Analysis for dc Boost Control System Using Z-Source Inverter

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ABSTRACT

The paper aims on an analysis for dc boost control using Z-source inverter. The modified space vector PWM method is used for controlling both the dc boost and ac output controls in the Z-source inverter. The capacitor voltage and the voltage stress of device with both the shoot-through time and modulation index are analyzed considering the zero state time of inverter. The theoretical analysis is verified with the simulation studies and experiments with 32-bit DSP

Index - Z-source inverter, modified space vector PWM, dc boost control

I. INTRODUCTION

Nowadays, the PWM inverter has widely utilities in the ac machine drive, UPS and so on. It however has some limitations. The ac output voltage is constrained below dc input voltage, and so the additional dc-dc boost converter is required. The dead time to block both upper and lower devices of each phase leg is provided in order to prevent the short circuit across load terminal. It causes a waveform distortion of ac output voltage.

To overcome the mentioned limitations, a new Z-source inverter (ZSI) is recently proposed in [1][2], shown in Fig.1. For ZSI, the traditional dc link is replaced by an impedance network (Z-source network). The ac output voltage and dc capacitor voltage can be boosted to any desirable value by shoot-through state, in which both devices of a phase leg are conducted simultaneously without damaging the switching device[1]

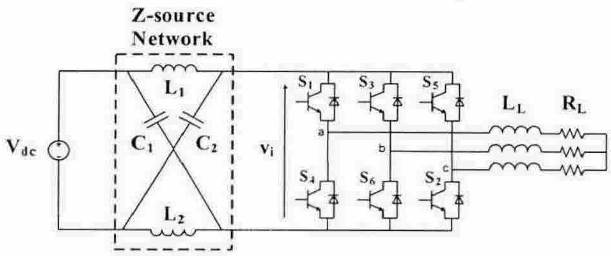


Fig. 1 General configuration of ZSI

The basic structure and operation principle of ZSI is described in[1][4]. The maximum boost control method in the ZSI is presented in[3]. However, at these papers the operation of ZSI and dc boost control is analyzed by using carrier-based PWM. The carrier-based PWM method is not effective and feasible for dc boost control, compared with space voltage PWM.

In this paper, modified space vector PWM (MSVPWM) is proposed for both the dc to control the boost control and ac output voltage control in the ZSI, and the operation of ZSI using the MSVPWM method is analyzed. Moreover the voltage gain and the stress voltage of device versus the shoot-through time are also explained herein. The simulation studies and experimental results with 32-bit DSP are carried out in order to verify the suggested theoretical analysis.

II. OPERATION OF Z-SOURCE INVERTER

The operation principle of ZSI can be explained through three operation modes: normal mode, zero-state mode and shoot-through mode which are shown in Fig.2.

In normal mode and zero-state mode, ZSI operates under the conventional SVPWM. When the ZSI is in six active vector states, the dc voltage is applied across the load terminal. The ZSI is in two zero states, when the load terminals are shorted through either the lower or upper three devices. Whereas, the shoot-through mode is a unique mode of ZSI, both devices in one phase-leg are simultaneously conducted in this mode which is forbidden in the conventional inverter. Through this mode, the dc capacitor voltage and hence the ac output voltage are boosted to the designed value.

Assuming that inductors L_1, L_2 and capacitors C_1, C_2 have the same inductance and capacitance. Thus the Z-source network becomes symmetric

$$v_{L1} = v_{L2} = v_L \quad V_{C1} = V_{C2} = V_C \tag{1}$$

Whenever ZSI is in one of six active states of normal mode for an interval of T_a, from the equivalent circuit Fig.2 (a), one has:

$$v_L = V_{dc} - V_C \tag{2}$$

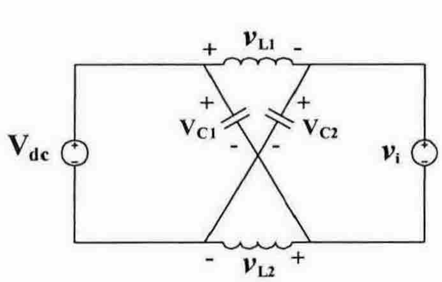
$$v_i = V_C - v_L = 2V_C - V_{dc} \tag{3}$$

When ZSI is in the zero-state mode for an interval of T_0, the load terminals are shorted through either the lower or upper three switching devices, the inductor current becomes to zero.

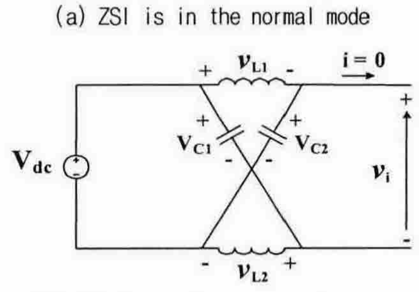
$$i_L = 0 \qquad v_L = 0 \qquad v_i = V_C \tag{4}$$

Now consider that ZSI is in the shoot-through mode for an interval of T_{sh}. The dc link voltage V_i is equal to zero.

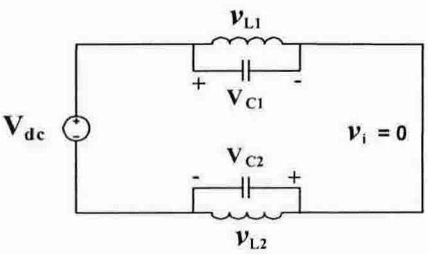
$$v_i = 0 \qquad v_L = V_C \tag{5}$$



(a) ZSI is in the normal mode



(b) ZSI is in the zero-state mode



(c) ZSI is in the shoot-through mode

Fig. 2 Operation principle of ZSI

The average voltage of the inductors over one switching period T_s becomes to zero in steady state.

$$V_L = \frac{(V_{dc} - V_C)T_a + V_C T_{sh} + 0\,T_0}{T_s} = 0 \tag{6}$$

And the capacitor voltage is given by below equation.

$$V_C = \frac{T_a}{T_a - T_{sh}} V_{dc} \tag{7}$$

The peak input voltage of inverter bridge or stress voltage of switching device is determined by

$$\hat{V}_i = 2V_C - V_{dc} = \frac{T_a + T_{sh}}{T_a - T_{sh}} V_{dc} \tag{8}$$

III. MODIFIED SPACE VECTOR PWM

The conventional SVPWM uses eight space vectors $V_0 \div V_7$ to obtain therefore voltage V_{ref} or inverter output voltage, where $V_1 \div V_6$ are active vectors and V_0, V_7 are zero vectors. When the reference voltage is located at sector I, the reference voltage is resolved into the voltage vectors, V_1 and V_2. In one sampling time, the vectors V_1 and V_2 are applied at the time intervals T_1 and, T_2 respectively.[4]

The reference voltage can be obtained as follows

$$V_{ref} = V_1 T_1 + V_2 T_2 \tag{9}$$

$$T_1 = \sqrt{3}\frac{V_{ref}}{\hat{V}_i} T_s \sin\alpha \tag{10}$$

$$T_2 = \sqrt{3}\frac{V_{ref}}{\hat{V}_i} T_s \sin\left(\frac{\pi}{3} - \alpha\right) \tag{11}$$

where α is the angle between the reference voltage V_{ref} and voltage vector V_1.

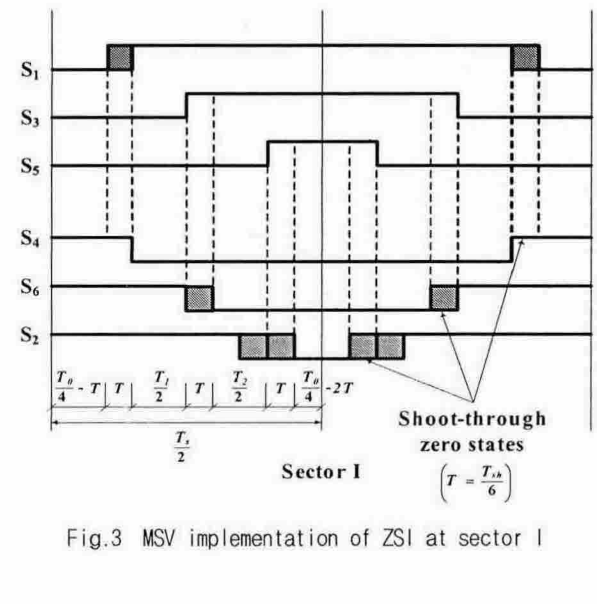


Fig.3 MSV implementation of ZSI at sector I

Fig.3 shows the MSVPWM implementation of ZSI at sector I. Unlike the conventional SVPWM, the MSVPWM has one extra shoot-through zero time T_{sh} besides conventional time intervals T_1, T_2, T_0. During shoot-through time, both switches of one leg are conducted simultaneously in order to boost the dc capacitor voltage as well as the ac inverter output voltage to any desirable value. In the MSPWM, the shoot-through time can be generated by increasing active time of upper switch whereas active time of bottom switch is maintained constant. The time T_0 should be diminished to generate a shoot through time T_{sh} respectively whereas two active times T_1, T_2 are still maintained like that of conventional SVPWM. The shoot-through time is evenly allocated at each phase with $T_{sh}/6$.

IV. ANALYSIS OF DC BOOST CONTROL

The active voltage vector is applied to the load terminal at time T_1, T_2 at SVPWM. The active state time T_a is expressed as

$$T_a = T_1 + T_2 \tag{12}$$

As shown in Fig.5, one sampling period consists of the active state time T_a and shoot-through time T_{sh} and zero state time T_0 at MSVPWM for ZSI as

$$T_s = (T_1 + T_2) + T_0 + T_{sh} = T_a + T_0 + T_{sh} \tag{13}$$

From (7), the capacitor voltage is derived as

$$V_C = \frac{1}{1-\frac{T_{sh}}{T_a}} V_{dc} = \frac{1}{1-M_{sh}} V_{dc} \tag{14}$$

where $M_{sh} = \frac{T_{sh}}{T_a}$

Using (8), the stress voltage of switching device is expressed in terms of M_{sh}.

$$\hat{V}_i = \frac{1+M_{sh}}{1-M_{sh}} V_{dc} \tag{15}$$

It can be seen that the capacitor voltage and the voltage stress are dependent on the active state time as well as the shoot-through time. The ratio between the capacitor voltage and stress voltage to a dc input voltage according to M_{sh} are plotted in Fig.4 and Fig.5, respectively.

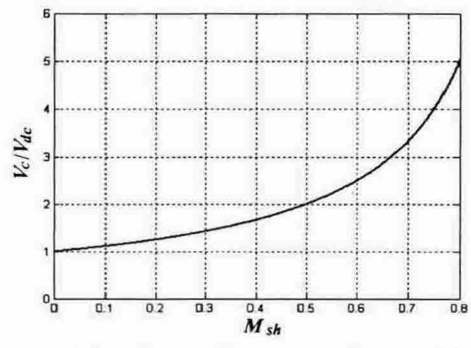


Fig.4 Capacitor voltage according to M_{sh}

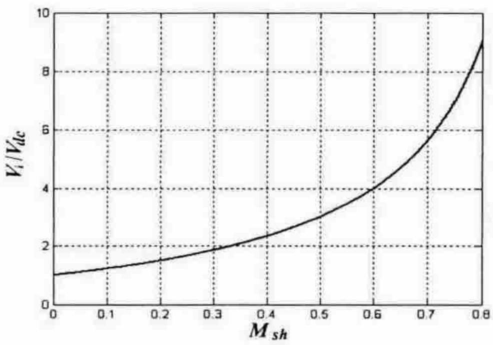


Fig.5 Voltage stress of device according to M_{sh}

Both the dc capacitor voltage and stress voltage can be boosted to five times and nine times, respectively, as the input voltage as M_{sh}increases from 0 to 0.8. This means application of the shoot-through time can augment the capacitor voltage or stress voltage more times than the input voltage without adding a boost converter. It is significant and unique characteristic of ZSI which can't be offered in the traditional inverters.

The voltage stress across the switching device is quite higher as the M_{sh} is increased. The M_{sh} should be restricted to the maximum value because of the limitation of device voltage rating.

V. SIMULATION AND EXPERIMENTAL RESULT

To verify the mentioned theoretical analysis, some simulations and experiments with 32-bit DSP TMS320F2812 are performed under the following conditions: dc input voltage $V_{dc} = 100\,V$, capacitors $C_1 = C_2 = 1mF$, inductors: $L_1 = L_2 = 1mH$

Fig.6 shows the responses of the capacitor voltage V_C, the stress voltage of device V_i, and the ac voltage when the shoot-through time T_{sh} is increased from $10\mu s$ to $15\mu s$ at $V_{ref} = 30\,V$. As the shoot-through time is developed, both the capacitor voltage and stress voltage are increased, and the stress voltage is much

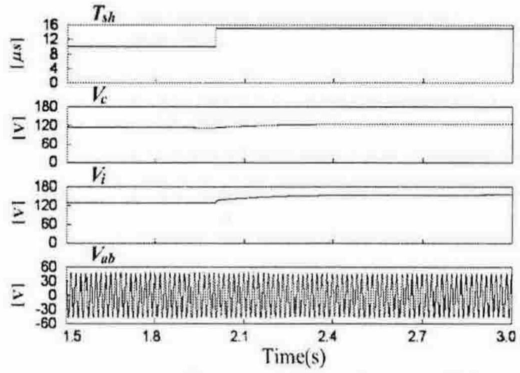


Fig.6 Simulation result when T_{sh} is increased from $10\mu s$ to $15\mu s$

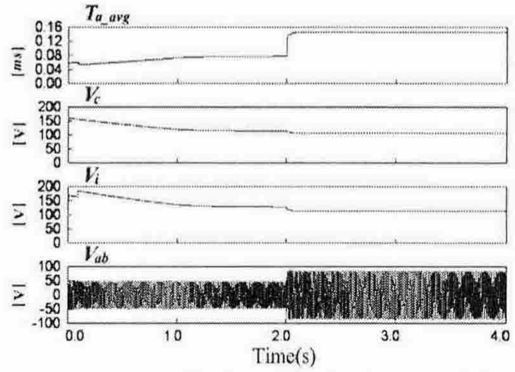


Fig.7 Simulation result when V_{ref} is increased from 30 V to 50 V

greater then the capacitor voltage. The ac voltage is not changed because the V_{ref} remains constant. Fig.7 shows the responses of the active time, capacitor voltage, voltage stress, and ac output voltage, when the V_{ref} is rapidly increased from 50V to 100V at $T_{sh} = 10\mu s$. When the V_{ref} is increased, the active state time and ac output voltage are increased, and both the capacitor voltage and voltage stress are decreased, due to the reduction of M_{sh}.

Experiments are carried out at the same operation conditions as the simulation studies. The responses of the capacitor voltage, stress voltage, and ac output voltage according to the shoot-through time and reference voltage shown in Fig.8 and Fig.9 are nearly the same as those of simulation results.

VI. CONCLUSION

This paper has proposed a valid theoretical analysis for Z-source inverter by using MSVPWM to control both the dc boost and ac output voltage. Herein the significant equation of the dc voltage and stress voltage are derived and explained considering zero state time of inverter. The variations of the capacitor

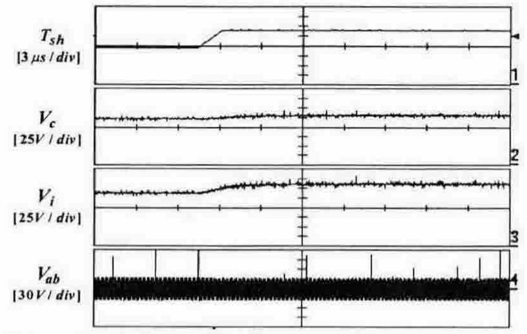


Fig.8 Experimental result when T_{sh} increases from $10\mu s$ to $15\mu s$

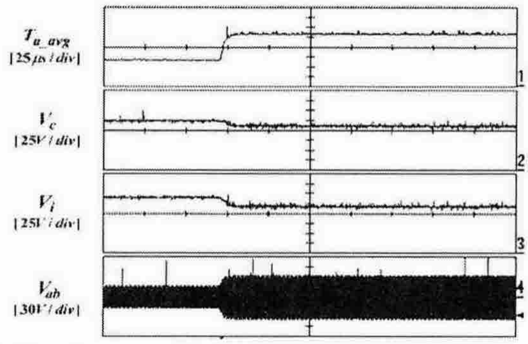


Fig.9 Experimental result when V_{ref} is increased from 30V to 50V

voltage and stress voltage and ac output voltage according to the shoot-through time and reference voltage were investigated. The theoretical analysis is verified by simulation and experiments with 32-bit DSP TMS320F2812.

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