3 상 Z-Source 인버터 관한 연구

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A Study on the 3-Phase Z-Source Inverter

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ABSTRACT

There are lots of control methods can be used in the 3-phase Z-Source inverter. In this paper several typical control methods are analyzed and compared through the simulation in the PSIM and Matlab.

1. Introduction

The recently presented Z-Source inverter has been researched actively especially on application in the fuel cell system and photovoltaic system. The 3-phase Z-Source inverter has advantages that it can boost or buck input DC voltage and it enhances the reliability of the inverter for avoiding influence of the shoot-through by EMI. There are lots of control methods can be used in the 3-phase Z-Source inverter. In this paper several typical control methods are analyzed and compared through the simulation in the PSIM and Matlab.

2. Z-source inverter

The structure of 3-phase Z-source inverter[1] is shown in Fig. 1. It has advantages that it can boost or buck input DC voltage and it enhances the reliability of the inverter for avoiding influence of the shoot-through by EMI. It is difficult in the traditional 3-phase inverter.

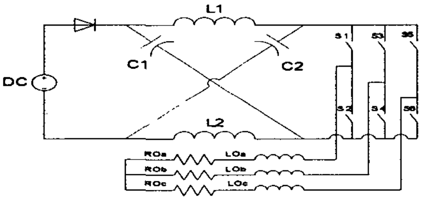


Fig. 1 3-Phase Z-Source inverter

2.1 Traditional control method

As shown in Fig.2, the gate signals are generated by comparing sinusoidal reference signals with a triangular carrier signal. There are three sinusoidal reference waves each shifted by 120 degree. The carrier wave is compared with the reference signal corresponding to a phase to generate the gate signals for that phase.

2.2 Simple boost control method

If two straight lines are employed in the traditional PWM control method, simple boost control method is got[2]. One straight line is equal to the maximum of the 3-phase reference, the other is equal to the minimum of the 3-phase reference. When the carrier triangular signal is greater than V_{r+} or smaller than V_{r-}, the inverter works in shoot-through zero state that is forbidden in the traditional method.

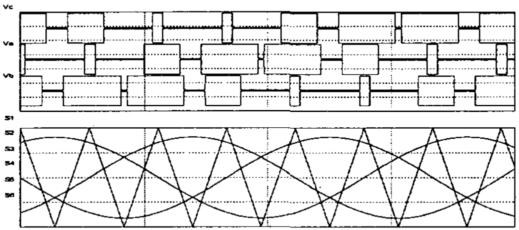


Fig. 2 Traditional 3-phase inverter control method

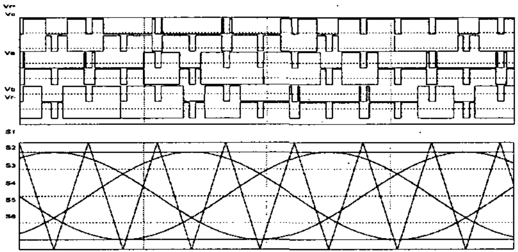


Fig. 3 Simple 3-phase Z-Source inverter control method

2.3 Maximum boost control method

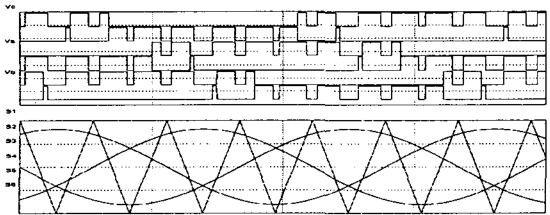


Fig. 4 Maximum boost 3-phase Z-Source inverter control method

In this method all zero states of traditional method are turned into shoot-through zero states. By this way the maximum boost output voltage is obtained.

2.4 Constant boost control method

Instead of two straight lines in the simple control method, two sine curves are used to get the shoot-through time. As shown in Fig. 5, when the carrier triangle signal is greater than V_{r+} or smaller than V_{r-}, the inverter works in shoot-through zero state.

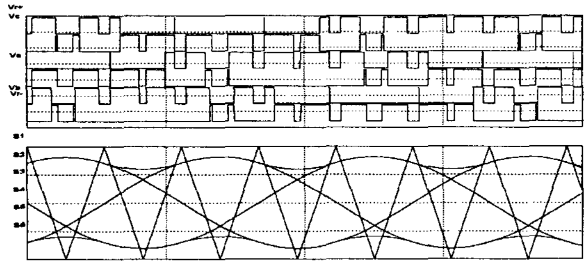


Fig. 5 Constant boost 3-phase Z-Source inverter control method

3. Basic Expressions

The boost factor B is

$$B=\frac{1}{1-2\frac{T_0}{T}}=\frac{1}{1-2D_0} \tag{1}$$

The voltage gain of the Z-Source inverter is

$$G=\frac{\widehat{V_{ac}}}{V_i/2}=MB=\frac{M}{1-2D_0} \tag{2}$$

3.1 Simple boost control method

The maximum shoot-through duty ratio is

$$D_0=1-M \tag{3}$$

The relationship in G and M is

$$G=\frac{M}{1-2D_0}=\frac{M}{2M-1} \tag{4}$$

The relationship in M and G is

$$M=\frac{G}{2G-1} \tag{5}$$

From (2) (5),

$$B=2G-1 \tag{6}$$

The voltage stress on the switches is

$$V_s=BV_i=(2G-1)V_i=\frac{1}{2M-1}V_i \tag{7}$$

3.2 Maximum boost control method

In the period (π/6, π/2), the average shoot-through duty ratio is

$$\frac{\widehat{T_0}}{T}=\int_{\pi/6}^{\pi/2}\frac{2-(M\sin\theta-M\sin(\theta-2\pi/3))}{2}d\theta$$

$$=\frac{2\pi-3\sqrt{3}M}{2\pi} \tag{8}$$

The maximum shoot-through duty ratio is

$$D_0\equiv\frac{2\pi-3\sqrt{3}M}{2\pi} \tag{9}$$

The relationship in G and M is

$$G=\frac{M}{1-2D_0}=\frac{M\pi}{3\sqrt{3}M-\pi} \tag{10}$$

The relationship in M and G is

$$M=\frac{\pi G}{3\sqrt{3}G-\pi} \tag{11}$$

From (2) (5),

$$B=\frac{3\sqrt{3}G-\pi}{\pi} \tag{12}$$

The voltage stress on the switches is

$$V_s=BV_i=\frac{3\sqrt{3}G-\pi}{\pi}V_i=\frac{\pi}{3\sqrt{3}M-\pi}V_i \tag{13}$$

3.3 Constant boost control method

The shoot-through duty ratio is

$$D_0\equiv\frac{2-\sqrt{3}M}{2}=1-\frac{\sqrt{3}M}{2} \tag{14}$$

The relationship in G and M is

$$G=\frac{M}{1-2D_0}=\frac{M}{\sqrt{3}M-1} \tag{15}$$

The relationship in M and G is

$$M=\frac{G}{\sqrt{3}G-1} \tag{16}$$

From (2) (5),

$$B=\sqrt{3}G-1 \tag{17}$$

The voltage stress on the switches is

$$V_s=BV_i=(\sqrt{3}G-1)V_i=\frac{1}{\sqrt{3}M-1}V_i \tag{18}$$

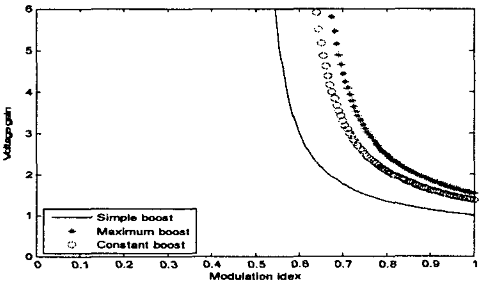


Fig. 6 Voltage gain versus Modulation index

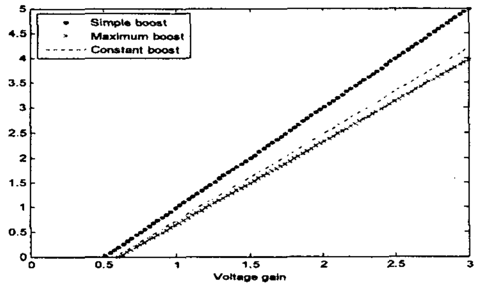


Fig. 7 Voltage stress versus voltage gain

4. Simulation Results

Three simulations are done. The parameters are: Z-Source unit L=1mH, C= 1mF, frequency of carry triangle signal is 10k. First is getting constant output RMS voltage by regulating the modulation index of each control method. Second is comparing the outputs when the modulation index is set to 1 in each control method. Third is comparing the output phase current of each method in same output line-line RMS voltage and same output impedance.

4.1 Constant Output Simulation

The input voltage is 120V, and output line-line RMS voltage is set to 220V. The output power is determined to 30kVA.

Table 1 Constant Output Simulation

	Simple		Maximum		Constant	
	Matlab	PSIM	Matlab	PSIM	Matlab	PSIM
M	0.6676	0.6676	0.8273	0.8273	0.7874	0.7874
V_{LLRMS}	220V	220.0V	220V	220.1V	220V	219.7V
$V_{phaseRMS}$	127.0V	127.0V	127.0V	127.1V	127.0V	126.9V
$I_{phaseRMS}$	7.87A	7.86A	7.87A	7.87A	7.87A	7.87A
V_S	360.0V	370.8V	325.9V	330.1V	329.9V	338.3V
$\widehat{V_{AC}}$	119.5V	118.9V	134.8V	132.9V	129.9V	130.1V
L(H)		0.0177		0.0194		0.0188
R(Ω)		8.8658		9.7021		9.4624

From the simulation result, it is obvious that the required voltage and power can be made, but the voltage stress across the switch is different. There is minimum value in the maximum control method.

4.2 Constant Modulation Index Simulation

The input voltage is 120V, and the modulation index is set to 1.

Table 2 Constant Modulation Index Simulation

	Simple		Maximum		Constant	
	Matlab	PSIM	Matlab	PSIM	Matlab	PSIM
M	1	1	1	1	1	1
V_{LLRMS}		88.7V		139.0V		121.6
$V_{phaseRMS}$		51.2V		80.2V		70.2
$I_{phaseRMS}$		3.82A		5.46A		4.93
V_S	120V	120.7V	183.5V	192.1V	163.9V	166.8
$\widehat{V_{AC}}$	60V	59.6V	91.7V	93.5V	82.0V	81.9V
L(H)		0.0177		0.0194		0.0188
R(Ω)		8.8658		9.7693		9.4624

From the result, we can know that the maximum output line-line voltage can be made in the maximum control method when the modulation index is set to same.

4.3 Output THD Compare Simulation

The input voltage is 120V, and output line-line RMS voltage is 220V. The output R=12.9 Ω, L=0.0257H.

Table 3 Output THD Compare Simulation

	Simple		Maximum		Constant	
	Matlab	PSIM	Matlab	PSIM	Matlab	PSIM
M	0.6676	0.6676	0.8273	0.8273	0.7874	0.7874
V_{LLRMS}	220V	220.1V	220V	222.8V	220V	219.8V
$V_{phaseRMS}$	127.0V	127.1V	127.0V	128.6V	127.0V	126.9V
$I_{phaseRMS}$		5.41A		6.00A		5.77A
V_S	360.0V	369.2V	325.9V	334.6V	329.9V	338.1V
$\widehat{V_{AC}}$	119.5V	123.7V	134.8	135.1V	129.9V	131.7V
L(H)		0.0257		0.0257		0.0257
R(Ω)		12.9		12.9		12.9
THD		2.211		1.741		1.834

For an ac waveform that contains both the fundamental and harmonic components. The total harmonic distortion of the waveform is shown as Fig. 8. The best THD is got in the simple control method as shown in Fig. 8. The FFT results is shown in Fig. 9.

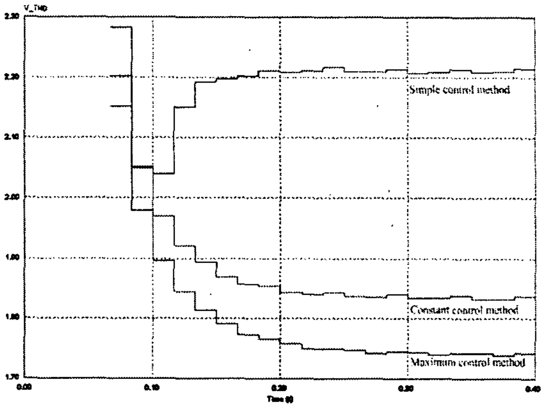
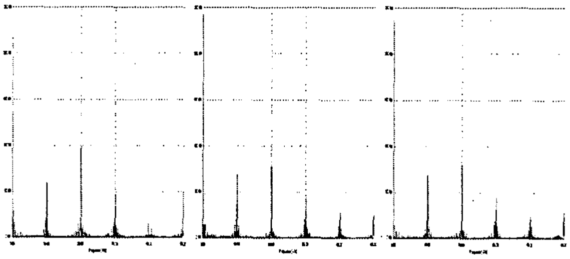


Fig. 8 THD analysis



Simple Maximum Constant

Fig. 9 FFT of Line-Line Voltage

5. Conclusion

Three typical control methods in Z-Source inverter was analyzed in this paper. For each method, the boost factor, voltage gain, duty ration and voltage stress across the switches were expressed and the relationships among them are analyzed in detail. Through the comparison among them, we can select the proper method according as different demand.

References

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[2] Fang Zheng Peng and Miaosen Shen, Zhaoming Qian, "Maximum Boost Control of the Z-source inverter",IEEE Transactions on Power Electronics, Vol. 20, No 4, pp. 833-838, 2005, July.

[3] Muhammad H. Rashid, "Power Electronics: Circuits, Devices, and Applications", Prentice Hall, May 21, 1993.