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PISB Control of Single Phase Cascaded Quasi ZSI DC-DC Converter

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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 nine fold increased gain, over two fold boost factor and reduced ripple free output, the topology contains cascaded quasi ZSI (Impedance Source Inverter) which has one diode, three capacitors, four 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 proportional Integral based Simple boost control (PISB) technique is achieved in quasi ZSI (impedance source inverter), voltage boost factor and component stresses are considerably reduced and ripple in the output voltage are prominently reduced when compared to the conventional method, single stage quasi dc to dc converter.

Key words: Impedance Source Inverter (ZSI) · Shoot through technique · High efficiency · Pulse Width Modulation (PWM) · Full-bridge converter

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 unique characteristic of the qZSI/ZSI is known as allowing shoot-through states(e.g. both the upper and lower devices of any one, two or all three phase legs are gated on in a three-phase qZSI/ZSI) when doing conventional pulse-width modulation (PWM) for the dc-ac conversion. By doing so, the input voltage of qZSI-ASD system can be boosted to the higher dc-link voltage of the inverter bridge (Vpn), with which the voltage sag ride-through ability has achieved.

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 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 Fig. 1, 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

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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 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), voltage fed quasi Z source (qzsI) with continuous input current are discussed [4-6]. Dmitri vinnikov [7], provide two fold voltage boost of the DC input voltage with the overlapping of the active states control technique.

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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 Vin=230V to the output voltage of V_{out}=295(peak) [11]. The resonant period 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 reduced shoot through ratio produces increase in voltage boost level. For 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. This paper lower [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 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 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 rating s and constant dc Current from the source [16-18].

Analysis of Proposed 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.

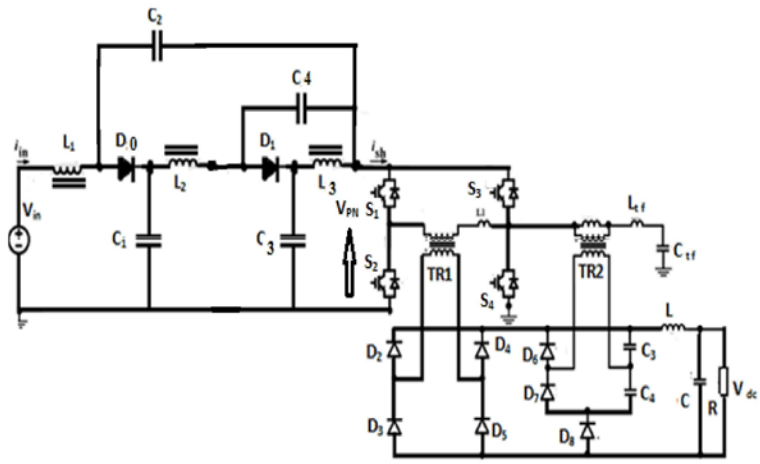

Fig. 1: Proposed converter.

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 Iin 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 which 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, Fig. 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 (TS) 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,

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

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

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

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

where n is number of stages

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

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

D_{ST} 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,

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

Where M is modulation index

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

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) & (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

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

Where B_{BB} is buck boost factor.

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

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

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

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,

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

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,

$$0 \le D_{ST} \le 0.5 \tag{21}$$

Closed Loop Control of Cascaded Quasi Converter Using Pisb Control: The compensator in this investigation is a PI Controller which is described by the following transfer function

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

In this equation, K_P is the proportional gain, K_I is the integral gain. In Fig. 2 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 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 Fig. 8. The complete generalized diagram of two quasi stage dc to dc converter shown in Fig: 4 also various stages of control signal generation are shown in Fig: 2 Fig. 6 Simulated waveforms of current of inductor 1& 2, shoot through leading leg (Ish1) and lagging current (Ish2) under PI closed loop control for D_{ST}=0.3. In Fig.7 shows the simulated waveforms of input voltage capacitor voltage 1 & 2 and ac link voltage are clearly shown for the proportional gain and integral gain was set as Kp & KI=0.002 under the closed loop operation of PI control for cascading stage of quasi converter and also. 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 Fig. 7. Table. 1 depict comparison of the voltage stress capability across the capacitor 1 and capacitor 2, capacitor 3 and capacitor 4 under the closed loop control (OLC) for various duty cycle ratio that are in the accepted calculated value V_{C1}= V_{C1} = 70V for the shoot through duty ratio D_{ST}=0.3 as in equation (23) and as shown in Fig. 6.

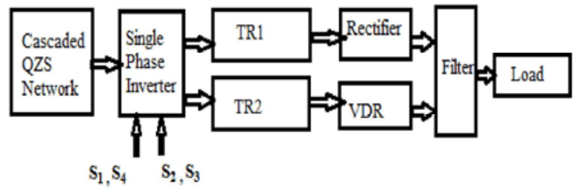

Fig. 2: Generalized block diagram of gating signal generator for closed loop

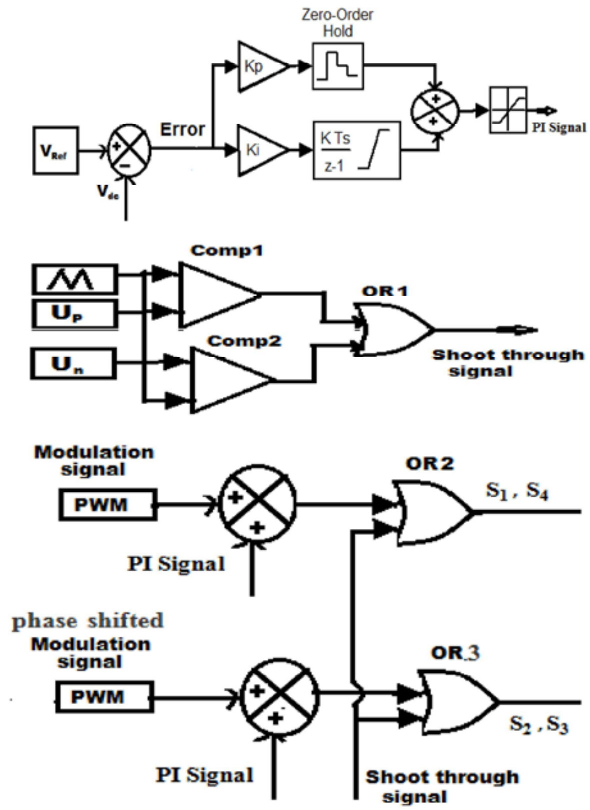

Fig. 3: Various stages of diagram of gating signal generator for closed loop

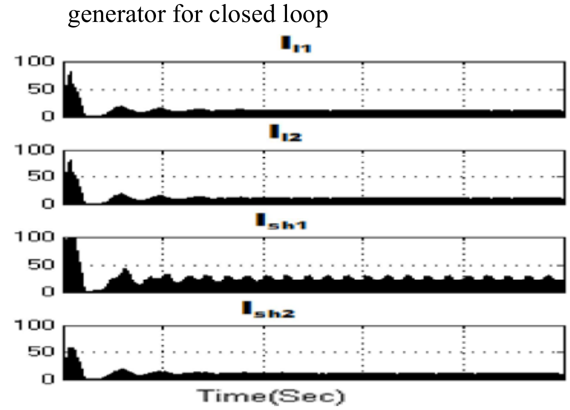

Fig. 4: Simulated waveforms of current of inductor 1& 2, shoot through leading leg(I_{sh1}) and lagging current (I_{sh2}) underPI closed loop control for D_{ST}=0.3

Table 1: Comparison of capacitor Voltages for various shoot through duty for cascaded Stage with PI closed loop

Capacitor Voltage across various V_C	D_{ST}=0.1	D_{ST}=0.2	D_{ST}=0.25	D_{ST}=0.3
V_{C1}	42.05	62.08	79.46	173
V_{C2}	9.162	38.77	73.16	233
V_{C3}	47.05	79.68	112.7	282
V_{C4}	9.62	38.77	73.6	233

Various capacitor voltages for single quasi converter and proposed cascaded stage converter simulated waveforms for the duty cycle ratio D_{ST}=0.25 and D_{ST}=0.3 are shown in Fig.5 and Fig. 6. Compared with two waveforms voltage stess on capacitor 1 and capacitor 2 nearly same for reduced duty cycle ratio D_{ST}=0.3 to D_{ST}=0.25 and much voltage hike on the capacitor 3 and capacitor 4 for cascaded stage quasi converter. Increased voltage stress on capacitor 3 and capacitor 4 is very essential to meet the boost requirement of output voltage and current. Fig.7 illustrate shoot through lagging leg current of 2A in the positive cycle and leading leg current of 0.5A in the negative cycle and summation of two current 1.5A current flows through the output under short circuit condition under PI closed loop control for D_{ST}=0.3; R=900 ohm for n=2. Output voltage 150 V and current 3.2A are obtained iunder PI closed loop control for D_{ST}=0.25; R=900 ohm for n=2. Various inductor currents waveforms are shown in Fig.8

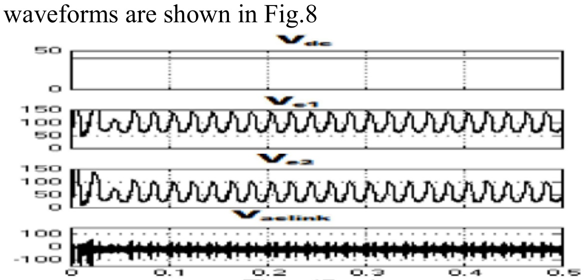

Fig. 5: Simulated waveforms of various capacitor, ac link and dc voltage with PI closed loop control for D_{ST}=0.25; n=1

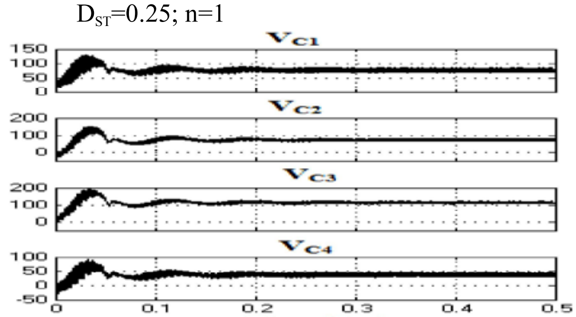

Fig. 6: Simulated waveforms of various capacitor voltage with PI closed loop control for D_{ST}=0.25; for n=2

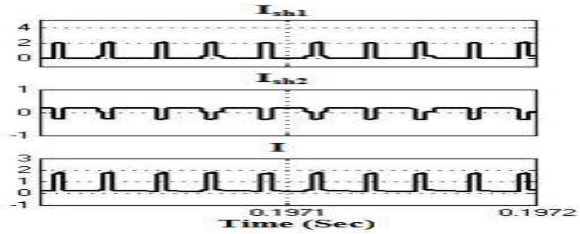

Fig. 7: Simulated waveforms of shoot through current of leading and lagging leg and under short circuit condition under PI closed loop control for D_{ST}=0.3; R=900 ohm for n

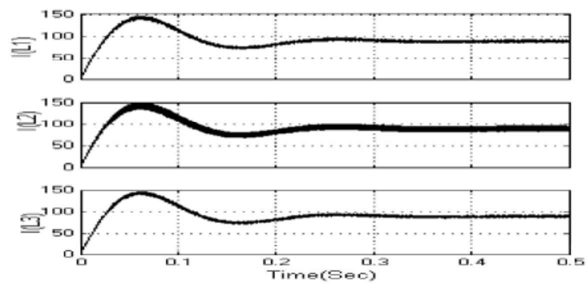

Fig. 8: Simulated waveforms of various inductor current underPI closed loop control for R $_{out}$ = 900 ohm,Dst=0.3,=2

Further increasing the duty cycle 0.25 to 0.3 correspondingly output voltage and =2 boost factor are rasised. Fig.11 and Fig.18 shows the simulated output voltage and output current waveforms for under PI closed loop control n=2 for the same duty cycle ratio D_{ST}=0.3. From the observation of two waveforms for the same duty cycle ratio of D_{ST}=0.3 ripples are drastically reduced and also output voltage and output current and boost factor are greatly increased in the cascaded stage compared with single stage.The comparision of output voltage and boost factor for duty cycle D_{ST}=0.25 ;n=1 and D_{ST}=0.3 ; n=2 for same input voltage are depicted in Table:2. From the observation of Table :2 increasing quasi network give output voltage, low ripple and high boost factor with reduced shoot through cycle ratio.

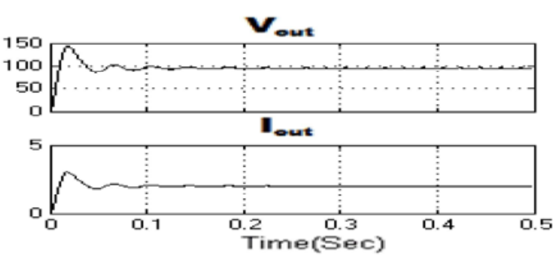

Fig. 9: Simulated waveforms of Output voltage and Output current underPI closed loop control for D_{ST}=0.3 for n=1

Table 2: Comparison of output Voltages for various shoot through duty cycle for n=1 & n=2

Duty cycle/ quasi stage	n=1 V_{out}	n=1 B	n=2 V_{out}	n=2 B
D_{ST}=0.25	77	2	150	3.75
D_{ST}=0.3	100	2.5	360	9

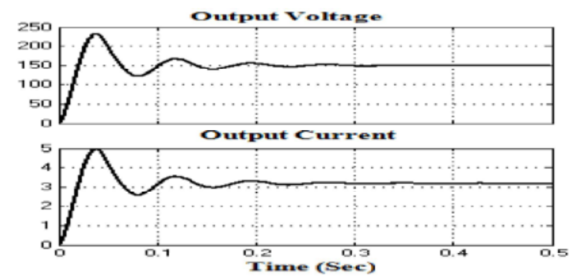

Fig. 10: Simulated waveforms Output voltage and Output current underPI closed loop control for D_{ST}=0.25 for n=2

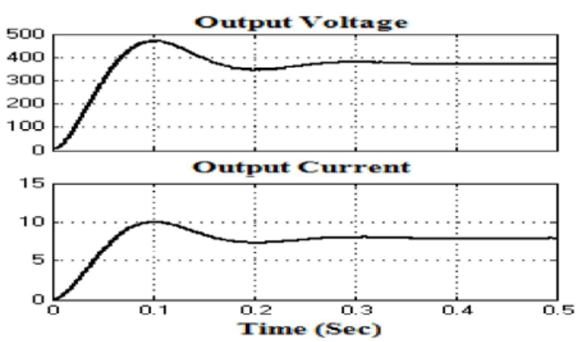

Fig. 11: Simulated waveforms Output voltage and Output current under PI closed loop control for D_{ST}=0.3 for n=2

Performence Analysis: The results are taken for various operating condition for boost factor and voltage gain. 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 and 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 100V dc output voltage without PI Controller and 360V with the PI controller based Simple Boost PWM control of proposed cascaded quasi converters with input Voltage Vin = 40, shoot through duty ratio D_{ST} = 0.3, modulation index M = 0.7 with voltage gain G = 9 and the boost factor B = 2.5 when using the SB control method the following simulation parameters are selected for the converters $L_1=L_2=L_3$=3mH, $C_1=C_2=C_3=C_4$= 20uF, R=900?. to demonstrate the waveforms the input voltage is set to 40V, switching frequency was f_s =46.6KHz,. 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 Fig.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 & 2 for a single stage converter is

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

$n = 1$ *for single stage*

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

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