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An Advanced Boost for Controlling the Gain and Minimizing the VS for ASC/SL-qZSI

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Abstract- **In this paper three control techniques simple boost, maximum boost and MCBC are rendered for ASC/SL-quasi-Source inverter topology. By utilitarian of max boost control technique G can be maneuvered for given MI and also minimizes the VS. While by means of MCBC it is made possible to overcome the low frequency ripple and also minimizes the VS. The switching techniques for the implementation of proposed control methodologies are also elaborated in this manuscript. Similarly the relationship of G against MI, VS versus G are also evaluated in detail and verified by simulations. key words:**

Index Terms-- **ASC/SL-qZSI, low frequency ripple, MI, Voltage gain, Voltage stresses.**

I. INTRODUCTION

As the population of human being increases, the energy demand increases with the every passing day. The energy demand is met with different type of energy resource which include renewable and nonrenewable energy resources. Some of the nonrenewable energy sources like coal power plants and combine cycle power plants causes global warming. While dams for hydel energy have their own negative retrospect's on the environment. This encouraged the researchers to shift towards environment friendly renewable energy sources like fuel cell, Biomass, wind forms and photovoltaic panel [1]. Most often, the extracted power from renewable energy like PV panel is in dc form, so we have to convert it into ac. Conventionally voltage source inverter (VSI) [2] and current source inverter (CSI) [3] are used for conversion processes. But the output ac voltage of VSI is less than that of dc voltage at input, so an extra dc-dc boost converter is needed to achieve the required ac voltage at output, which results in two stage power conversion. This two-stage conversion increases the circuit complexity, cost and power losses.

Furthermore, during the conversion process, a problem of shoot through may arise in which both the upper and lower switches of phase leg become simultaneously ON. This shoot through can cause damage in the circuit. To compensate these aforementioned limitations, Z-source inverter [4] has been developed which dominated over VSI to use the shoot-through state, to improve the G. In Z-source inverters, no extra boost converter is required so single stage conversion take place, which minimizes the total number of component and improves the system reliability. Due to their vast applications and advantages, the ZSI become prominent in the area of power electronics. Quasi Z-source inverter [5] have advantages over z-source inverter, QZSI have low component VS and draw continuous input current.

One of the major problem of qzsi (Quasi Z-source inverter) is that they have infinite theoretical gains, but in actual scenario their gains are restricted because of high VS on the components and minimum output power quality due to their low MI. Recently, some changes has been made in the circuit of qZSI/ZSI. The main motive of this amendment is to improve their boosting limit. Both the capacitor (C) and inductor (L) based switching designs has been developed [6]. Four converter topologies categories, classified as discontinuous or continuous current capacitor assisted boosts and discontinuous or continuous assisted boosts were introduced [7]. Referred from [8-10], many forms of switched inductor impedance networks linked

TABLE I

simple boost control	SBC
Maximum boost control	MBC
Maximum constant boost control	MCBC
Voltage stresses	VS
Modulation Index	MI
Voltage gain	G
Shoot-Through-State	STS
Non-Shoot-Through State	NSTS
duty ratio	DR
Third harmonic	TH

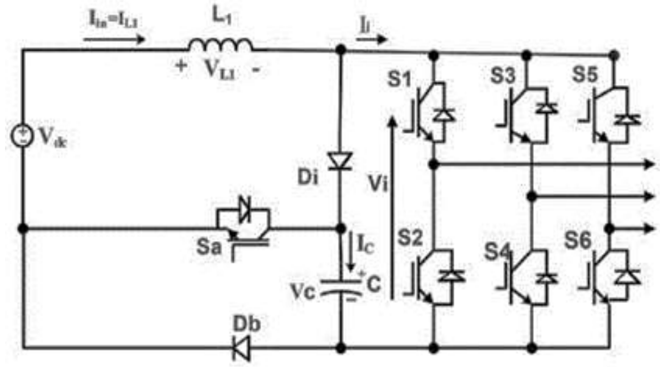


FIGURE 1. ASC-qZSI

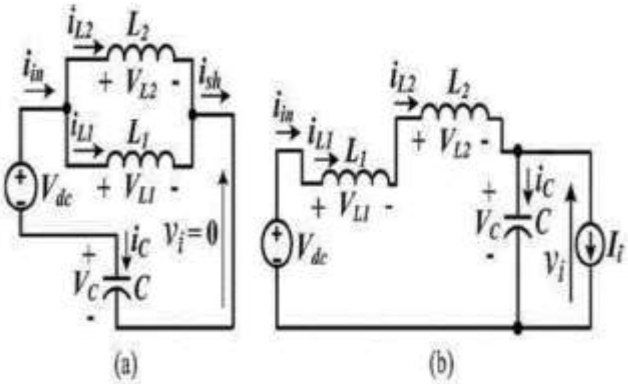


FIGURE 3. Equivalent circuits of ASC/SL-qZSI: (a) SH and (b) NSH

to a ZSI or qZSI were initiated. More cells are successively passed on generalized switched capacitors ZSI and switch inductors or non isolated dc-dc converter, for expanding the enhancement ability [11], [12]. Easy construction and high boosting ability in cascaded and transformer less constructions are given by them. Moreover, at impedance network, more inductors and capacitors are required to increase the enhancement element. they raise the expense as well as magnitude of power converter. Transformer based design of qzsi has been introduced in [13] and [14] which is also called T-source and trans-Z-source inverters which depends on turns ratio to improve the boost ability without adding any extra component. Furthermore to increase boosting ability, it need larger turns ratio, which required more insulation between the winding, and also causes the increase in leakage of inductance. To reduce the number of passive components, voltage and current source switched inverter topologies has been introduced in [15] and [16]. But the boost factor for both of them is limited as for classical ZSI. Further improvements have been made in the circuit of qZSI topology named as ASC-qZSI topology [17], Circuit contain an active switch consist of 1-inductor, 1-capacitor and 2-diodes couples the inverter bridge to the power source, as shown in Fig. 1. The boost factor of this topology is similar to that of a conventional qZSI.

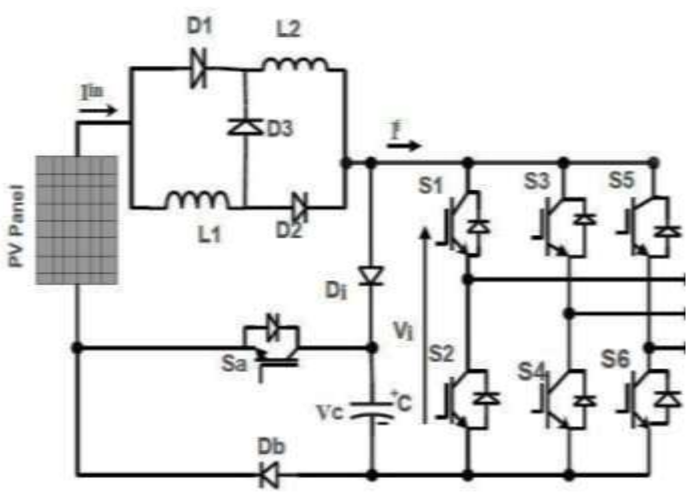


FIGURE 2. ASC-SL-qZS

To improve the boost factor, a cell consist of1-inductor and 3-diodes is added to the circuit of active switched capacitor Quasi Z-source inverter as shown in Fig 2. This inverter is named as active switched capacitor/switched inductor quasi-Z-source inverter (ASC/SL-qZSI) [17].

Circuit contain less passive components such as inductor and capacitor in impedance circuit then other Z-Source topologies, having low VS across the components and high boosting ability, also it requires a switching device to control the SH and NSHs as described in [17].

In this paper, we have implemented three different types of switching schemes (simple boost, max boost and max constant boost) on ASC/SL-QZSI. After this their comparison is elaborated in terms of G vs MI, voltage boost ability, switch voltage/current stresses, total harmonic distortion (THD) and output power quality. We have also recorded simulation results of all the techniques for comparing results of these techniques.

II. ACTIVE SWITCHED CAPACITOR SWITCHED/INDUCTOR QUASI Z-SOURCE INVERTER (ASC/SL QZSI)

Active switched capacitor/switched inductor quasi Z-source inverter is constructed by adding a cell contain 1-inductor and 3-diodes to the circuit of ASC-qZSI [17] as shown in Fig. 2. It operates in two states, shoot-through and non-shoot-through. The equivalent circuits of ASC/SL-qZSI in two states, shoot through and non shoot through are shown in fig. 3(a) and 3(b) respectively.

Shoot-through state is shown in the Fig. 3(a), In this switching device Sa as in basic ASC-qZSI is turned on and inverter bridge is shorted. Diodes D1 as well as D2 are ON and Di, Db along with D3 are OFF during this state. The L1 and L2 inductors are connected in parallel. Capacitor C through Sa switch and inverter bridge and DC input source Vdc helps the inductors to store charge, due to this there is the discharging of capacitor C.

As shown in Fig. 3(b), in the non-SH the switching device Sa is switched OFF and voltage is supplied to load side by inverter sup-plies. During non-shoot-through state, the diodes D1 as well as D2 are OFF and Di, Db along with D3 are ON. The inductors L1 and L2 are connected in series combination. Diodes D3, Di and Db helps the two inductors and dc input voltage to transmit power to capacitor as well as inverter. So because of this the capacitor C is charged. ASC/SL qZSI are characterized as the inverters with the improved boosting factor. Boost factor for ASC/SL qZSI can be written as

$$B = \frac{1 + D_{sh}}{1 + 3D_{sh}} (1)$$

Dsh is the shoot-through DR Dsh = (To/T), where to is the shoot-through time duration over switching period T. As explained in [4]

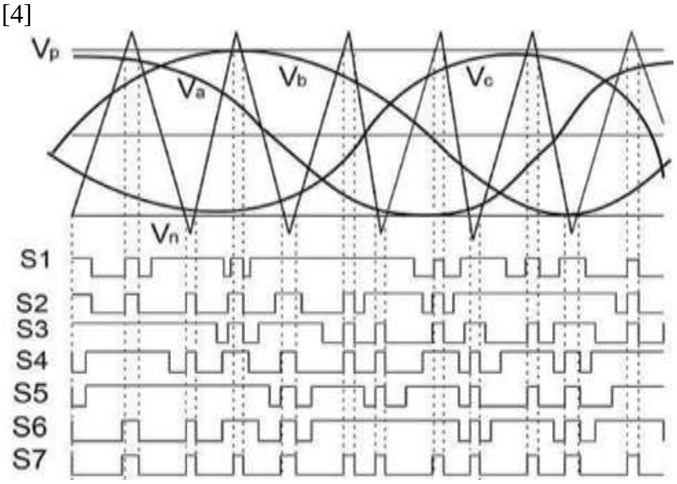


FIGURE 4. Switching Scheme for SBC

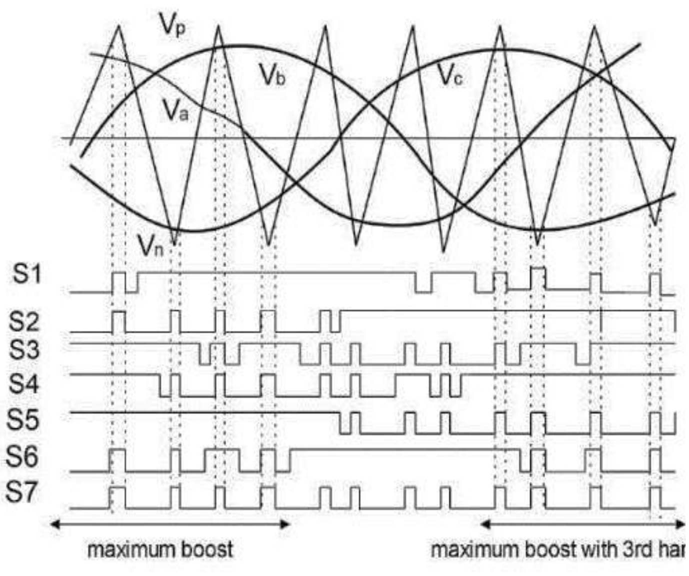


FIGURE 5. Switching scheme for max boost with and without 3rd harmonic injection

the voltage gain of inverter can be described as

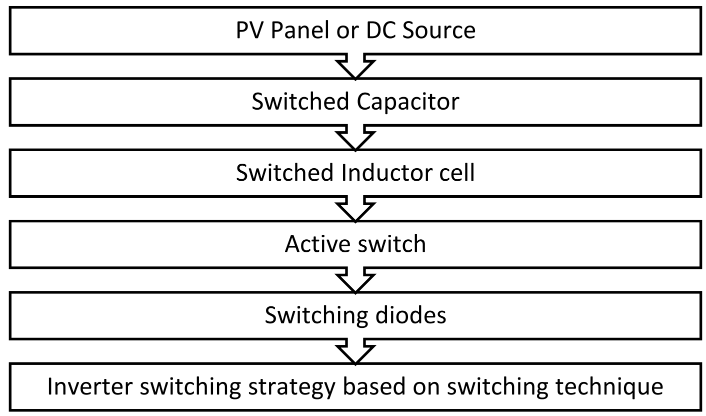
$$G = \frac{V_o}{V_{dc}} = MB \qquad (2)$$

where Vo is the peak output voltage, M is the MI and B is the boost factor which can b calculated by using (1) and (2)

$$B = \frac{1 + D_{sh}}{1 - 3D_{sh}} \qquad (3)$$

III. DESIGN AND IMPLEMENTATION OF THE PROPOSED SWITCHING METHODOLOGIES

Block diagram for proposed system is:



A. SIMPLE BOOST SWITCHING SCHEME

A switching technique, which is used to maintain the shoot through DRs as described in [18]. Figure 4 shows the SBC that comprises a straight line equal to or higher than the peak of three phase reference signal to maintain the shoot-through duty. As shown in Fig. 4, When carrier signal is greater or lower than the Vp and Vn signals respectively than shoot through will occur and switching device Sa is ON, in shoot through state. Duty ratio for SBC is $1 - M$, where M is MI, from equation it is clear that DR decreases as the MI increase, and DR is zero when M is one, so shoot through DR is restricted to 1-M

$$D=1-M \qquad (4)$$

In Fig. 7 curve named as SBC shows the maximum attainable G

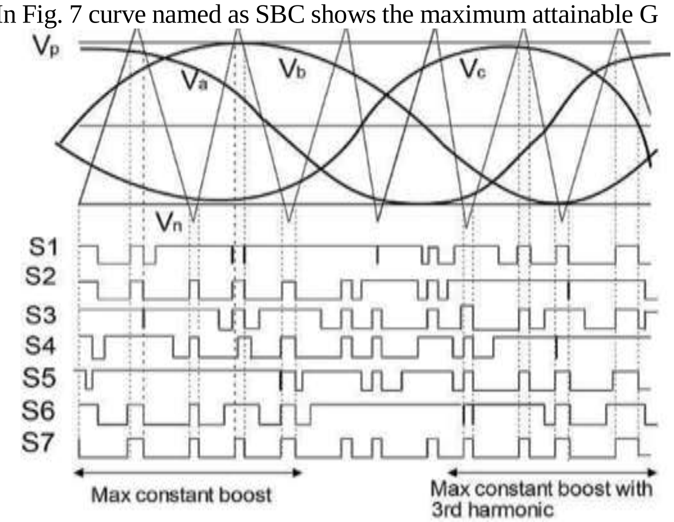


FIGURE 6. Switching scheme for max constant boost with and without 3rd harmonic injection

across the given MI.

In certain systems, where excessive G is needed, a small MI is used which causes VS on the switching components.
by using (3) and (4), Gain for SBC method can calculate as

$$G = \frac{2M - M^2}{3M - 2} \tag{5}$$

from (5), the maximum value of MI at which we can achieve desired G is

$$M = \frac{2 - 3G + \sqrt{9G^2 - 4G + 4}}{2} \tag{6}$$

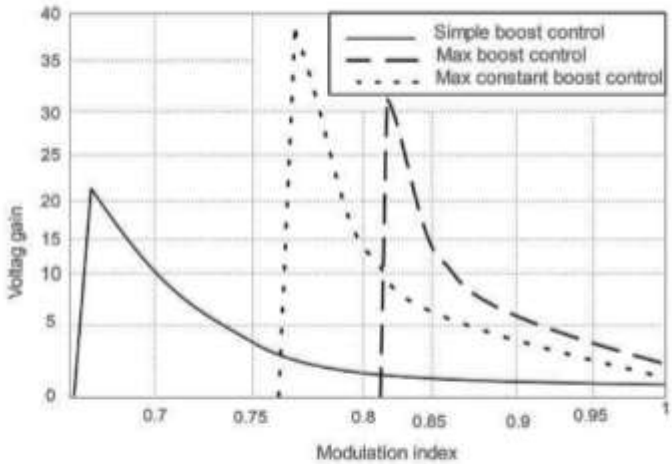


FIGURE 7. Voltage gain against MI

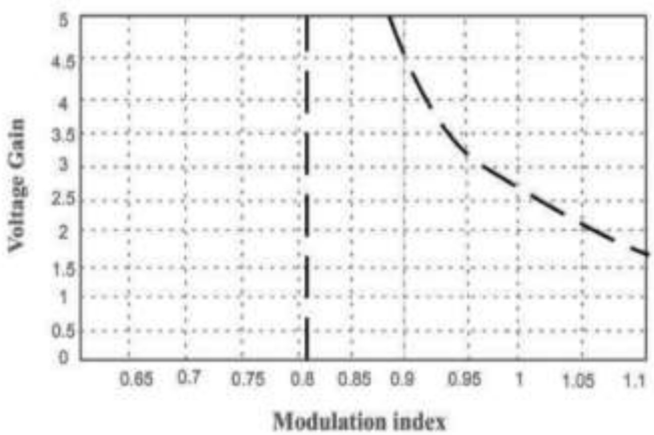


FIGURE 8. Voltage gain against MI with and without 3rd harmonic injection for max boost control

As described in [18] the VS over the switches is BVo.

$$Vs = BVo \tag{7}$$

so VS for this PWM technique can be calculated by using (6) and (7)

$$V_s = \frac{2G}{2 - 3G + \sqrt{9G^2 - 4G + 4}} \tag{8}$$

Voltage stress on the switching devices is shown in Fig. 10. By using SBC technique, VS on the switches is high.

Ratio of VS to Equivalent dc Voltage has been also analyzed in

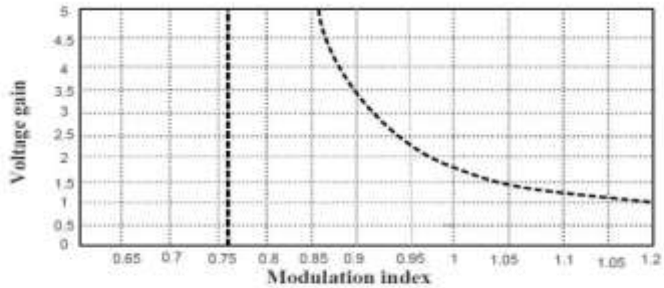


FIGURE 9. Voltage gain versus MI with 3rd harmonic injection for max boost control

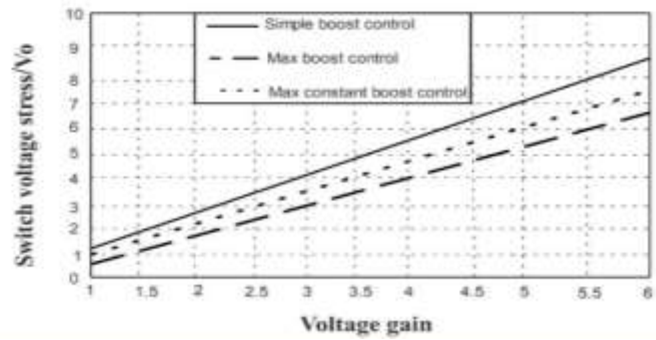


FIGURE 10. Switch VS against G

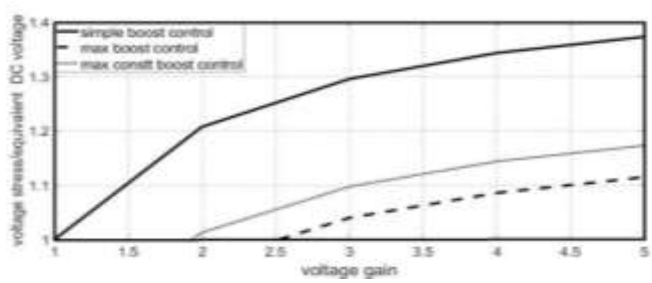


FIGURE 11. Stress ratio versus G

SBC switching technique. Equivalent dc Voltage can be defined as the lowest value of dc voltage required to generate output voltage and It is denoted by GVdc [19]. This ratio shows the cost that ASC/SL-QZS inverter has to pay to attain voltage boost. By using (7) and (8), ratio of VS to Equivalent dc Voltage can be calculated as

$$\frac{V_s}{GV_{cd}} = \frac{2}{2 - 3G + \sqrt{9G^2 - 4G + 4}} \tag{9}$$

In Fig. 11, curve show the stress ratio for SBC which is extremely high. The main drawback of using this switching technique is that the VS across the switches is high, which will affect the attainable voltage.

B. MAXIMUM BOOST SWITCHING SCHEME

In SBC of ASC/SL QZSI, The VS over the switching devices is quite high as shown in fig.10. To minimize VS across switching devices for required G is very crucial for ASC/SL-ZSI. required discussion we should have to maximize B for given MI to get desired G, consequently, from (1) so we should have to increase the DR at their maximum limit. For this purpose, a switching technique has been introduced named as maximum boost switching technique, which is almost similar to traditional PWM control technique. But the difference is that it sustains all six active states unaltered and convert each of the zero sate into SH, which is briefly described in [18]. Implementation of MBC technique on ASC/SL QZSI, and its PWM control scheme is shown in Fig. 5.

When triangular carrier signal is greater or lower than the reference curves Vp and Vn respectively, Shoot-through will occur and switch Sa is on in shoot through state.

from [18] DR for MBC is

$$D_{sh} = \frac{2\pi - 3\sqrt{3}M}{2pi} \quad (10)$$

Plot shown in Fig. 7, named as MBC, is between G versus MI. This curve provides a wider operating area compared to SBC technique, so provides larger MI for desired G, which in turn lower the VS on the switching devices.

From (3) and (10), gain for this control method can be calculated as

$$G = \frac{4piM - 3M^2\sqrt{3}}{9M\sqrt{3} - 4pi} \quad (11)$$

From (11), The maximum MI that can produce required G can be expressed as

$$M = \frac{-9G\sqrt{3} - 4pi + \sqrt{243G^2 - 24\sqrt{3}piG + 16pi^2}}{6\sqrt{3}G} \quad (12)$$

by using (7) and (12), the VS over the switches can be determined as

$$V_s = \frac{2\sqrt{3}}{-3G\sqrt{3} + 4_{\sqrt{27G^2 - 8\sqrt{3}G + 16}}} \quad (13)$$

Voltage stress against the given G is shown in Fig. 10.

If we compare to SBC technique, VS over the switches is very low in suggested switching technique, which results to produce high G. stress ratio has been also defined in simple boost and for maximum boost, strategy it is calculated as by using (7) and (13)

$$\frac{V_s}{GV_{cd}} = \frac{6\sqrt{3}}{-9G\sqrt{3} - 4pi + \sqrt{243G^2 - 24\sqrt{3}piG + 16pi^2}} \quad (14)$$

Figure 11 shows the VS to Equivalent dc Voltage (stress ratio) versus G. Curve shows that proposed method has relatively lower stress ratio in comparison with SBC. A TH is also injected in maximum boost strategy as plotted in Fig. 5. By the use of TH injection, MI(M) is p- [18]. Fig. 8 shows the plot between G and MI with 3rd harmonic injection, from which we can analyze that the operating area become wider due to increase in MI.

The G after TH injection is

$$G = \frac{2M - M^2}{3M - 2} \quad (15)$$

From (5) and (15), it is cleared that Gain for both control methods (with and without 3rd harmonic injection) is same. So, the VS for both is also same, difference is that MI range has been increased in TH injection.

But the main drawback of this technique is that all the zero states are changed into SH. Since the SH changes at six times the inverter frequency, due to this variation voltage and current ripples are produced because of passive components like inductor and capacitor respectively.

C. MAXIMUM CONSTANT BOOST SWITCHING SCHEME

To overcome these low frequency voltage and current ripples and to get maximum voltage boost, MCBC [19] is introduced, which is applied on ASC/SL QZSI topology [17]. Its PWM switching technique is shown in Fig. 6. Vp and Vn are constant shoot through envelopes, which are used to control the shoot through state, as described in [19-24]. when carrier signal is higher than the Vp or lower than Vn, SH will occur, and in SH the switching device S_a is ON. Maximum shoot-through DR that can attained from this control method is

$$D_{sh} = 1 - \frac{\sqrt{3}M}{2}$$

For this control method, G can be determined as by using (3) and (16) as

$$G = \frac{4M - \sqrt{3}M^2}{3\sqrt{3}M - 4}$$

Plot shown in Fig. 7, is between G and MI for max constant boost control technique. The G proceed towards infinity as MI (M) approaches to $\sqrt{3}/3$. From (17), highest value of MI which can produce required G is

$$M = \frac{-3G\sqrt{3} + 4 + \sqrt{(27G^2 - 8\sqrt{3}G + 16)}}{2\sqrt{3}}$$

Third harmonic component is injected into 3 phase reference volt-ages as shown in fig. 6. Voltage gain calculation is same for both control methods but the only difference is that in TH injection the range of MI increased from 1 to $2/\sqrt{3}$. Voltage gain for this control method can be expressed as.

$$M = \frac{-3G\sqrt{3} + 4 + \sqrt{27G^2 - 8\sqrt{3}G + 16}}{2\sqrt{3}} \quad (19)$$

The relationship between G and MI with 3rd harmonic injection is shown in Fig. 7. From (7) and (18), Voltage stress across the switches can be calculated as

$$V_s = BV_o = \frac{6\sqrt{3}}{-9G\sqrt{3} - 4pi + \sqrt{243G^2 - 24\sqrt{3}piG + 16pi^2}} \quad (20)$$

In Fig. 10 VS on the switches for max constant boost control is shown. Curve show that the VS is slightly lower than the SBC and little bit greater than the max boost control.

By using (7) and (20), Stress Ratio (VS/Equivalent dc Voltage) can be expressed as

$$\frac{V_s}{GV_{cd}} = \frac{2\sqrt{3}}{-3G\sqrt{3} + 4 + \sqrt{27G^2 - 8\sqrt{3}G + 16}} \quad (21)$$

Fig. 11 shows the comparison graph of all proposed switching techniques. As can be seen from figure that stress ratio for proposed technique is much lower than the SBC and slightly higher than the MBC. So, the stress ratio for this control method is ideally 1. The main advantage of this technique is that there will be no low frequency ripples linked with output voltage.

IV. SIMULATION RESULTS

To show the reliability of all of the three suggested control tech-niques, simulations have been performed. Fig. 1 shows the circuit configuration and all of the three switching control methods are applied on the the circuit, and the circuit parameters are set as shown in table 2.

TABLE II

PARAMETERS DESIGN OF PROPOSED INVERTER

Input voltage, Vdc	40v
fundamental frequency, f	60HZ
Switching frequency, fs	5KHZ
Capacitor, C	500uF
Inductor, L1 =L2	1mH
Output filter capacitor, Cf	100uf
output filter inductor, Lf	0.7mH

Saber software is used for simulation purpose. Because of constant duty cycle in shoot through state, the implementation of simulation by an analogue PWM circuit is easy. Simulation results for SBC method is shown in Fig. 12. According to (5), D is 0.3 and M is 0.7, Vpn which is also called VSes is 370v for SBC, which is quite high. As explained earlier, the switching device Sa is ON in shoot through state and inductors L1 and L2 stores energy, and in NSH, switch Sa is OFF and inductors L1 and L2 transfer their energy to both inverter and capacitor as shown in Fig. 12 To minimize VS, MBC is introduced. Simulation results for this technique is shown in Fig. 13. According to (10)-(12), we suppose that MI M=0.8, so we get D=0.28, Vpn = 315, B=10. By using 3rd harmonic injection MI increased to 1.1 and duty D=0.26, Vpn = 275, Vo = 220. Fig.14 shows the simulation results for MBC with 3rd harmonic injection In comparison to SBC, as shown the VSes in this case is relatively low. But it causes ripples on both inductor current and capacitor voltage. To overcome low frequency ripples across inductor and capacitor, MCBC strategy is introduced. Fig. 15 shows the simulation results for suggested technique. The simulation results with the modulation for MBC with MI M=0.82 without 3rd harmonic injection and Fig. 16 shows the simulation results for M=1.1 with 3rd harmonic injection. By using equations (16)-(18), we get duty D=0.258, Vpn = 240, Vo = 220. Due to 3rd harmonic injection, duty is adjusted to D=0.25 and Vpn decreased to 210V. Simulation results are:

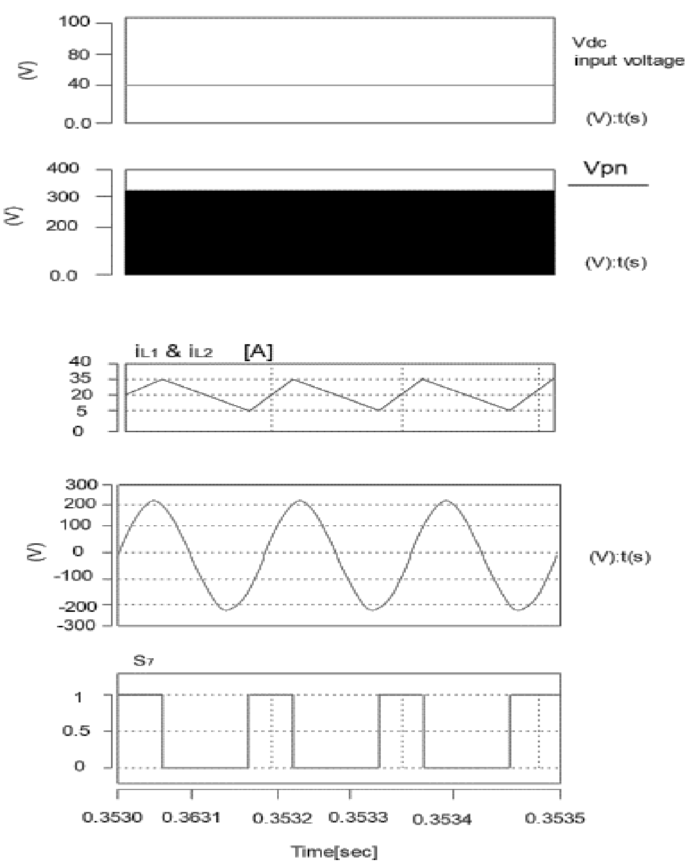


FIGURE 12. Simulation results for SBC

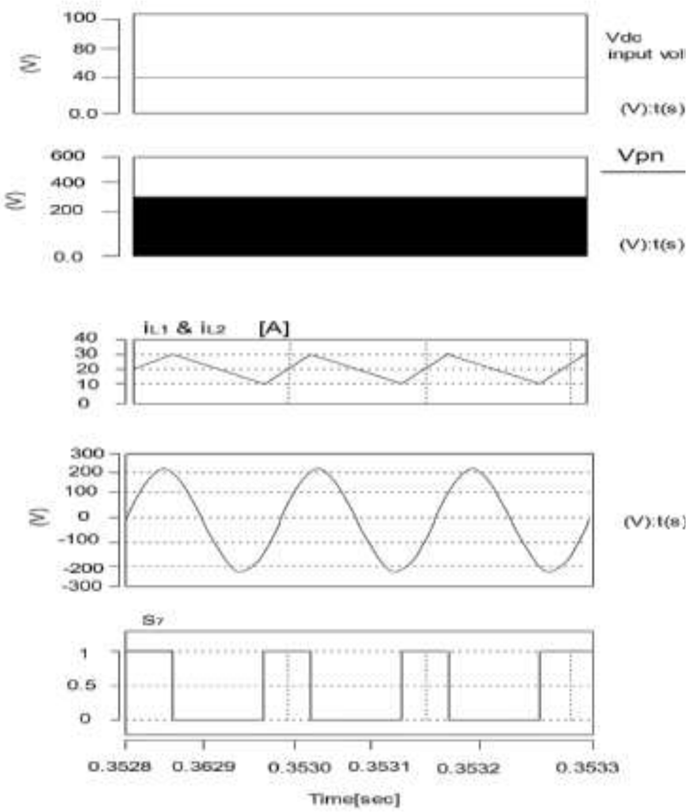


FIGURE 13. Simulation results for MBC

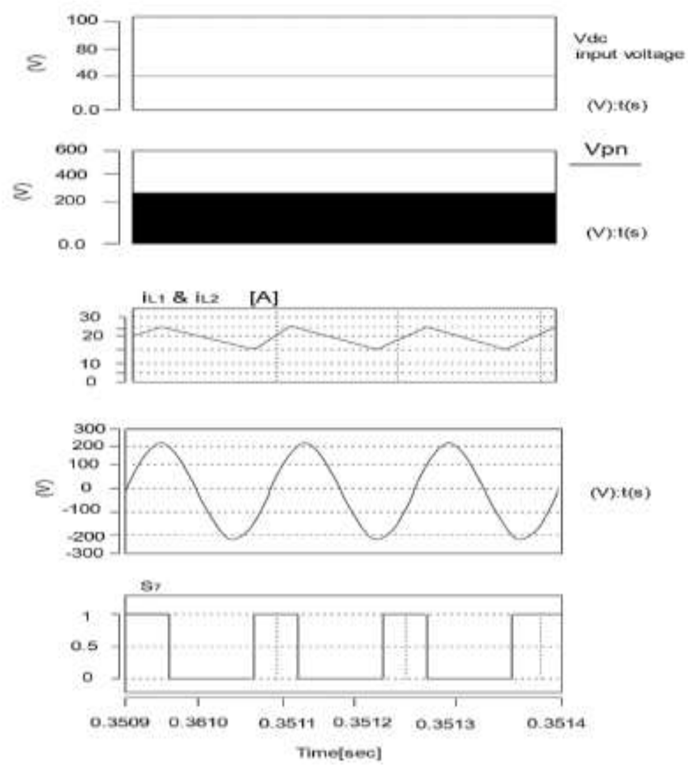


FIGURE 15. Simulation results for CBC

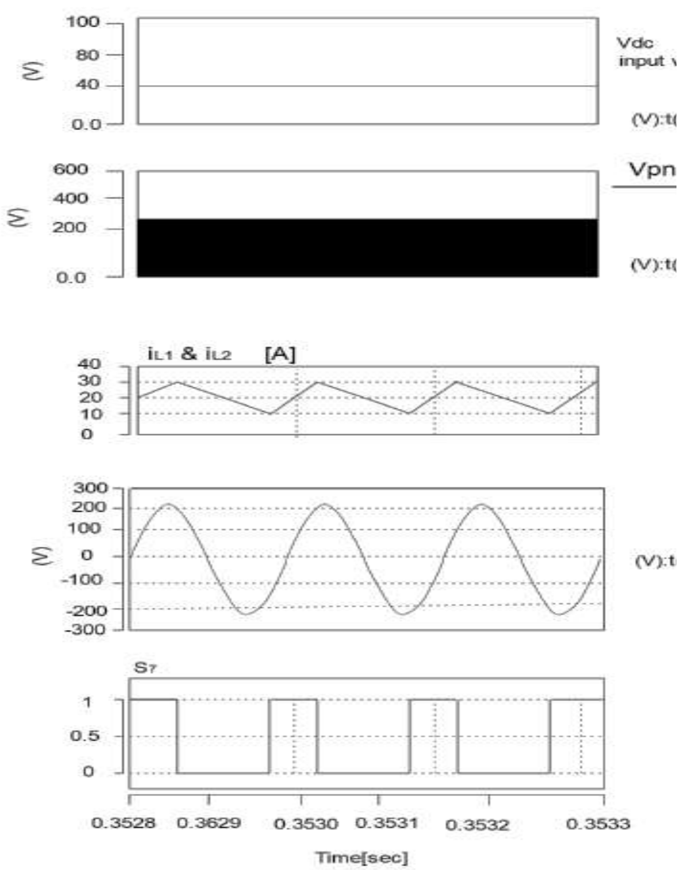


FIGURE 14. Simulation results of MBC with 3rd harmonic injection

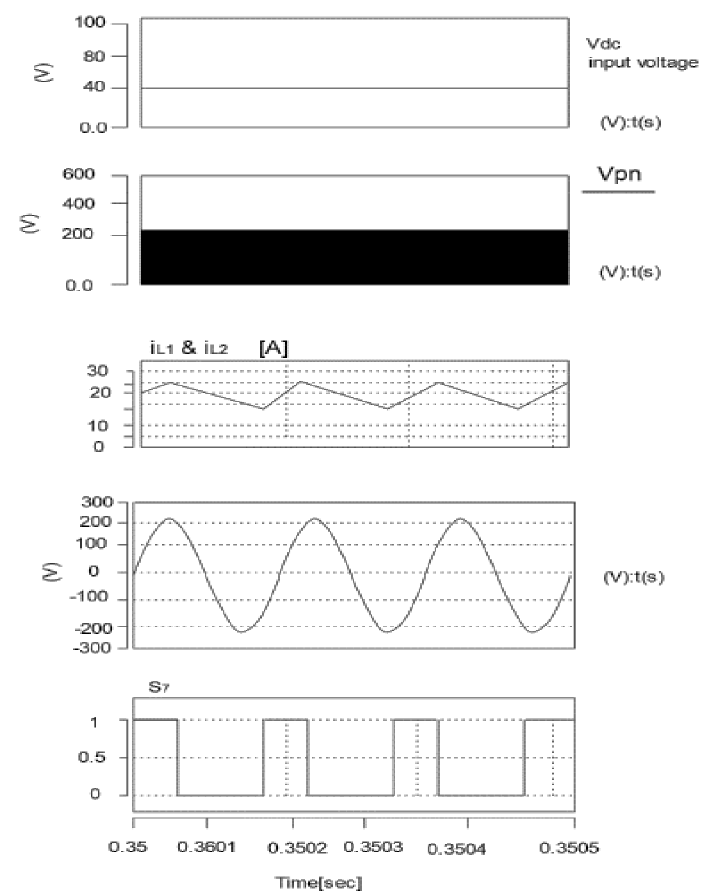


FIGURE 16. Simulation results for CBC with 3rd harmonic injection

The gain table will be:

Table III
GAIN TABLE FOR PROPOSED TECHNIQUES

Switching Technique	**Gain**
Simple Boost Control	9.1
Maximum Boost Control	3.3
Maximum Constant Boost Control	5.13

V. CONCLUSION

This paper shows the three control techniques to achieve maximum G for ASC/SL-qZSI. The technique increases the shoot through time interval, so maximum G is produced for specific MI. Therefore, maximum value of MI is used to produce any required G. Also minimizes the VS across the switching devices. The need of Passive components has been minimized and the low frequency ripples related with the output has been eliminated, 3rd harmonic injection is used to enhance the range of MI. comparison of different control methods has been shown on the basis of G against MI, VS against G and stress ratio against G are investigated in detail. Simulations were performed to prove the control techniques and evaluation.

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