A Survey on modulation approaches for Z-source inverter

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***Abstract*—This paper discusses and compares several control strategies for the Z-source inverter, contrary to the traditional inverters the impedance network in the ZSI provides one extra switching state called shoot-through state which ensures the unique buck-boost voltage feature. This study aims to analyze and compare four control methods namely, SBC simple boost control, MBC maximum boost control, MCBC maximum constant boost control and maximum constant boost control with third harmonic injection.**

Keywords—Z Source inverter, SBC, MBC, MCBC

ZSI	Z-source inverter
SBC	Simple Boost Control
MBC	Maximum Boost Control
MCBC	Maximum Constant Boost Control
PWM	Pulse width modulation

I. Introduction

Conventionally the used inverters can be classified into current source and voltage source inverter, despite their extensive use in the industrial field, there are several drawbacks to adopting these inverters such as they can either boost or buck the input voltage [1].

One of the other major drawbacks, the delivered voltage by the VSI cannot be greater than the input voltage, therefor another boost converter is required to step-up the input voltage until it reaches the desired level, the extra added converter will decrease the efficiency of the system and increases its complexity [1][2].

A new Z-source topology has been proposed by [1] to overcome the existing problems in the conventional topologies, this topology is based on a network made of two capacitors and two inductors connecting the source to the inverter, this network provides the buck-boost ability using the same interchangeable main circuit [3].

Contrary to the classilcal three phase VSI which has six active states and two zero states, the three phase ZSI has one extra state beside the mentioned states called shoot-through zero state.

The shout-through zero state is generated when both the upper and lower switches of any phase are turned on at the same time, it can be produced in seven cases: one phase leg, tow phase legs and three phase legs. This state is dangerous in the conventional voltage source inverters and it may damage the devices of the same leg if they gated on simultaneously [1].

There exist various control techniques for the z-source inverter namely, SBC, MBC, MCBC and maximum constant boost control with third harmonic injection. This study intended to analyze and provide full description and mathematical modeling for the above-cited control techniques.

II. Z-source inverter

In the z-source topology a symmetrical impedance network is used for the purpose of connecting the DC source to the inverter, this network composed of two capacitors and two inductors as illustrated in figure 1-a, the Z-source inverter has two operating modes, non-shoot through mode and shoot through mode [4] as shown in figure 1-b and figure 1-c respectively.

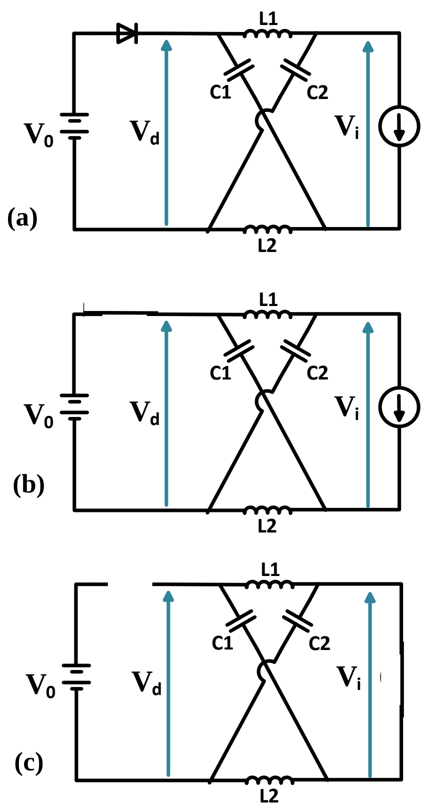

Fig. 1. a- Equivalent circuit for ZSI b- non-shoot through mode c- shoot through mode

Since the ZSI network components are identical

$$V_{C1} = V_{C2} = V_C \quad (1)$$

$$V_{L1} = V_{L2} = V_L \quad (2)$$

During T_0 when the inverter operates in the shoot-through mode as illustrated in figure 1-c:

$$V_d = 2V_c \quad (3)$$

$$V_c = V_L \quad (4)$$

$$V_i = 0 \quad (5)$$

During the non-shoot through mode for the duration of T_1 as $T=T_1+T_0$

$$V_0 = V_d \quad (6)$$

$$V_L = V_{in} - V_c \quad (7)$$

$$V_i = 2V_c - V_0 \quad (8)$$

The boost factor is expressed as:

$$B = \frac{T}{(T_1 - T_0)} \quad (9)$$

The peak output voltage is given in the following equation

$$\hat{V}_{ac} = MB\frac{V_0}{2} \quad (10)$$

Given that M is the modulation index [1].

The Voltage across the capacitor is:

$$V_c = \frac{1-D_0}{1-2D_0}V_0 \quad (11)$$

III. Z-SOURCE INVERTER

There are numerous control strategies have been developed attempting to improve the classical simple boost control technique which suffers from several drawbacks such as low boost factor and high voltage stress across the devices, the analyzed strategies as follows:

A. *Simple boost control (SBC)*

In this control method the six active states of the traditional PWM stayed the same in addition to a positive straight line equal to the positive peak value of the sinusoidal voltage and negative straight line equal to the negative peak value of the sinusoidal voltage [5], as illustrated in figure 2

The duty ratio is varying according to the comparison between the two lines and the triangular signal, the inverter operates in the shoot-through mode in case when the positive straight line is lower than the triangular signal or the negative one is higher than the triangular signal, however, the inverter operates in the active mode during the rest period [6].

In this control approach the shoot-through duty ratio varies inversely with the modulation index as expressed in equation (12)

$$D_0 = 1 - M \quad (12)$$

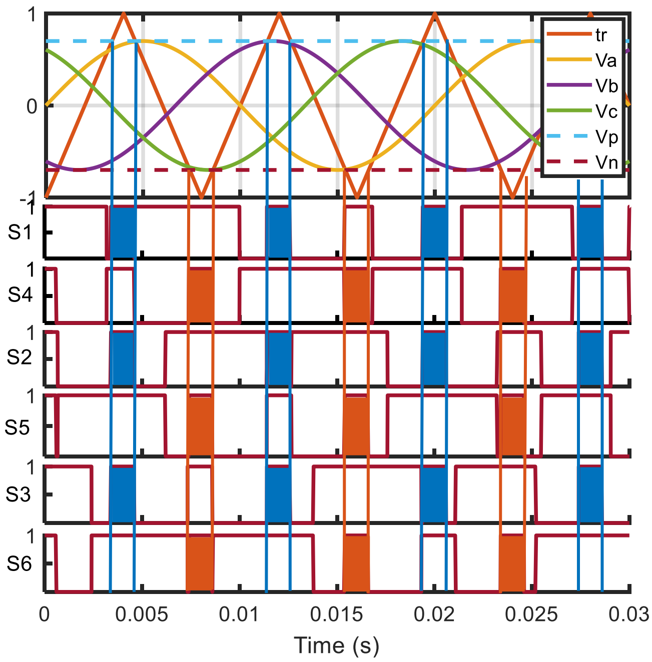

Fig. 2. Simple boost control scheme

The voltage gain of the z-source inverter and the boost factor are respectively:

$$G = \frac{M}{2M - 1} \quad (13)$$

$$B = \frac{1}{2M - 1} \quad (14)$$

Finally the voltage stress across the inverter devices can be expressed as:

$$V_{dc} = \frac{1}{2M - 1}V_0 \quad (15)$$

B. *Maximum boost control (MBC)*

The maximum boost control strategy has been proposed as a solution to minimize the high stress voltage across the inverter switches produced the simple boost control method and maximize the shoot-through duty ratio, for such reason all the zero states are converted to a shoot-through states, therefore whenever the triangular wave is bigger than the positive peak of the reference signal or lower than the negative one the inverter operates in the shoot-through mode, otherwise it operates one of the six active states same as in the traditional PWM [7].

Contrary to the simple boost control, the shoot-through duty ratio varies every cycle [5hus], however, it average value can be expressed as:

$$D_0 = \frac{2\pi - 3\sqrt{3}M}{2\pi} \quad (16)$$

The boost factor is

$$B = \frac{\pi}{3\sqrt{3}M - \pi} \quad (17)$$

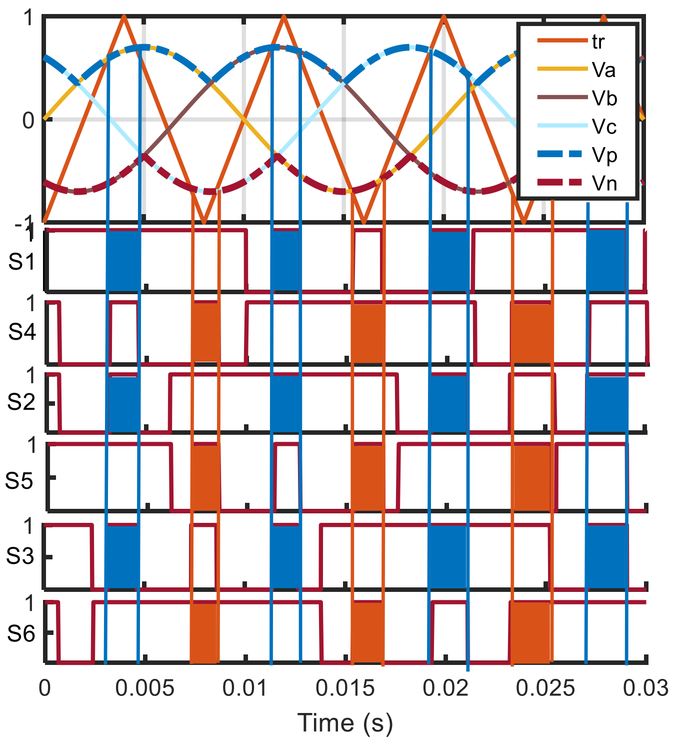

Fig. 3. Maximum boost control scheme

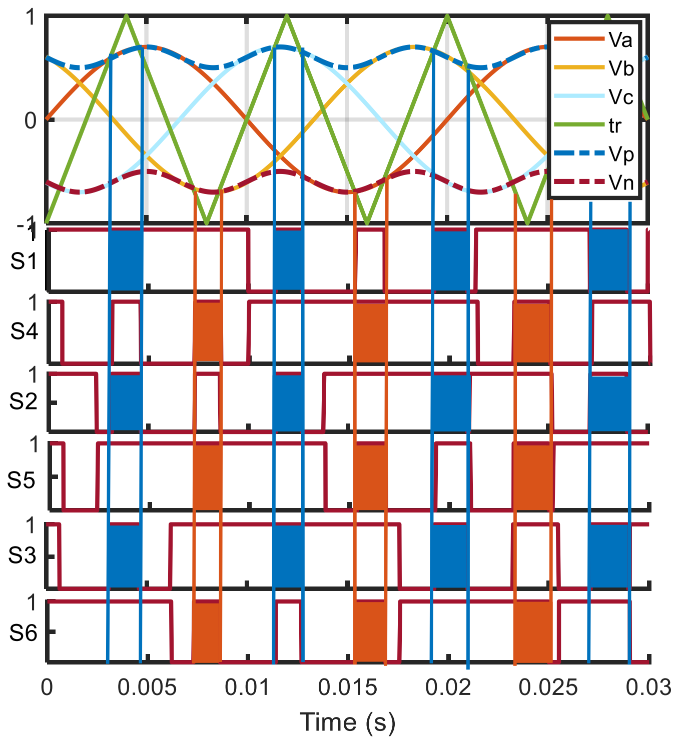

Fig. 4. Maximum constant boost control scheme

Then the voltage gain can be approximated as:

$$G = \frac{\pi M}{3\sqrt{3}M - \pi} \tag{18}$$

The voltage stress across the devices is:

$$V_{dc} = \frac{3\sqrt{3}G - \pi}{\pi} V_0 \tag{19}$$

C. Maximum Constant boost control (MCBC)

Due to the problem of the varying shoot-through duty ratio in the maximum boost control method, a new control strategy called maximum constant boost control has been proposed in [8]. This control strategy guarantees a constant shoot-through duty ratio, a high boost factor and reduced voltage stress. In this strategy two envelopes Vp and Vn have been used, whenever the triangular signal is bigger than the positive envelope or smaller than the negative one, the inverter operates in shoot-through mode, otherwise the inverter is operating same as in the traditional six active states [8].

The two used envelopes are periodical with a frequency equals three times the reference signal frequency.

In the first part (0, π/3) the envelopes can be expressed as:

$$V_p = \sqrt{3}M + \sin\left(\theta - \frac{2\pi}{3}\right)M \tag{20}$$

$$V_n = \sin\left(\theta - \frac{2\pi}{3}\right)M \tag{21}$$

While in the second part (π/3, 2π/3) they can be calculated by:

$$V_p = \sin(\theta)M \tag{22}$$

$$V_n = \sin(\theta)M - \sqrt{3}M \tag{23}$$

From figure 4, the distance between the two envelopes are the same, which makes the shoot-through duty ratio constant and can be approximated by the formula:

$$D_0 = 1 - \frac{\sqrt{3}M}{2} \tag{24}$$

The voltage gain and the boost factor meet equations (25) and (26) respectively

$$G = \frac{M}{\sqrt{3}M - 1} \tag{25}$$

$$B = \frac{1}{\sqrt{3}M - 1} \tag{26}$$

The voltage gain decreased from infinity to zero by increasing the modulation index from ($\frac{\sqrt{3}}{3}$) to 1[8].

D. Maximum Constant boost control with third harmonic injection (MCBCT)

There is another way to implement the maximum constant boost control strategy by injecting a third harmonic signal whose an amplitude equals to one-sixth of the sinusoidal and frequency equals three times the main frequency. The advantage of this method is that the modulation index range is increased to ($\frac{2*\sqrt{3}}{3}$) instead of 1 in the previous technique [8], in addition to the fact that this method overcomes the problem of the variable shoot-through duty ratio and provide a constant shoot through duty ratio can be represented by two straight lines same as in the simple boost [6].

The shoot-through duty ratio can be calculated by:

$$D_0 = 1 - \frac{\sqrt{3}M}{2} \tag{27}$$

The voltage gain and the boost factor can be expressed by equations (28) and (29) respectively:

$$G = \frac{M}{\sqrt{3}M - 1} \tag{28}$$

$$B = \frac{1}{\sqrt{3}M - 1} \tag{29}$$

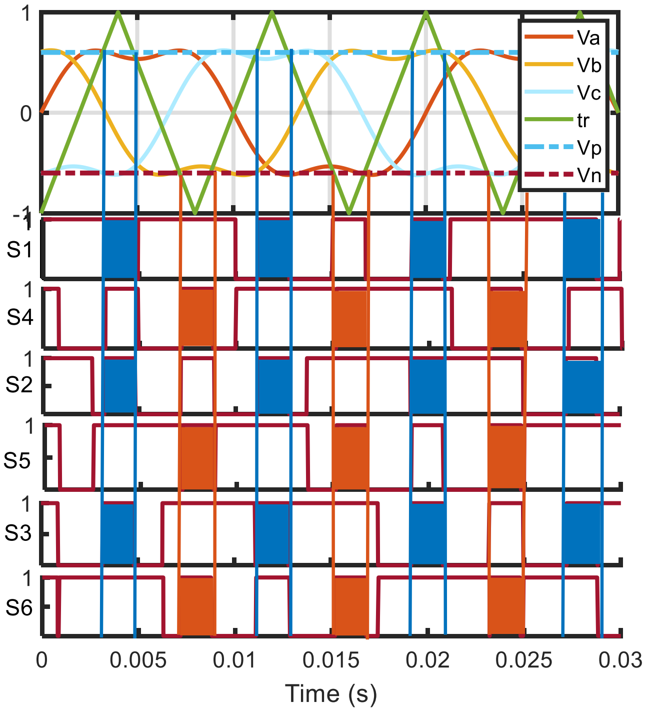

Fig. 5. Maximum constant boost control with third harmonic injection

IV. Conclusion

This paper provides a full review and mathematical analysis of several control methods developed to control Z-source inverter, this topology ensures the features of the traditional inverter in addition to the boost feature. The control techniques discussed in this paper are (SBC simple boost control, MBC maximum boost control, MCBC maximum constant boost control and MCBC with third harmonic injection).

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