Proceedings of 2010 IEEE Student Conference on Research and Development (SCOReD 2010),
13 - 14 Dec 2010, Putrajaya, Malaysia

Analysis of various PWM controls on single-phase Z-source inverter

Mohd. Shafie Bakar
Faculty of Electrical & Electronics Engineering, Universiti Malaysia Pahang,
PAHANG, MALAYSIA
shafie@ump.edu.my

Nasrudin Abd. Rahim
Centre of Research of Power Electronics (UMPEDAC),
University of Malaya,
K.L, MALAYSIA
nasrudin@um.edu.my

Kamarul Hawari Ghazali
Faculty of Electrical & Electronics Engineering, Universiti Malaysia Pahang,
PAHANG, MALAYSIA
kamarul@ump.edu.my

Abstract - **The paper compares three PWM control methods on a single-phase Z-source inverter (ZSI); traditional, simple-boost (SB-PWM), and modified-reference (MR-PWM). A model of the inverter in an open-loop system was built in Matlab/Simulink. The methods and their modulation indices were analyzed against two design parameters (dc-input voltage and switching frequency), the analysis basing determination of the Z-source inverter's performance.**

Keywords - pulsewidth modulation (PWM); Z-source inverter; total harmonic distortion (THD)

I. INTRODUCTION

Traditional inverters are voltage-source inverter (VSI) and current-source inverter (CSI). VSI input is dc-voltage source: battery, fuel-cell stack, diode rectifier, and/or capacitor [1, 2]. Despite widespread use, VSI has limitations;

- In dc-to-ac power conversion, a buck (step-down) inverter is used, so an additional dc-to-dc boost converter is required for ac output to be obtained in applications where dc voltage is limited and overdrive is desired [2], the addition increasing system cost and lowering efficiency [2].
- The dead-time needed to avoid simultaneous gating of phase legs distorts waveform [2].
- Unlike in current-source inverter, an output LC filter is needed to provide sinusoidal voltage, adding to power loss and complicating control [2].

CSI input is dc current source fed by converter main circuit [1]. The dc current source can be a large dc inductor fed by a voltage source such as a battery, a fuel-cell stack, a diode rectifier, or a thyristor converter. CSI limits are:

- 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 [2], increasing cost and lowering efficiency [2].
- For safe commutation of current, overlap time is necessary, distorting waveform [2].

So, both the inverters have these problems [2]:

- Neither can be a buck–boost converter, i.e., the obtainable output voltage range of each is limited to either greater, or smaller, than the input voltage.
- The VSI main circuit cannot be used for the CSI, and vice versa.

Z-source converter (ZSC) is a problem-solving option. 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 focus here, however, is dc-to-ac power conversion known as Z-source inverter (ZSI). Three types of PWM control, i.e., traditional PWM, simple boost PWM (SB-PWM), and modified-reference PWM (MR-PWM), were each implemented in a single-phase ZSI, in open-loop system, simulated with various dc input voltages and various switching frequencies, and the effect of changing the modulation indices analyzed to determine the inverter's performance.

II. Z-SOURCE INVERTER

Figure 1 shows the general structure of a ZSI, which comprises four main blocks: dc voltage source, Z-source network, inverter network, and ac load. The dc source can be either a voltage source or a current source. The Z-source network comprises split inductors L_1 and L_2, and X-connected capacitors C_1 and C_2, for coupling of the inverter network to the dc source. The inverter network can be single-phase or three-phase; the focus here is the single phase. The end block is an ac load, which can be connected to the load (i.e., motor), or to another converter.

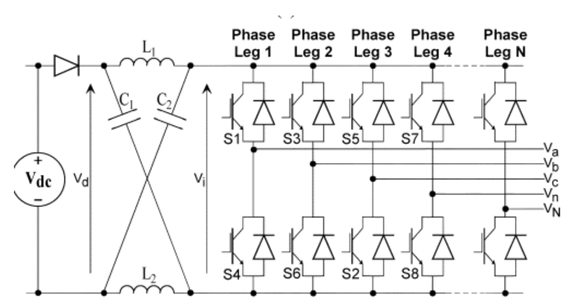


Figure 3. General structure of a Z-source converter [3]

A diode and Z-source network connected between the dc-input voltage and inverter are the main differences in the power circuit [5]. The diode function is to prevent discharging capacitor through the dc-input voltage [5].

A special feature of ZSI operation is that it allows both power switches of a phase leg to be turned on simultaneously without damaging inverter network [3] (a scenario called shoot-through). The inverter's performance can be analyzed via its equivalent circuits; see Figure 2. In shoot-through state, the ZSI is shorted; see Figure 2 (a). By assuming $C_1=C_2=C$, we get:

$$V_{L1}=V_{L2}=V_L=V_{C1}=V_{C2}=V_C \quad (1)$$
$$V_d=V_L+V_C \quad (2)$$
$$V_i=0 \quad (3)$$

No energy is transferred to the load.

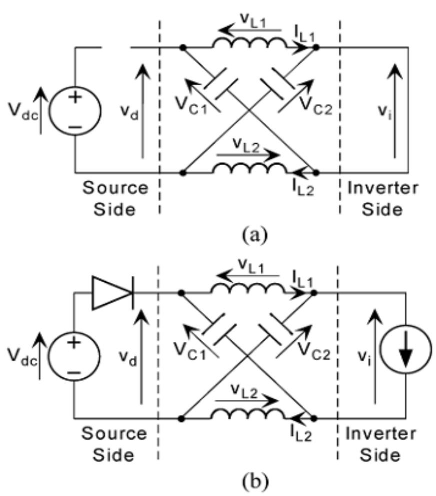


Figure 2. Equivalent Z-source inverter circuits in (a) shoot-through state (b) non-shoot –through state [3].

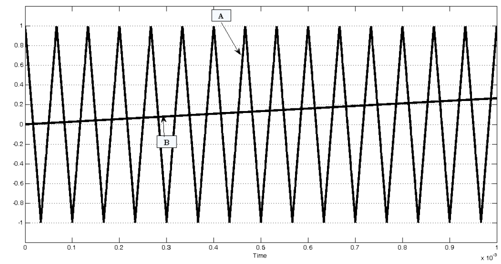
During non-shoot-through state, current flows from the Z-source network through the inverter network, to the connected ac load. The Z-source network can now be represented by an equivalent current source; see Figure 2(b). The following equations thus result:

$$V_L=V_{dc}-V_C \quad (4)$$
$$V_d = V_{dc} \quad (5)$$
$$V_i = V_C - V_L = 2V_C - V_{dc} \quad (6)$$

III. PWM CONTROL

A. Traditional PWM

The gate signals are generated by comparing sinusoidal reference signals with a triangular carrier signal; see Figure 3.



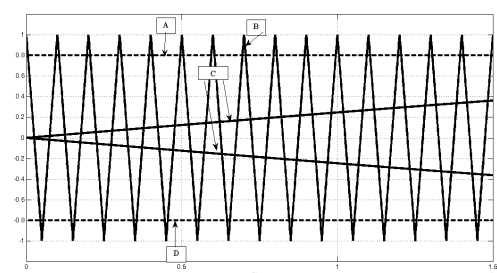
Legends:
A – carrier signal
B – reference signal

Figure 3. Traditional PWM control

B. Simple boost PWM (SB-PWM)

Past research [2, 4, 6] implemented this method in three-phase Z-source converter. This work used the same concept as of Figure 4 and implemented it in single-phase ZSI. For control of shoot-through duty ratio, two straight lines equal to, or greater than, the peak value of the reference signal, are used. When the carrier signal is greater than the upper straight line or lower than the bottom straight line, the circuit turns into shoot-through state [6]; else, it operates like a traditional carrier-based PWM.

Legends:

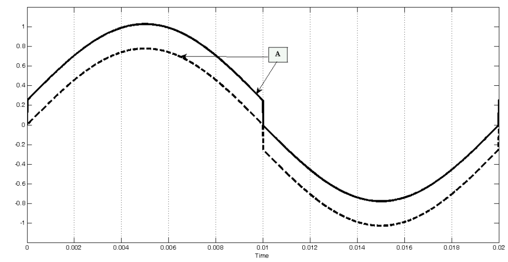


A – upper straight line
B – carrier signal
C – reference signals
D – lower straight line

Figure 4. Simple boost PWM control

C. Modified-reference PWM (MR-PWM)

In [3, 7], the method was implemented in single-phase Z-source converter and was more extensively studied than the results of its simulations were discussed. It uses four modified reference signals to control four switches independently; see Figure 5. For control of the two switches in the first-phase leg, two positive references compare with the carrier signal, and for control of the two switches on the second-phase leg, two negative references compare with the carrier signal.



Legend:
A – Modified references

Figure 5. MR-PWM on the single-phase Z-source inverter [7]

IV. SIMULATION AND RESULTS

The Z-source network values for L and C were 1000 uH and 1000 uF respectively, to gain around 500W output power at 50Hz, for an input range of 70V-135V with 10kHz switching frequency. Figure 5 shows system configuration used for simulation work. The work process runs in 3-steps.

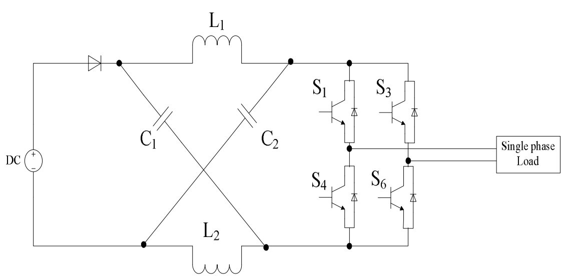


Figure 5. System configuration

The first step was getting 10kHz constant switching frequency by regulating the modulation index and the dc input voltage of each PWM control. The second step was getting constant dc input voltage by regulating switching frequency and modulation index of each PWM control. The third step was getting constant output power by regulating the modulation index and the dc input voltage to find the THD output power.

A. *Constant Switching Frequency & Output Voltage (RMS)*

Table 1 shows the resulting output voltages (RMS) at 10kHz switching frequency. Changing the dc-input voltage and the modulation index changed the output voltage at around 500W constant output power.

TABLE 1. COMPARISON OF OUTPUT VOLTAGES (RMS) OF THE THREE PWM CONTROLS, AT 10KHZ SWITCHING FREQUENCY

	DC input voltage (V)	**Modulation Index**	**Output voltage (RMS)**
Traditional PWM	160	0.86	100
	180	0.75	99
	200	0.68	106
SB-PWM	70	0.65	104
	80	0.72	101
	135	0.95	103
MR-PWM	95	0.78	103
	107	0.65	102
	130	0.55	102

B. *Constant dc-input voltage*

Table 2 compares the results for simulation at 130V constant dc-input voltage. The highest modulation index for the traditional PWM was found to be 0.97, nearly the range's maximum of 1. The maximum voltage stress and the output power (around 400W) were thus determined, but the other PWM methods obtained around 500W, making comparison with the former unfair.

TABLE 2. COMPARISON OF OUTPUT VOLTAGES (RMS) OF THE THREE PWM CONTROLS, AT 130V DC-INPUT VOLTAGE

	DC input voltage (V)	**Switching frequency (kHz)**	**Output voltage (RMS)**
Traditional PWM	130	5	88
		15	85
SB-PWM	130	5	106
		15	103
MR-PWM	130	5	108
		15	103

C. *Improved THD of output current*

As shown in Table 3, at 15kHz switching frequency, the output-current THD in SB-PWM and in MR-PWM was each improved compared with that in traditional PWM. Similar output power of around 500W can be obtained by regulating the dc input voltage and the modulation index.

TABLE 3. COMPARISON OF OUTPUT-CURRENT THD OF THE THREE PWM CONTROL METHODS, AT 15KHZ SWITCHING FREQUENCY

	DC input voltage (V)	Modulation Index	THD of output current (%)
Traditional PWM	160	0.86	4.81
	180	0.75	7.14
	200	0.68	14.69
SB-PWM	70	0.65	2.79
	80	0.72	2.79
	135	0.95	2.79
MR-PWM	95	0.78	2.94
	107	0.65	2.12
	130	0.55	2.19

V. CONCLUSION

A simulation model for the ZSI has been presented with three PWM control methods; traditional PWM, SB-PWM and MR-PWM. Results of the simulation at 2.12%, under similar output power of around 500W and 15kHz switching frequency, showed the MR-PWM control to give better output-current THD than did the SB-PWM and the traditional PWM methods. Dc-input voltage was set to 107V and modulation index to 0.65. The MR-PWM is thus a better PWM control method, as shown by its output current THD.

ACKNOWLEDGMENT

This work was financed by the Engineering Science Program of Universiti Malaysia Pahang (UMP), vote number RDU0903134. The author thanks UMPEDAC for placement throughout the research tenure.

REFERENCES

[1] R. Senthilkumar, R. Bharanikumar, and J. Jerom, "Z-source inverter for UPS application," in *Intelligent and Advanced Systems, 2007. ICIAS 2007. International Conference on*, 2007, pp. 835-839.

[2] P. Fang Zheng, "Z-source inverter," *IEEE Transactions on industry applications,* vol. 39, pp. 504-510, 2003.

[3] L. Poh Chiang, D. M. Vilathgamuwa, Y. S. Lai, C. Geok Tin, and Y. Li, "Pulse-width modulation of Z-source inverters," *IEEE Transactions on Power Electronics,* vol. 20, pp. 1346-1355, 2005.

[4] H. Rostami and D. A. Khaburi, "Voltage gain comparison of different control methods of the Z-source inverter," in *Electrical and Electronics Engineering, 2009. ELECO 2009. International Conference on*, 2009, pp. I-268-I-272.

[5] S. R. and L. Jayawickrama, "Steady-State Analysis and Designing Impedance Network of Z-Source Inverters," *IEEE Transactions on industrial electronics,* vol. 57, p. 9, July 2010.

[6] O. Ellabban, J. Van Mierlo, and P. Lataire, "Comparison between different PWM control methods for different Z-source inverter topologies," in *Power Electronics and Applications, 2009. EPE '09. 13th European Conference on*, 2009, pp. 1-11.

[7] P. C. Loh, D. M. Vilathgamuwa, C. J. Gajanayake, L. T. Wong, and C. P. Ang, "Z-source current-type inverters: digital modulation and logic implementation," in *Industry Applications Conference, 2005. Fourtieth IAS Annual Meeting. Conference Record of the 2005*, 2005, pp. 940-947 Vol. 2.

BIOGRAPHIES

Mohd. Shafie Bakar received his Bachelor of Engineering in Electronics from Oxford Brookes University in 1996 and Master in Electrical Engineering from Universiti Teknologi Malaysia in 2003. Currently he is doing PhD with Faculty of Electrical & Electronics Engineering, Universiti Malaysia Pahang. His research interests include power converters, battery management systems and renewable energy systems.

Nasrudin Abd. Rahim (M'89-SM'08) was born in 1960 in Johor, Malaysia. He received his B.Sc. (Hons.) and his M.Sc. degrees from the University of Strathclyde, Glasgow, U.K., and his Ph.D. degree in 1995 from Heriot-Watt University, Edinburgh, U.K.He is currently a Professor with the Department of Electrical Engineering,University of Malaya, Kuala Lumpur, Malaysia, the Director of the Center of Research for Power Electronics, Drives, Automation and Control, and Chairman of University of Malaya's Advanced Engineering & Technology Research Cluster. Dr. Rahim is a Fellow of the Institution of Engineering and Technology, U.K. and a Chartered Engineer. He is also Chairman of the Working Group WG-8, covering reluctance motors, of the IEEE Motor Subcommittee under IEEE Power Engineering Society/Electric Machinery Committee. His research interests include power electronics, real-time control systems, and electrical drives, and renewable energy (solar and wind).

Kamarul Hawari Ghazali received his Degree in Electrical Engineering from Universiti Teknologi Malaysia in 1996 and Master in Electrical Engineering from Universiti Teknologi Malaysia in 2003. He received his PhD in Electronic and System from Universiti Kebangsaan Malaysia in 2009. His research interest is in Vision System and Renewable Energy.