UACEE International Journal of Advancements in Electronics and Electrical Engineering
Volume 1: Issue 1

Performance Analysis of Different PWM Controls for Three-Phase Z-Source Inverter

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***Abstract*—This paper presents hardware comparative evaluation of different PWM schemes of three phase Z-source inverter by feeding to an induction motor. For purpose of comparison, all PWM controls are evaluated at same input DC voltage, same value of shoot through duty ratio, switching frequency. The comparison shows that the maximum constant boost control is the most suitable PWM control scheme for Z-source inverter.**

***Keywords*—maximum boost, MSVPWM, PWM, shoot-through zero states, Z-source inverter**

I. Introduction

The recently presented Z-Source Inverter has been researched actively especially on application in the fuel cell system and photo voltaic system. The three phase Z-source inverter employs a unique impedance network to couple the inverter main circuit to the power source, thus providing unique features that cannot be obtained in the traditional voltage-source and current-source inverters.

The three phase Z-source inverter bridge has nine permissible switching states unlike the traditional three phase voltage source inverter that has eight. However, the Z-source inverter bridge has one extra zero (i.e., both devices are gated on of any two phase legs, or of all three phase legs). This shoot-through zero state is forbidden in the traditional voltage source inverter. For the traditional voltage source inverter, both switches of any phase leg can never be gated on at the same time or a short circuit (shoot through) would occur and destroy the inverter.

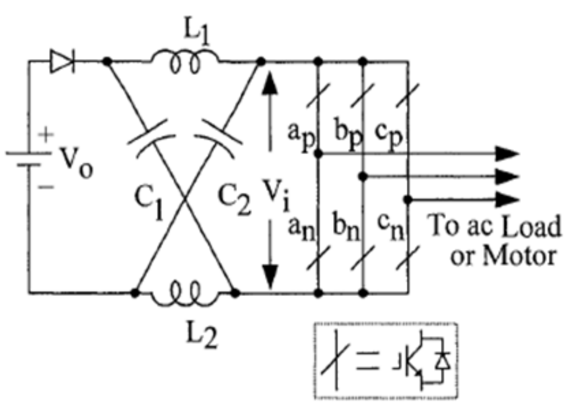

Figure 1. Z-source inverter

The new Z-source inverter advantageously utilizes the shoot through states to boost the DC bus voltage and produce a desirable output voltage that is greater than the available DC bus voltage. In addition, the reliability of the inverter is greatly improved because the shoot through can no longer destroys the circuit.

In ref [1], the main circuit of the Z-source inverter and the operation principle has been described in detail. In this paper, control schemes are implemented over FPGA kit using system generator tool of Xilinx software.

II. Control Schemes

All traditional PWM control schemes can holds good for Z-Source inverter. However to utilize the special feature of Z-source inverter, shoot through states has to be included over traditional PWM schemes, so how to insert shoot through zero state becomes the key point of the control methods. It is obvious that during the shoot through state, the output terminals of the inverter are shorted and the output voltage to the load is zero. The output voltage of the shoot through state is zero, which is the same as traditional zero states, therefore the duty ratio of the active states has to be maintained to output a sinusoidal voltage, which means shoot through only replaces some or all the traditional zero states. The various control schemes are listed as below.

- SPWM schemes
  - Traditional control
  - Simple boost control
  - Maximum boost control
  - Maximum constant boost control
- Modified SVPWM

A. Traditional Control Methods

As shown in Figure 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.

B. Simple Boost Control Method

If two straight lines are employed in the traditional PWM control method, simple boost control method is achieved [2] and it is shown in Figure 3.

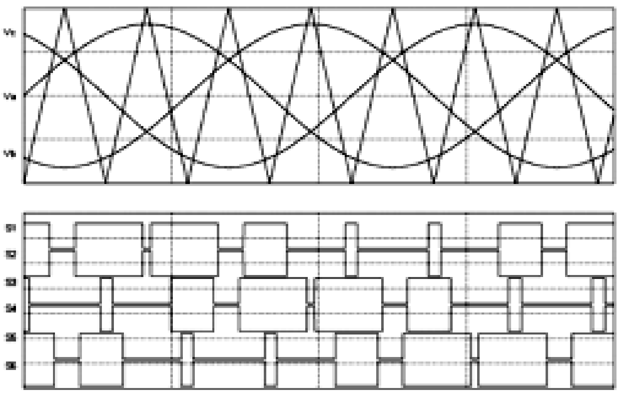

Figure 2. Traditional three-phase inverter control method

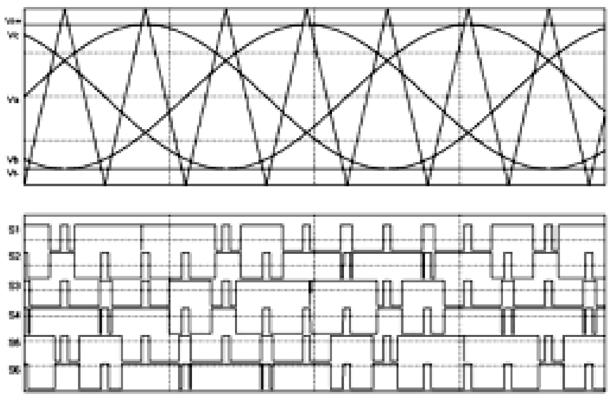

Figure 3. Simple boost control

One straight line is equal to the maximum of the three phase reference; the other is equal to the minimum of the three 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.

C. Maximum Boost Control Method

In this method [2] all zero states of traditional method are turned into shoot-through zero states. By this way the maximum boost output voltage is obtained. This control scheme is shown in Figure 4.

D. Maximum 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 Figure 5, when the carrier triangle signal is greater than V_{r+} or smaller than V_{r-}, the inverter works in shoot through zero state [3].

E. Modified SVPWM

Unlike the traditional SVPWM, the MSPWM [5] has an additional shoot through time T_{sh} besides time intervals T_1, T_2, T_0.

The zero voltage period To should be diminished for generating a shoot through time T_{sh}. The shoot through time is evenly assigned to each phase with $T_{sh}/6$, while the active state times T_1, T_2 are not changed as shown in Figure 6.

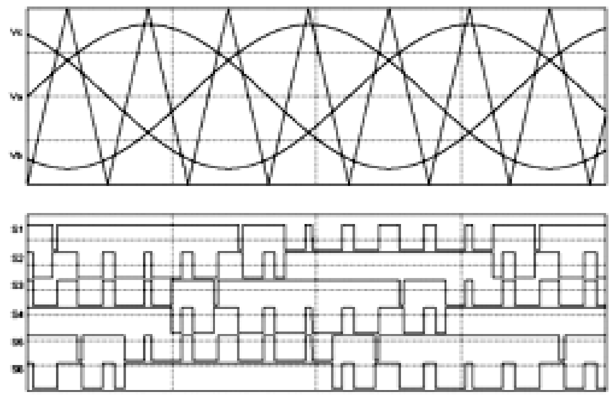

Figure 4. Maximum boost control

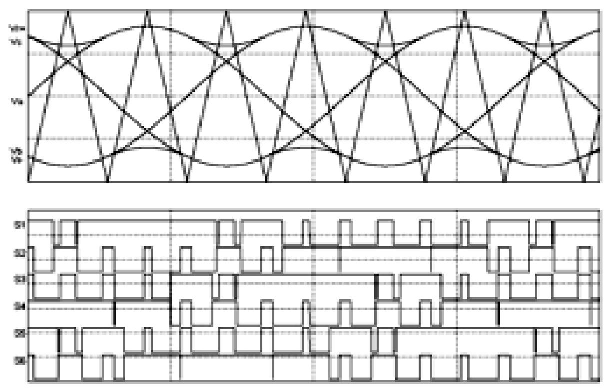

Figure 5. Maximum constant boost control

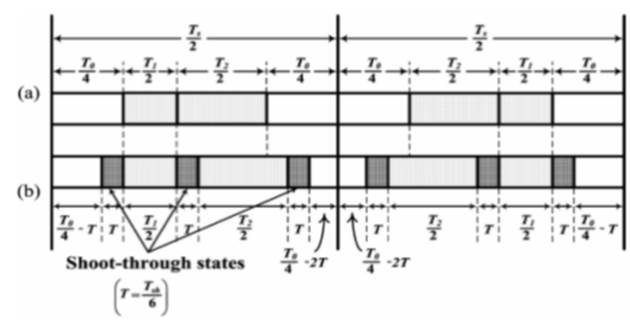

Figure 6. Modified SVPWM

III. SOFTWARE IMPLEMENTATION

The control schemes are implemented using Xilinx system generator 10.1. This tool is compatible with MATLAB 2008a. Using this MATLAB simulations are done using Xilinx block sets, and then VHDL code is generated.

This VHDL code is converted into Bitstream file using Xilinx ISE software and then downloaded into FPGA Spartan 3 kit. All control schemes are implemented practically in system generator and are tested with Z-source inverter for induction motor drive. But the typical model is presented for one control scheme i.e. maximum boost control scheme developed in MATLAB SIMULINK using Xilinx System Generator [6] is shown Figure 7. Here In and Out blocks can be configured to give input, here it is modulation index value and to take output pulses from FPGA kit respectively. I/P switches and free I/Os of FPGA are interfaced for this purpose.

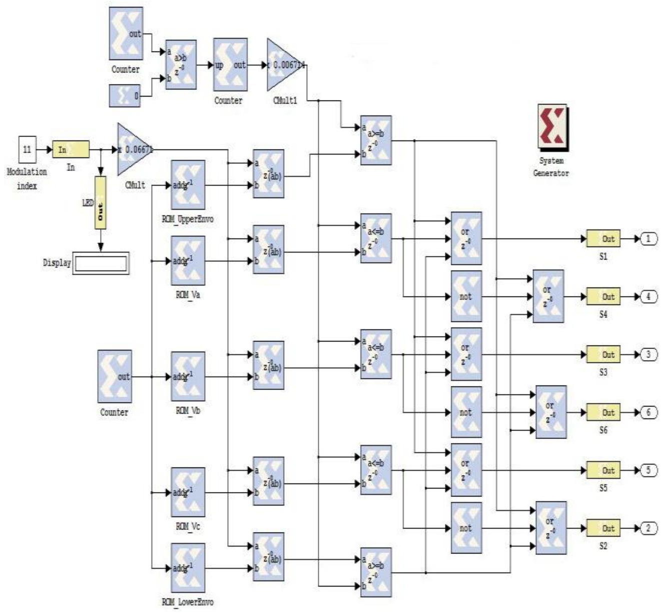

Figure 7. Maximum constant boost control implementation using Xilinx block set

IV. Basic Expressions

The boost factor B is

$$B = \frac{1}{1 - 2\frac{T_0}{T}} = \frac{1}{1 - 2D_0} \quad (1)$$

The voltage gain of the Z-source inverter is

$$G = MB = \frac{V_{ac}}{V_0 / 2} = \frac{M}{1 - 2D_0} \quad (2)$$

A. Simple boost control method

The maximum shoot-through duty ratio is

$$D_0 = 1 - M \quad (3)$$

The relationship in G and M is

$$G = \frac{M}{1 - 2D_0} = \frac{M}{2M - 1} \quad (4)$$

The relationship in M and G is

$$M = \frac{G}{2G - 1} \quad (5)$$

From (2) and (5),

$$B = 2G - 1 \quad (6)$$

The voltage stress on the switches is

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

B. Maximum boost control method

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

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

$$= \frac{2\pi - 3\sqrt{3}M}{2\pi} \quad (8)$$

The maximum shoot-through duty ratio is

$$D_0 = \frac{2\pi - 3\sqrt{3}M}{2\pi} \quad (9)$$

The relationship in G and M is

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

The relationship in M and G is

$$M = \frac{\pi G}{3\sqrt{3}G - \pi} \quad (11)$$

From (2) and (11),

$$B = \frac{3\sqrt{3}G - \pi}{\pi} \quad (12)$$

The voltage stress on the switches is

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

C. Maximum constant boost control method

The shoot-through duty ratio is

$$D_0 = \frac{2 - \sqrt{3}M}{2} = 1 - \frac{\sqrt{3}M}{2} \quad (14)$$

The relationship in G and M is

$$G = \frac{M}{1 - 2D_0} = \frac{M}{\sqrt{3}G - 1} \quad (15)$$

The relationship in M and G is

$$M = \frac{G}{\sqrt{3}G - 1} \qquad (16)$$

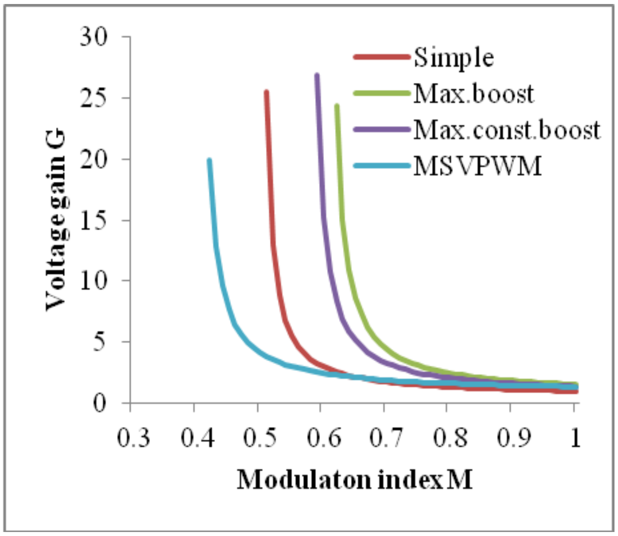

Figure 8. Modulation index vs voltage gain

From (2) and (16),

$$B = \sqrt{3}G - 1 \qquad (17)$$

The voltage stress on the switches is

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

D. Modified SVPWM

The shoot-through duty ratio is

$$D_0 = \frac{3}{4} \cdot \frac{2\pi - 3\sqrt{3}M}{2\pi} \qquad (19)$$

The relationship in G and M is

$$G = \frac{4\pi M}{9\sqrt{3}M - 2\pi} \qquad (20)$$

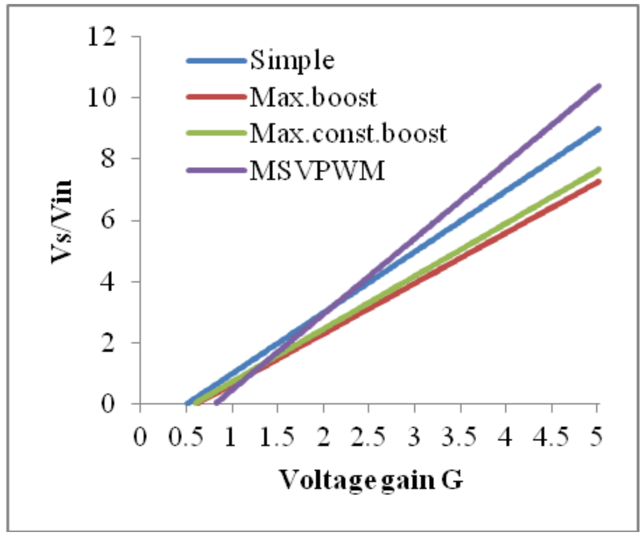

Figure 9. Voltage gain vs switch voltage stress

Figure 10. Output line volt and volt across switch for simple boost control

Figure 11. Output line voltage and voltage across switch for maximum boost control

The boost factor is derived from

$$B = \frac{9\sqrt{3}G - 4\pi}{2\pi} \tag{21}$$

The voltage stress on the switches is

$$V_s = BV_i = \frac{9\sqrt{3}G - 4\pi}{2\pi} V_i \tag{22}$$

From the above expressions, the following graphs are plotted. One is between modulation index (M) versus voltage gain (G), another plot is between voltage gain (G) versus switch voltage stress m Figures.

V. Experimental Results

The three phase Z-source inverter is made in the laboratory by choosing Z-impedance parameters as L = 3mH, C = 1000µF, frequency of carrier triangular signal is 3.3 KHz. The control schemes are tested with constant modulation index of M = 0.812, and with input DC voltage of 70V. Induction motor parameters are: 3-ph, 110V, 50 Hz, 1500 rpm.

In this testing, THDs of output line voltages and output currents are noted for all control schemes and voltage across the switch also noted down and those are given in Table I.

The simulation results are shown in Figures 10-13 for various control schemes such as simple boost, maximum boost, maximum constant boost and modified SVPWM. The results of THDs are shown in Figures 14-17 for various control schemes of Z-Source inverter fed induction motor drive

Figure 12. Output line voltage and voltage across switch for maximum constant boost

Figure 13. Output line voltage and voltage across switch for modified SVPWM

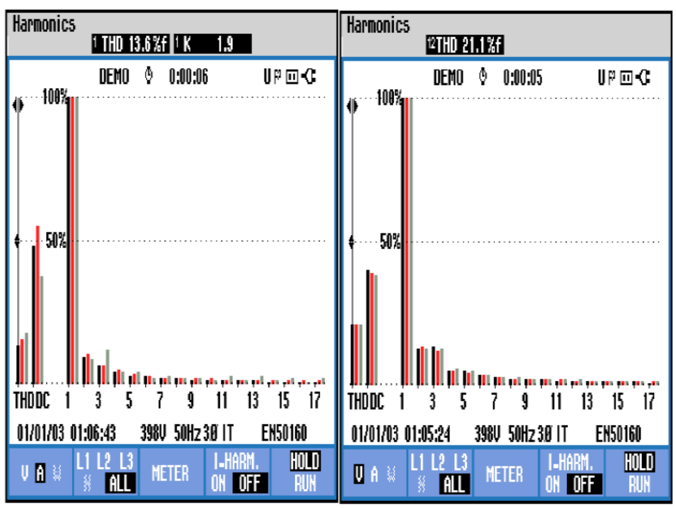

Figure 14. THDs of line current and output line voltage for simple boost control

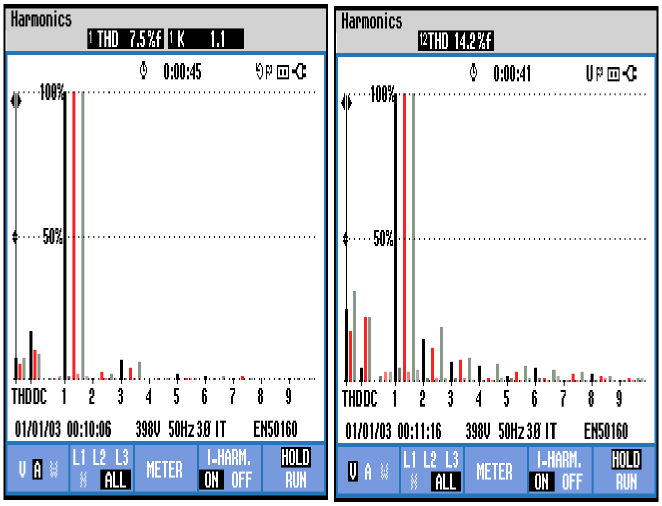

Figure 15. THDs of line current and output line voltage for maximum boost control

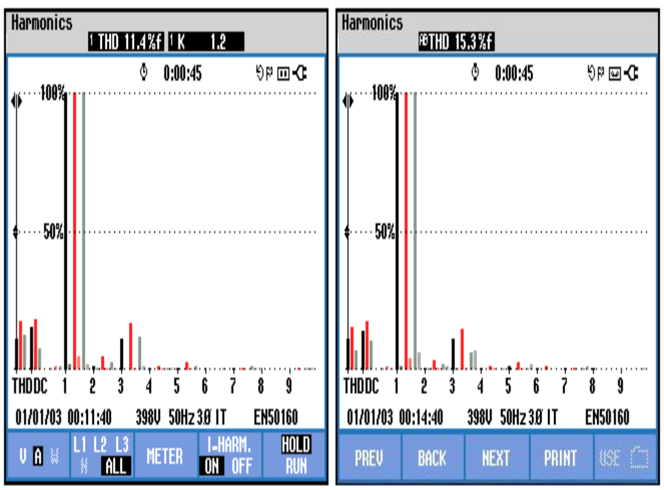

Figure 16. THDs of line current and output line voltage for maximum constant boost control

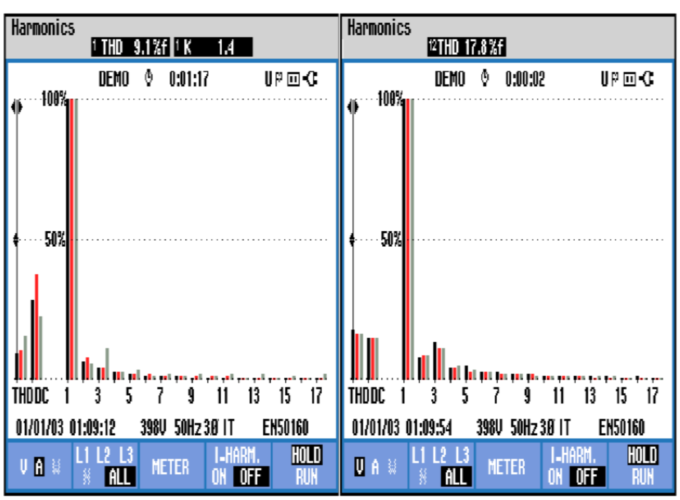

Figure 17. THDs of line current and output line voltage for modified SVPWM

TABLE I. SUMMAY OF RESULTS

Scheme	THD_{VLL} %	THD_{IL} %	Voltage across switch (V)
Simple boost	21.1	13.6	75
Maximum boost	14.2	7.5	102
Max constant boost	15.3	11.2	94
MSVM	17.8	9.1	88

Table-1 shows the comparison of % THDs of all control schemes and also voltage across the switch.

The hardware circuitry of Z-source inverter implemented in lab, and it is tested with an induction motor and the control schemes are implemented in the FPGA Spartan-3 kit. The FPGA controlled Z-source inverter feeding to induction motor is shown in Figure 18.

Figure 18. Hardware setup in the laboratory

VI. CONCLUSION

From above experimental results and plots from expressions, it is concluded that for a modulation index of 0.812, maximum boost control scheme is having highest voltage gain value and simple boost is having lowest voltage gain value. While comparing voltage stress on switches, simple boost is having high voltage stress among other schemes. While comparing THD values for various schemes, maximum boost control scheme is having the better THD values.

REFERENCES

[1] F. Z. Peng, "Z-source inverter," IEEE Trans. on Industrial Applications, vol. 39, no. 2, pp. 504–510, March/April 2003.

[2] F. Z. Peng, M. Shen, and Z. Qian, "Maximum boost control of the z-source inverter," in Proc. 39th IEEE Industry Applications Conf., vol. 1, Oct. 2004.

[3] M. Shen, J. Wang, A. Joseph, F.Z. Peng and D. J. Adams, "Maximum constant boost control of the Z-source inverter," IEEE Industry Applications Soc. Annu. Meeting, 2004.

[4] Poh Chiang Loh, D. Mahinda Vilathgamuwa, Yue Sen Lai, Geok Tin Chua, and Yunwei Li, "Pulse width modulation of Z-source inverters," IEEE Trans. on Power Electronics, vol. 20, no. 6, nov. 2005.

[5] A. Das, D. Lahiri, and B. Kar, "Space vector PWM based AC output voltage control of Z-source inverter," International Conference on Control, Automation, Communication and Energy Conservation, 2009, pp. 1-4, 2009.

[6] System Generator help from Xilinx ISE software. Available: http://www.xilinx.com/tools/sysgen.htm.