ANALYSIS AND SIMULATION OF Z-SOURCE INVERTER CONTROL METHODS

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ABSTRACT

This thesis presents the analysis of switching control technique approach to Z-source inverter. Z-source inverter is a new inverter that can be implemented in all types of converter operation. This advantage has made the control methods became more complicated due to the Z-impedance and the different switching characteristics. The inverter model was constructed by using MATLAB/Simulink with the SimPowerSystems Block Set. The purposed of this project is to construct analysis and investigate the Z-source inverter and its switching techniques. i.e., constant boost and maximum boost PWM. These two types of switching techniques are analyzed and compared for each other. The Simple Boost control with independence relation between modulation index and shoot-through duty ratio is also simulated and analyzed. The selection of high modulation index and shoot-through duty ratio can reduce the inverter's dc link voltage overshoot and increasing power delivery capacity of the inverter. The detail analysis and comparison of the switching control techniques are presented in this thesis.

ABSTRAK

Tesis ini membentangkan analisis menukar kawalan pendekatan teknik untuk penyongsang Z-sumber. Z-sumber penyongsang adalah penyongsang baru yang boleh dilaksanakan dalam semua jenis operasi penukar. Kelebihan ini telah dibuat kaedah kawalan menjadi lebih rumit disebabkan oleh Z-galangan dan pensuisan characteristics.The model Simulink telah dibina dengan menggunakan MATLAB / Simulink dengan Blok SimPowerSystems yang Tetapkan. Berniatlah projek ini adalah untuk membina, analisis dan penilaian penyongsang Z-sumber dan pengawal mereka. Terdapat dua jenis kaedah kawalan untuk penyongsang Z-sumber diperiksa dalam kertas ini yang Boost Mudah dan Boost maksimum. Boost Mudah dan kaedah kawalan maksimum Boost penyongsang dianalisis dan dibandingkan antara satu sama lain. Kawalan Boost mudah dengan berhubung kemerdekaan antara indeks pemodulatan dan pucuk melalui nisbah duti juga simulasi dan dianalisis. Pemilihan indeks pemodulatan yang tinggi dan pucuk melalui nisbah duti boleh mengurangkan kait at penyongsang voltan lajakan dan meningkatkan penghantaran kapasiti kuasa penyongsang. Analisis terperinci dan perbandingan kaedah kawalan yang bertukar dibentangkan di dalam tesis ini.

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CHAPTER 1

INTRODUCTION

1.1 Background

Previously, there are two types of conventional inverter that exist which are voltage source inverter (VSI) and current source inverter (CSI). These types of inverters are widely used. However, both of this inverter has the limitation in their performance. For the first limitation, these types of conventional inverter are neither can be a buck-boost converter. That is, their obtainable output voltage range of each is limited to either greater, or smaller than input voltage. Then, neither the VSI main circuit can be used for the CSI, nor vice versa.

Z-source inverter (ZSI) or also known as the impedance source inverter is an inverter that can perform all type of power conversion. The ZSI is developed to overcome the limitation of the performance of the conventional inverter. The general structure of the ZSI consists of four main blocks i.e., dc source, Z-source network, inverter network and load.

The first ZSI was introduced in three phase, where it have nine permissible switching states unlike the traditional converter that has eight. The traditional three-phase V-source inverter has six active vectors when the dc voltage is impressed across the load and two zero vectors when the load terminals are shorted through either the lower or upper three devices, respectively. However, the three-phase Z-source inverter bridge has one extra zero state when the inverter bridge is in one of the eight nonshoot-through switching states. This shoot-through zero state is forbidden in the traditional V-source inverter, because it would cause a shoot-through. We call this third zero state the shoot-through zero state (or vector), which can be generated by seven different ways: shoot-through via any one phase leg, combinations of any two phase legs, and all three phase legs. The Z-source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique buck-boost feature to the inverter.

1.2 Problem Statement

Even though ZSI can overcome the limitation in conventional inverter, the difficulty in its switching technique has made its implementation become complicated. Compared to conventional PWM switching technique that used in conventional inverter, the implementation is quite easy and has widely used in practical.

1.3 Objectives

The project objectives are:

i. To develop the switching control techniques for Z-source inverter

ii. To simulate the switching technique use MATLAB/Simulink

iii. To analyze and do a comparison between the switching control techniques

1.4 Scope of Project

This project is based on the simulation and does the analysis the performance of Z-source inverter control methods. Firstly, there is needed to identify various switching control technique and function of Z-source inverter. After that, the simulation by using MATLAB/Simulink will be conducted and the result from the simulation will be analyzed. Lastly, make the comparison among the switching control techniques that used in this project to choose the best switching control technique.

1.5 Thesis Outline

Chapter 1 explains the operation of Z-source inverter. The overview of project objectives and project scopes also discuss in this chapter.

Chapter 2 focuses on the literature review that related to this project., inverter, Pulse Width Modulation (PWM), and Insulated Gate Bipolar Transistor (IGBT) switching characteristic.

Chapter 3 discusses about methodology of this project. This chapter also discuss about circuit design and the system work.

Chapter 4 explains and discusses all the results obtained and the analysis of the project. The comparisons of simulation's results are made between switching control technique.

Chapter 5 discusses the conclusion of advantages of the switching control technique that had been implemented into the project. This chapter also gives the recommendation about the future development of the project by using the software which used in this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Inverter

Inverter or power inverter is a device that converts the DC sources to AC sources. Inverters are used in a wide range of applications, from small switched power supplies for a computer to large electric utility applications in transport bulk power. This makes them very suitable for when you need to use AC power tools or appliances [9].

Power inverters produce one of three different types of wave output:

- Square Wave
- Modified Square Wave (Modified Sine Wave)
- Pure Sine Wave (True Sine Wave)

The three different wave signals represent three different qualities of power output. Square wave inverters result in uneven power delivery that is not efficient for running most devices [9].

Square wave inverters were the first types of inverters made and are obsolete. Modified square wave (modified sine wave) inverters deliver power that is consistent and efficient enough to run most of the devices. Some sensitive equipment requires a sine wave, like certain medical equipment and variable speed or rechargeable tools [9].

Modified Sine Wave

Modified sine wave or quasi-sine wave inverters were the second generation of power inverter. They are a considerable improvement over square wave inverters. These popular inverters represent a compromise between the low harmonics (a measure of waveform quality) of a true sine wave inverter and the higher cost and lower efficiency of a true sine wave inverter. Modified sine wave inverters approximate a sine wave and have low enough harmonics that they do not cause problems with household equipment. They runs TV's, stereos, induction motors (including capacitor start), universal motors, computers, microwave, and more quite well. The main disadvantage of a modified sine wave inverter is that the peak voltage varies with the battery voltage. Inexpensive electronic devices with no regulation of their power supply may behave erratically when the battery voltage fluctuates [9].

True Sine Wave

True sine wave inverters represent the latest inverter technology. The waveform produced by these inverters is the same as or better than the power delivered by the utility. Harmonics are virtually eliminated and all appliances operate properly with this type of inverter. They are, however, significantly more expensive than their modified sine wave cousins [9].

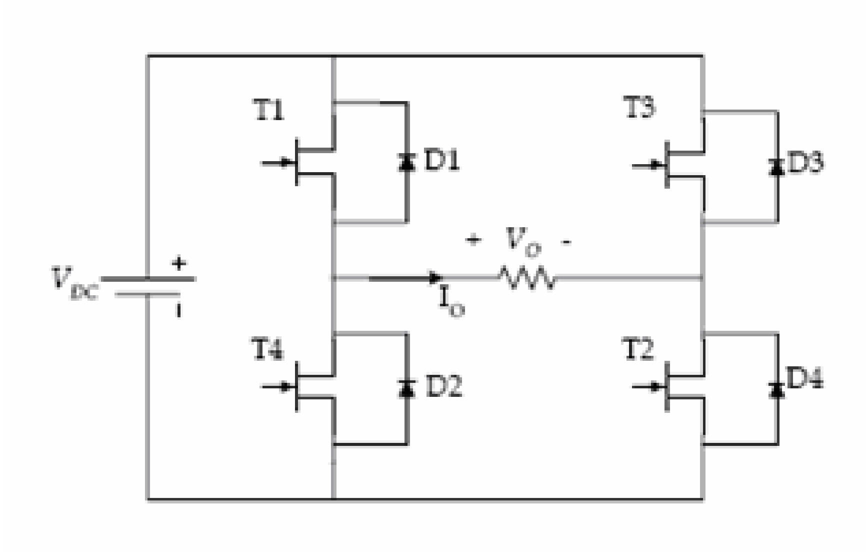

Figure 2.1: Basic single phase full-bridge inverter diagram

2.1.1 Traditional Inverter

There are two traditional converters exist which is voltage source inverter (VSI) and current source inverter (CSI). For VSI, the input is dc-voltage and for the CSI the input is dc-current source.

Fig.1 shows the three-phase VSI. The dc voltage source can be a battery, fuel cell stack, diode rectifier, and capacitor. In the main circuit, there are six switches used. Each of it is composed of a power transistor and antiparallel diode to provide bidirectional current flow and unidirectional voltage blocking capability. It is widely used but has several limitations. Firstly, in dc-to-ac power conversion, a buck (step-down) and ac-to-dc power conversion, a boost (step-up) there is required ac output to be obtained in applications where dc voltage is limited and overdrive is desired. In addition, it will increase system cost and lowering efficiency. Secondly, to avoid simultaneously gating of phase legs distorts waveform, the dead-time is needed to be applied. Then, the output filter is needed to provide sinusoidal voltage unlike the current-source inverter, which cause the power loss and complicating control [3].

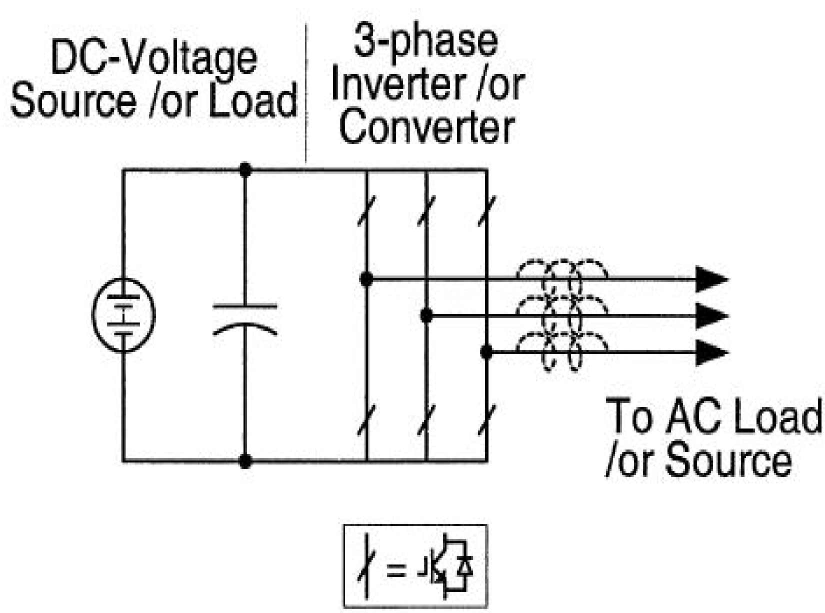

Figure 2.2 Traditional V-source Inverter

Fig. 2 shows three-phase CSI. The dc current source can be a relatively large dc inductor fed by a voltage source such as a battery, fuel cell stack, diode rectifier, or thyristor converter. There is having several limitations of CSI. Firstly, in dc-to-ac power conversion, a boost (step-up) inverter is used, so in applications with a wide voltage range an additional dc-to-dc buck converter is needed. It will increase cost and lowering efficiency. Then, for the safe commutation of current, overlap time is necessary, distorting waveform [3].

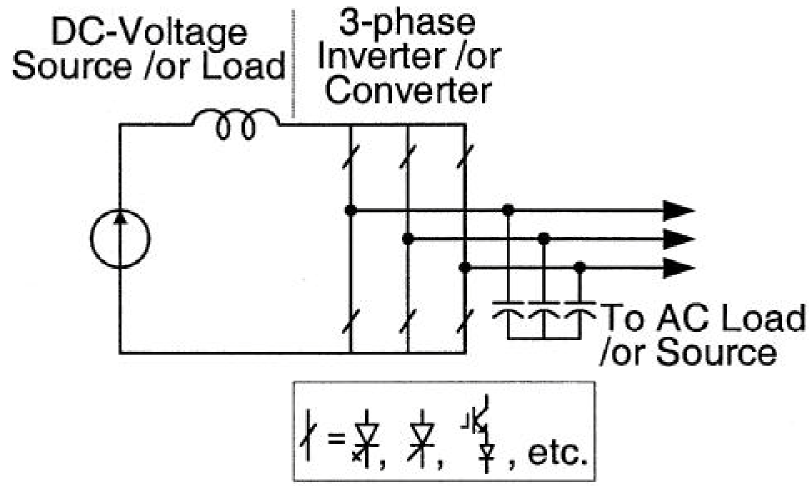

Figure 2.3 Traditional I-source Inverter

In addition, both of VSI and CSI have problem that have been summarized as follow [3]:

i. Either a boost or a buck converter cannot be a buck-boost converter. That is their obtainable output voltage range is limited to either greater or smaller than the input voltage.

ii. Their main circuit of VSI cannot be used in CSI, and vice versa.

2.1.2 Z-Source Inverter

The z-source inverter (ZSI) network has been applied to overcome the problem of the traditional converter [3], which has many limitations in its performance. There are two basics Z-source converter topologies including voltage-fed and current-fed which the networks are symmetric [1] as shown in Figure 2.4 and 2.5 respectively.

It is unique in that it can be applied to all power conversion topologies: dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc. The general structure of ZSI comprises four main blocks: dc voltage source, Z-source network, inverter network and an ac load [2].

The dc source can be either a voltage source or current source. The Z-source network is combination of split inductors L1 and L2, and X-connected capacitors C1 and C2 for coupling of the inverter network to dc source. The inverter network can be either single-phase or three-phase but the focus here is for single-phase ZSI. The end of the block is an ac load, which is can be connected to the load or to another converter.

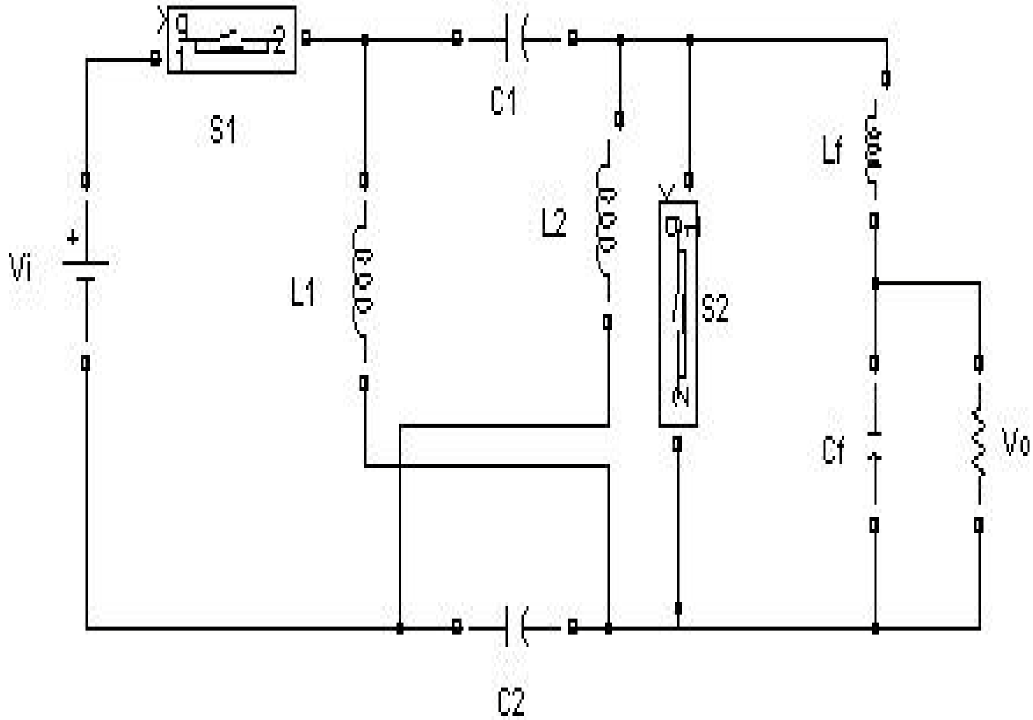

Figure 2.4 Z-source for voltage fed

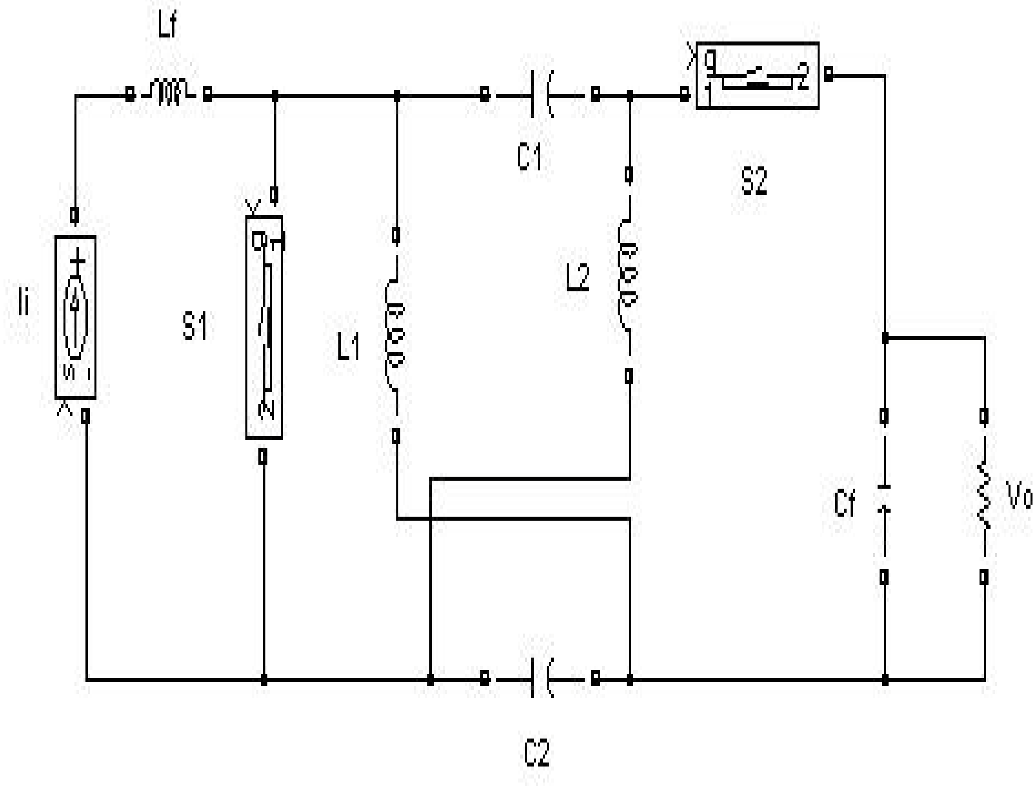

Figure 2.5 Z-source for current fed

2.2 Pulse Width Modulation

Pulse width-modulation (PWM) control for the *Z*-source inverter has to be modified to utilize the shoot-through states for voltage boost. Figure 2.6 shows the traditional carrier-based PWM scheme of the voltage-source inverter. There are eight permissible switching states: six active and two zero states. During the two zero states, the upper three or the lower three switches are turned on simultaneously, thus shorting the output terminals of the inverter and producing zero voltage to the load. During one of the six active states, the dc voltage is impressed across the load, positively or negatively. In addition to the eight traditional switching states, the *Z*-source inverter has several shoot-through zero states, during which both the upper and lower switches of one or multiple same-phase legs are turned on. It is obvious that during a shoot-through zero state, the output terminals of the inverter are shorted and the output voltage to the load is zero. Therefore, the shoot-through states have the same effect (i.e., zero voltage) to the load as the traditional zero states; however, these shoot-through states can boost the dc voltage. The active states have to be kept unchanged to maintain the output voltage waveform, and the traditional zero states can be replaced partially or entirely by the shoot-through zero states depending on how much voltage boost is needed [6].

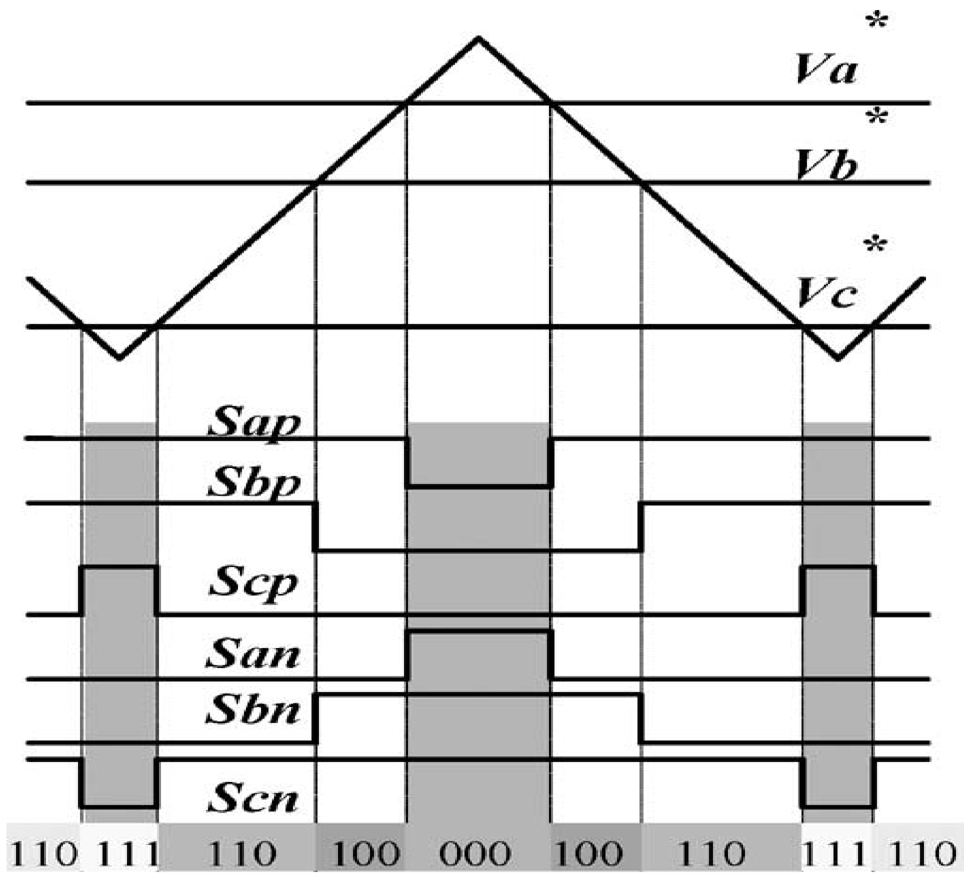

Figure 2.6 Carrier-based PWM for traditional voltage-source inverter

2.2.1 Constant Boost Control (CBC)

In order to reduce the volume and cost, it is important always to keep the shoot-through duty ratio constant. At the same time, a greater voltage boost for any given modulation index is desired to reduce the voltage stress across the switches. There are five modulation curves in this control method: three reference signals, *Va*, *Vb*, and *Vc*, and two shoot through envelope signals, *Vp* and *Vn*. When the carrier triangle wave is greater than the upper shoot-through envelope, *Vp*, or lower than the lower shoot-through envelope, *Vn*, the inverter is turned to a shoot-through zero state. In between, the inverter switches in the same way as in traditional carrier-based PWM control. CBC achieves maximum boost while keeping the shoot through duty ratio always constant; thus it results in no line frequency current ripple through the inductors. With this method, the inverter can buck and boost the voltage from zero to any desired value smoothly within the limit of the device voltage [5].

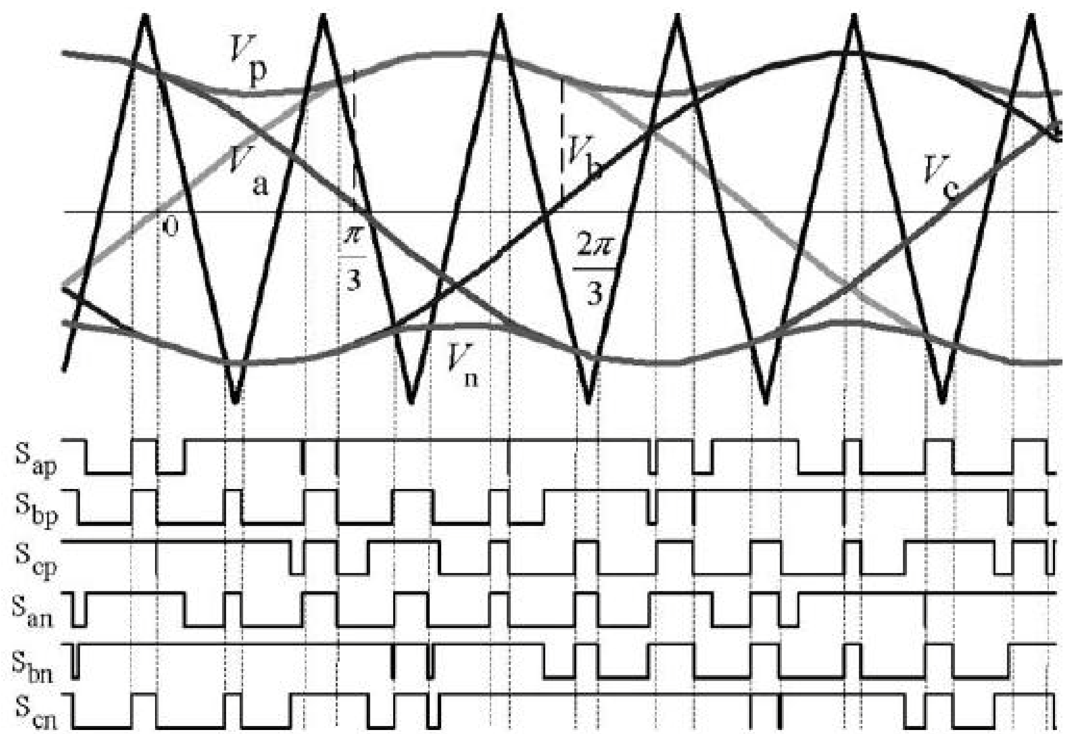

Figure 2.7 Sketch map of constant boost control.

Major expressions of CBC method are outlined here,

$$D_0 = \frac{2-\sqrt{3}m_a}{2} = 1 - \frac{\sqrt{3}m_a}{2} \quad (1)$$

$$B = \frac{1}{1-2\frac{T_0}{T}} = \frac{1}{\sqrt{3}m_a - 1} \tag{2}$$

$$\frac{v_i}{V_{dc}/2} = m_a * B = \frac{m_a}{\sqrt{3}m_a - 1} \tag{3}$$

$$G = m_a * B = \frac{m_a}{\sqrt{3}m_a - 1} \tag{4}$$

$$m_a = \frac{G}{\sqrt{3}G - 1} \tag{5}$$

$$V_s = B * V_{dc} = (\sqrt{3}G - 1)V_{dc} \tag{6}$$

The detail of these expressions can be referred in [1] and [3].

The voltage stress across the switches is quite high when CBC is used, this characteristic will restrict the obtainable voltage gain because of the limitation of device voltage rating [5].

2.2.2 Maximum Boost Control (MBC)

Reducing the voltage stress under a desired voltage gain now becomes important to the control of ZSI. Maximum boost control (MBC) turns all traditional zero states into shoot-through zero state. MBC maintains the six active states unchanged and turns all zero states into shoot through zero states. Thus maximum T_0 and *B* are obtained for any given modulation index without distorting the output waveform. The circuit is in shoot-through state when the triangular wave is either greater than the maximum curve of the references (*Va* ,*Vb and Vc*) or smaller than the minimum of the references. The shoot-through duty cycle varies each cycle. Low frequency current ripples associated with the output frequency are introduced in inductor current and capacitor voltage waveform [5].

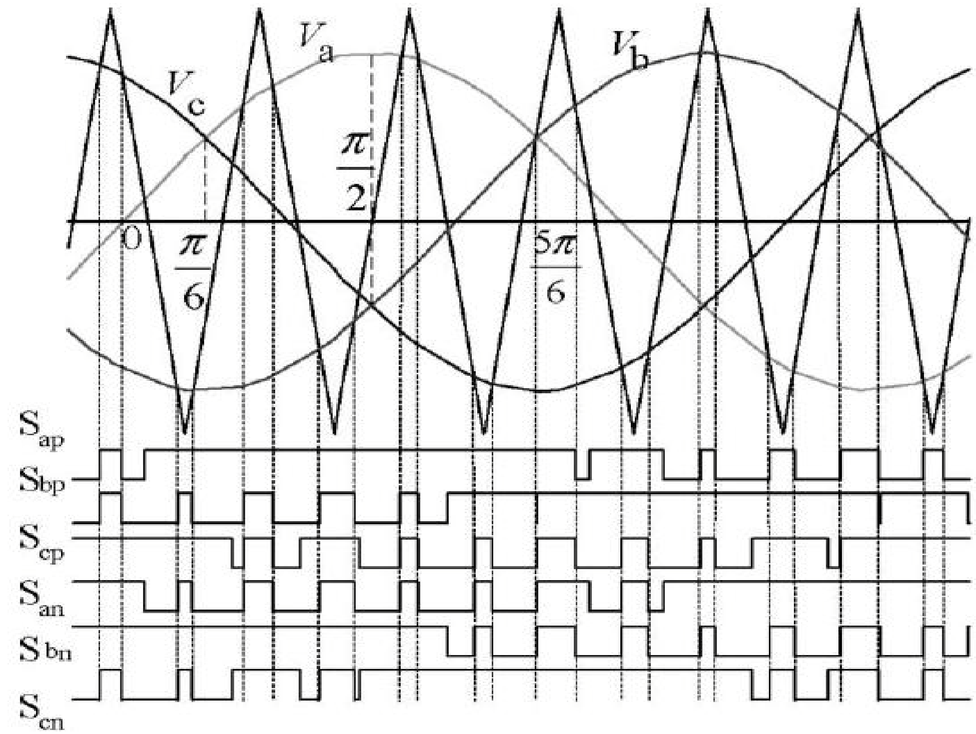

Figure 2.8 Sketch map of maximum boost control

Every (π/3) the shoot-through state is repeated periodically. Assume that the switching frequency is much higher than the modulation frequency; the average shoot-through duty ratio over one switching cycle in the interval (π / 6,π / 2) can be expressed as:

$$\frac{T0}{T} = \int_{\pi/6}^{\pi/2} \left(\frac{2 - ma\ \sin\theta - ma\ \sin\left(\theta - \frac{2\pi}{3}\right))}{2} \right.$$

$$= \frac{2\pi - 3\sqrt{3\pi}}{2\pi} \qquad (5)$$

Maximum shoot-through duty ratio can be written as,

$$Do = \frac{2\pi - 3\sqrt{3\pi}}{2\pi} \quad (6)$$

Major expressions of MBC method are,

$$G = \frac{m_a}{1-2D_0} = \frac{m_a \pi}{3\sqrt{3}m_a - \pi} \quad (7)$$

$$m_a = \frac{\pi G}{3\sqrt{3}G - \pi} \quad (8)$$

$$B = \frac{3\sqrt{3}G - \pi}{\pi} \quad (9)$$

$$V_s = \frac{3\sqrt{3}G - \pi}{\pi} V_{dc} = \frac{\pi}{3\sqrt{3}G - \pi} V_{dc} \quad (10)$$

$$\frac{V_s}{G * V_0} = \frac{3\sqrt{3}}{\pi} - \frac{1}{G}$$