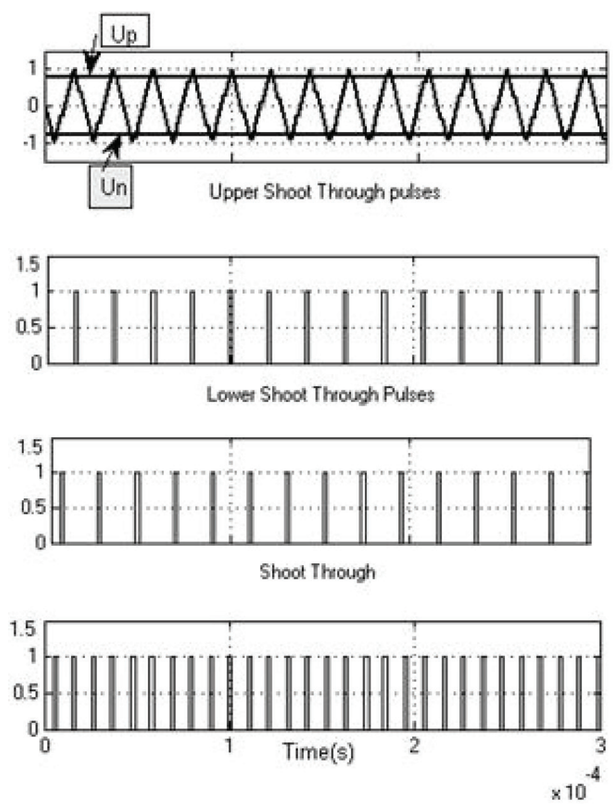

Figure 3. Generation of upper and lower shoot through pulses.

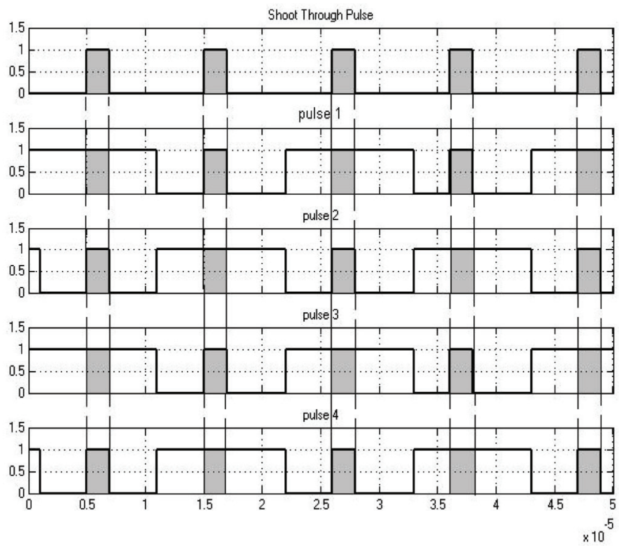

Figure 4. Pulses of various switches.

at same time period and remaining two pulse remains in zero position for small interval of time.

In order to generate different levels of analog signals, the duty cycle and pulse width of digital signal is varied. In Figure 5 shows the simulated waveforms of input voltage capacitor voltage 1 and 2 and ac link voltage are clearly shown and Figure 6 shows the enlarged simulated waveforms of input voltage capacitor voltage 1 and 2 and ac link voltage.

The current of inductor 1 and 2 waveforms, leading leg and lagging leg of shoot through duty ratio for DST = 0.3 are shown in Figure 7 also The Figure 8 shows simulated output voltage and current for proposed converter when Up = 0.7. 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 current waveform of inductor 1 and inductor 2. Table 1 shows the rapidly varying boost factor and voltage conversion ratio for various duty cycle ratio and

4. Closed Loop Control Using PISB Method

The compensator in this investigation is a PI Controller which is described by the following transfer function

$$G_C(S) = K_P + \frac{K_I}{S} \tag{22}$$

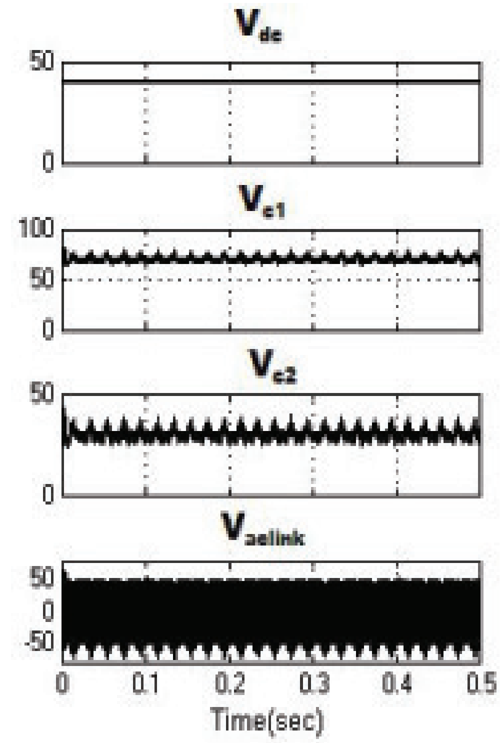

Figure 5. Simulated waveforms of input dc voltage capacitor voltage 1 and 2 and ac link voltage for DST = 0.3.

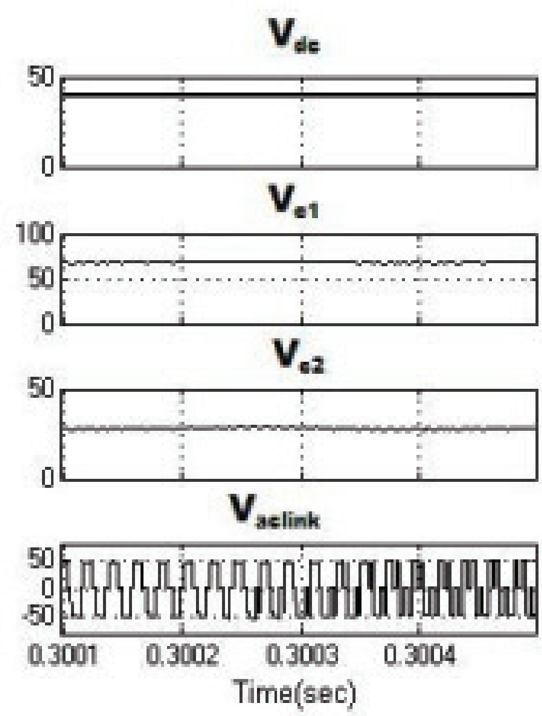

Figure 6. Zoom in view of the simulated waveforms of input dc voltage capacitor voltage 1 and 2 and ac link voltage for DST = 0.3.

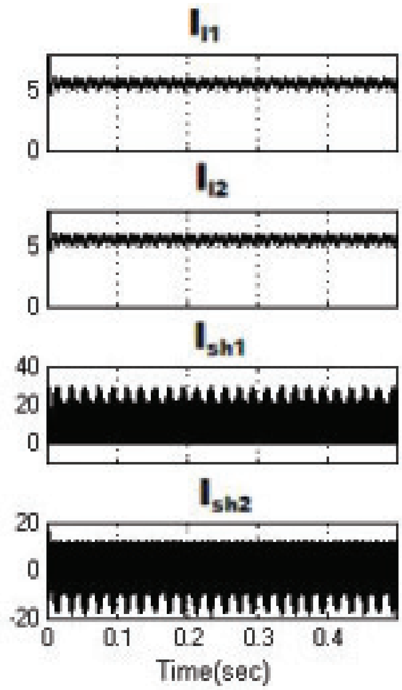

Figure 7. Simulated waveforms of current of inductor 1and 2, shoot through leading leg (Ish1) and lagging current (Ish2) under opn loop control.

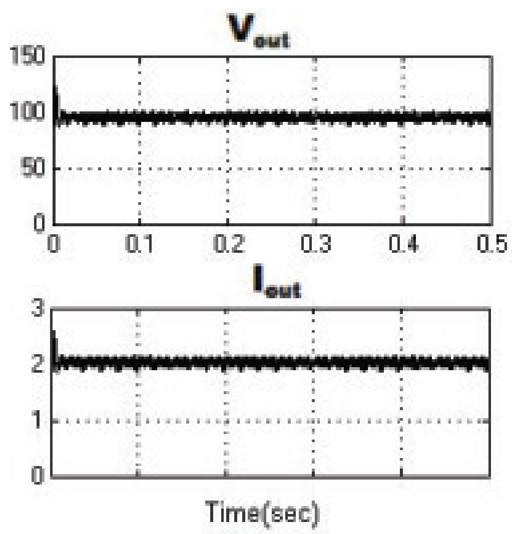

Figure 8. Simulated output voltage and current for proposed converter when Up = 0.7.

In this equation, K_p is the proportional gain, K_I is the integral gain. In Figure 9 the block diagram of gating signal generator is shown for closed loop system. The gating signal generator for closed loop control is same as that of open loop control except the Pulse Width Modulation (PWM) signals are summed with the PI controller. This

Table 1. Simulation results of boost factor and voltage gain in various operating conditions

V_{in}	D_{ST}	M	B	G	V_{dc}	
					Simu	Calc.
40V	0.1	0.9	1.25	1.125	45	50
	0.2	0.8	1.667	1.33	65.2	66.62
	0.25	0.75	2	1.5	77	80
	0.3	0.7	2.5	1.75	100	100
	0.4	0.6	5	3.0	200	200
	0.45	0.55	10	5.5	400	400

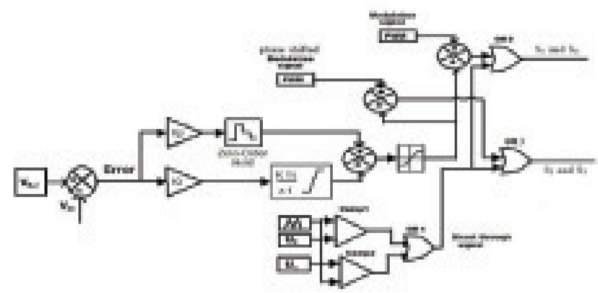

Figure 9. Generalized block diagram of gating signal generator for closed loop.

PI controller has one zero and one pole at the origin. The goal of the PI controller based simple boost (PISB) pulse width modulation control is to improve the transient response of output voltage and output current and V_{ref} is the value corresponding to the desired or the maximum dc output voltage. The steady state response for the shoot through duty ratio D_{ST} = 0.3 also examined. The ripple in the output voltage is very prominent under open loop operation is shown in Figure 8. The current of inductor 1and 2 waveforms, leading leg and lagging leg of shoot through duty ratio for D_{ST} = 0.3 are shown in Figure 10. In Figure 11 shows the simulated waveforms of input voltage capacitor voltage 1 and 2 and ac link voltage are clearly shown for the proportional gain and integral gain was set as Kp and KI = 0.002 under the closed loop operation of PI control . The magnitude of the ripple is largely reduced in the output voltage and current under closed loop operation and the waveform shows the perfect under damped second order system as shown in Figure 12. Table 2 depict comparison of the voltage stress capability across the capacitor 1 and capacitor 2 under the Open Loop Control (OLC) and the Closed Loop Control (CLC) that are in the accepted calculated value $V_{C1} = V_{C1}$ = 70V for the shoot

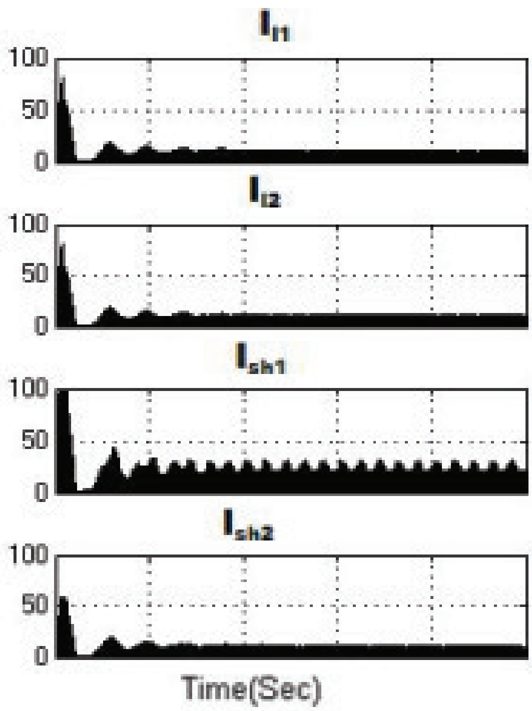

Figure 10. Simulated waveforms of current of inductor 1and 2, shoot through leading leg (Ish1) and lagging current (Ish2) under PI closed loop control for DST = 0.3.

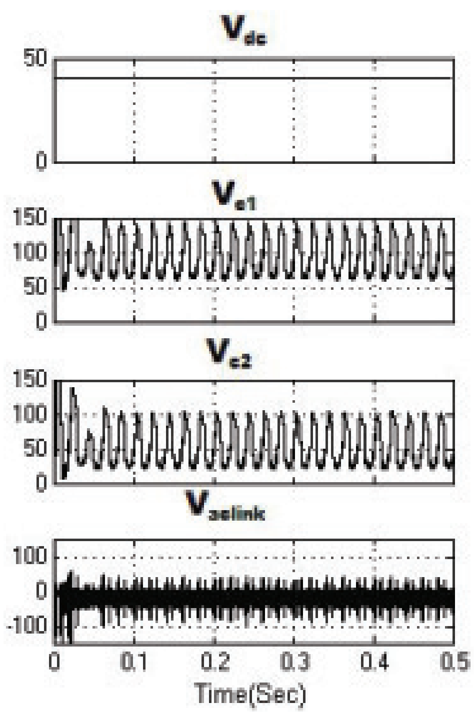

Figure 11. Simulated waveforms of input voltage capacitor voltage 1 and 2 and ac link voltage under the closed loop operation PI control.

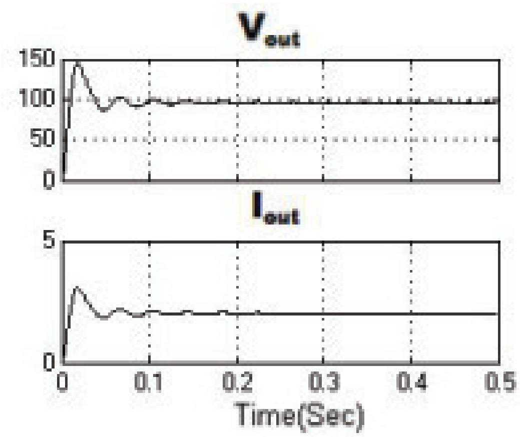

Figure 12. Simulated waveforms Output voltage and Output current under PI closed loop control for DST=0.3.

Table 2. Comparisons of capacitor voltages for various shoot through duty cycle for single stage and two stages

V_C	stage	$D_{ST} = 0.1$	$D_{ST} = 0.2$	$D_{ST} = 0.3$
V_{C1}	OLC	44.8	52.89	69.5
	CLC	49	53.41	70.5
V_{C2}	OLC	4.9	14.12	29.8
	CLC	14.68	13.34	28

through duty ratio $D_{ST} = 0.3$ as in equation (23) and as shown in Figure 11.

5. Performance Analysis

The results are taken for various operating condition for boost factor and voltage gain. The simulation results are shown in the Table 1. 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 Figure 12, 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 100 dc output voltage without PI Controller and 93 V with the PI controller based Simple Boost PWM control of proposed converters with input Voltage V_{in} = 40, 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 L1 and L2 = 3 mH, C1 and C2 = 10 μF and the switching frequency f_S = 47.6Hz. It can be explained with waveforms having different values of modulation index. It should be pointed out that the lower ripple in its output voltage and current with the PI controller. The maximum voltage conversion ratio occurs at value of approximately 0.55. In Figure 13, 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. From equation (19), voltage across the impedance network capacitor 1 and 2 for a single stage converter is

$$V_{C1} = V_{C2} = V_C = \frac{1 - D_{ST}}{1-(1+n)D_{ST}}.V_{in} = 70V(cal) \quad (23)$$

n = 1 for single stage

6. Conclusion

By using quasi ZSI, the energy losses can be greatly reduced in 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 stress and the voltage boost factor can be improved 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 drastically reduced by the Use Proportional Integral based Simple Boost (PISB) control to improve the efficiency of output.

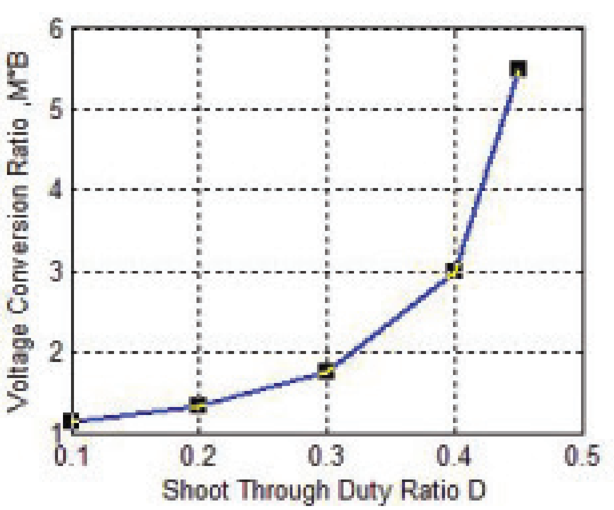

Figure 13. Maximum voltage conversion ratios of the proposed inverter, under the simple boost control condition for various Duty cycle ratios.

The value of Up can be adjusted to improve the performance of system.

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