A Study On Simulation of Voltage Sourced Inverter by Using SPWM Technique

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Abstract - **This paper presents a study on simulation of a Sinusoidal Pulse Width Modulation (SPWM) technique which is employed in three phase Voltage Sourced Inverter (VSI) to get the sinusoidal output waveform. The simulation method is established by using the software Powersim (PSIM). The simulation result is valuable to analyze the output produced in AC side with variable frequency and modulation index hence the generated harmonic can be observed.**

Keywords-Sinusoidal Pulse Width Modulation; Voltage Source Inverter

I. INTRODUCTION

At the present time, in numerous applications for power electronic circuits are utilized such as power electronic converters which change the voltage from one kind to another which is Direct Current (DC) to Alternating Current (AC) or AC to DC. These devices are called as Voltage Source Converter (VSC) and the type of converter used in this study is inverter as shown in Figure 1 which converts DC input into AC output [1]. The other type of inverter is Current Source Inverter (CSI). Inverter is one of the converter families which are broadly used in industrial applications like Uninterruptible Power Supplies (UPS), Variable Speed AC Motor Drives (VSD) and induction heating. Generally, inverters are utilized to deliver AC power fed form DC sources such as batteries, solar panels and other DC sources [2]. Besides, VSI can be interfaced with storage devices as well like Superconducting Magnetic Energy Storage (SMES). The system is called Power Conditioning System (PCS) which consists of a DC to DC chopper and a three phase VSC [3].

This paper concentrates on simulation of a three phase VSI where Pulse Width Modulation (PWM) control technique is broadly used. The major crisis faced by the power electronic design engineer is the harmonic content reduction in inverter circuits [6]. The traditional square wave inverter used in low or medium power application experienced from a serious weakness such as lower order harmonic in the output voltage. Hence, PWM control technique is proposed. This three phase VSI is mainly used for the supply of high voltage and power AC drive [4]. The output voltage of an ideal inverter is the sinusoidal waveform which can be fixed or variable at a fixed or variable frequency.

Control technique of Sinusoidal Pulse Width Modulation (SPWM) is used due to no lower order of harmonic components present in the output voltage and it is widely used method for main AC appliances. Generally, this technique compares triangle waveform and sinusoidal waveform where frequency is the preferred output frequency.

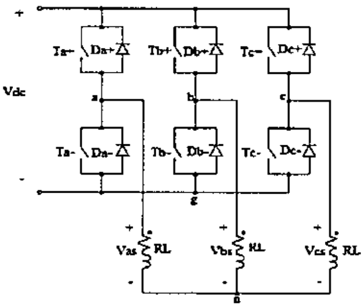

Figure 1. Basic Topology for Three Phase VSI with the Combination of Resistive and Inductive Load

II. METHODOLOGY

A. Voltage Sourced Inverter

Figure 2 shows the block diagram for VSI. VSI produces an AC voltage by switching the input voltage to provide positive and negative voltage pulses. As shown in Figure 3, the schematic diagram of VSI is constructed where pure resistive loads are used. The fast switching Metal Oxide Semiconductor Field Effect Transistor (MOSFET) was use as a switching control for producing variable AC output voltage.

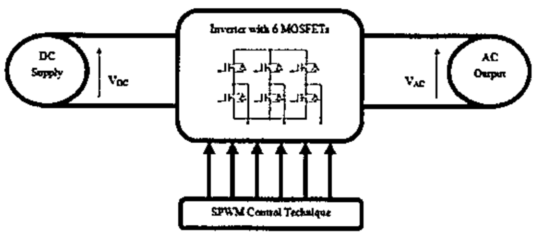

Figure 2. VSI Block Diagram

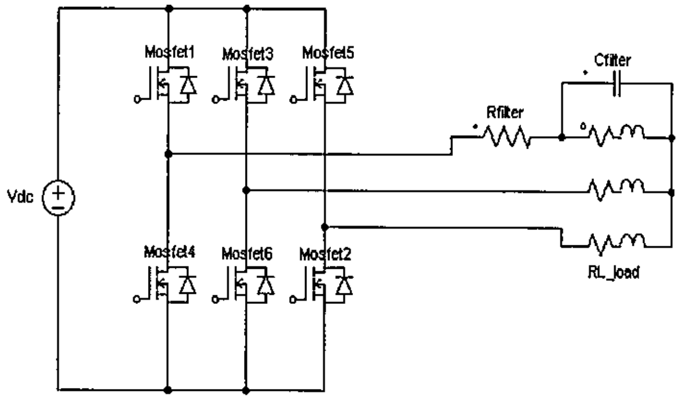

Figure 3. Schematic Diagram of VSI for RL Load

The output of the inverter has square waveform by reason of the switching model. With the intention of obtaining a pure sine wave signal, the filter is used to reduce harmonic content [10] and the filter type used in this study is RC filter where has been located at the AC load.

B. Sinusoidal Pulse Width Modulation Technique

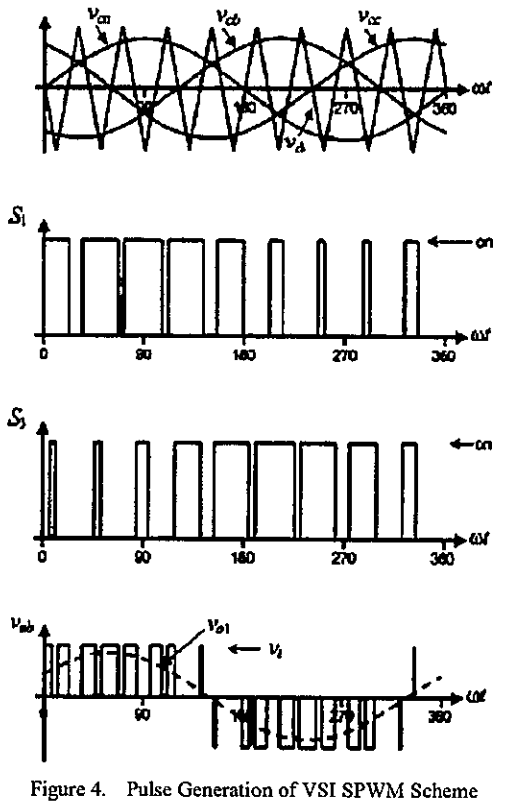

Figure 4. Pulse Generation of VSI SPWM Scheme

There are many techniques to vary the inverter output waveform. SPWM is also known as triangulation or PWM with natural sampling. In SPWM type as shown in Figure 4, in order to determine the amplitude of the inverter output voltage, a reference voltage or sinusoidal reference waveform is compared with a triangular carrier waveform which is also known as Modulation Index (MI). MI can be defined as (1).

$$MI = V_{ref} / V_{tri} \qquad (1)$$

The relation between the amplitude of the inverter output voltage and MI is shown in the next section. On-off time model of the inverter switching devices is determined by using intersection between the carrier signal (triangular waveform) and reference signal (sinusoidal waveform) [11]. Generally, the switch control for SPWM technique is when an upper switch is switched on which is equal to '1' (Mosfet1, Mosfet3 or Mosfet5), a lower switch is switched off which is equal to '0' (Mosfet4, Mosfet6, or Mosfet2) [13].

C. Control Scheme

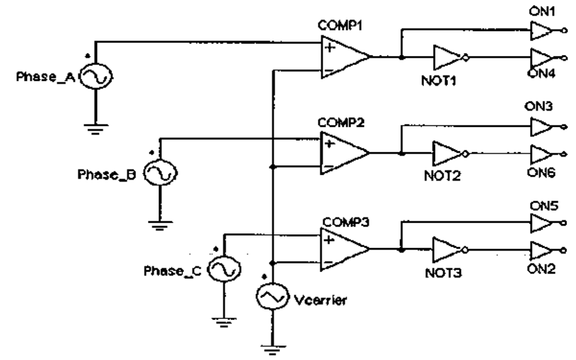

Figure 5. Control Switching for SPWM Technique

The pulse width is modulated to gain the inverter output voltage controlled and trim down its harmonic. Based on Figure 5, SPWM is accomplished by a comparator which produces the signals that command the switches. When the modulated signal which is sine wave is greater than the carrier signal which is triangle wave the comparator sends to the turn on switch [14]. In other word, when $V_{modulating\_phaseA}$ is greater than $V_{carrier}$, the comparator will give command to its output and hence Mosfet1 will be turned on and Mosfet4 will be turned off. Mosfet1 will be turned off and Mosfet4 will be turned on whenever $V_{modulating\_phaseA}$ is lesser than $V_{carrier}$. This achievement is proved as shown in Figure 6. This situation is similar to the other modulating voltage for phase B and phase C where two switching devices in the same arm cannot conduct at the same time to prevent short circuit existed. Three modulating signals that are 120° out of phase are used to generate 120° out-of-phase load voltages.

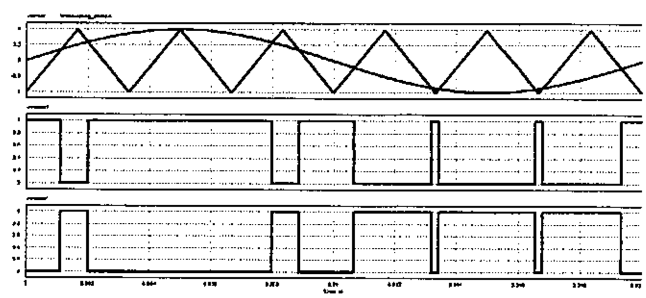

Figure 6. Switching Pattern for Mosfet1 and Mosfet4

D. Filter Design

With the aim of generating a pure sine wave for AC output, a filter is necessary and equation (2) can be applied to calculate the suitable combination of resistor and capacitor.

$$f = \frac{1}{2\pi RC} \qquad (2)$$

III. RESULTS AND DISCUSSION

Powersim (PSIM) has been used to simulate the performance of VSI using SPWM scheme. Fully schematic diagram for VSI with pure resistive load and resistor-inductor load as shown in Figure 7 and Figure 8 has been constructed in the software. PSIM simulation is using below parameters shown in Table I and Table II.

TABLE I. VSI PARAMETER FOR LOAD RESISTOR

Parameter	Value
Input DC Voltage, Vdc	200V
Load resistor, R_{Load}	3.5Ω
Filter Capacitor, C_{Filter}	159μF
Filter Resistor, R_{Filter}	1Ω
Carrier Frequency, f_c	3000Hz

TABLE II. VSI PARAMETER FOR LOAD RESISTOR-INDUCTOR

Parameter	Value
Input DC Voltage, Vdc	200V
Load resistor, R_{Load}	3.87Ω
Load Inductor, L_{Load}	7.7mH
Filter Capacitor, C_{Filter}	159μF
Filter Resistor, R_{Filter}	1Ω
Carrier Frequency, f_c	3000Hz

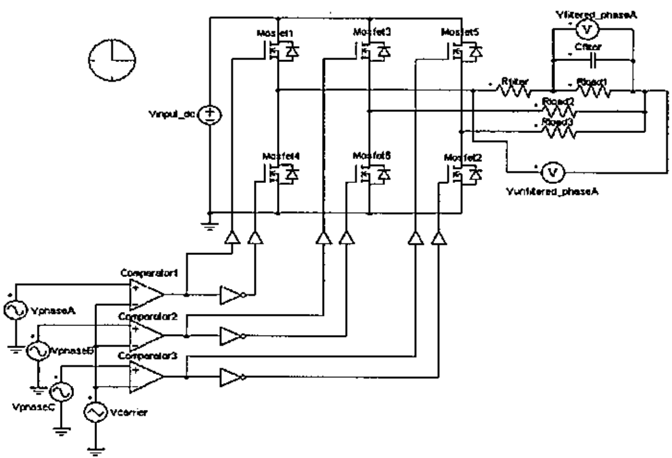

Figure 7. Circuit modeling of VSI for Pure Resistive Load

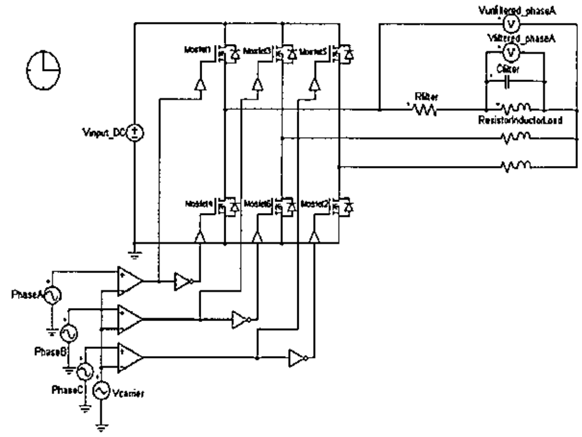

Figure 8. Circuit modeling of VSI for Resistor-Inductor Load

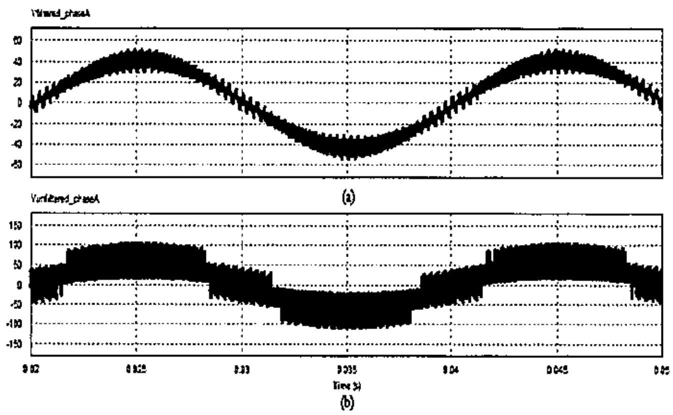

Figure 9. Output Voltage Phase A with Load Resistor with Switching Frequency of 3kHz (a) Filtered Output Voltage (b) Unfiltered Output Voltage

By referring to Figure 10, filter that is used is Low Pass Filter (LPF) where it reduced high order harmonic in the output side.

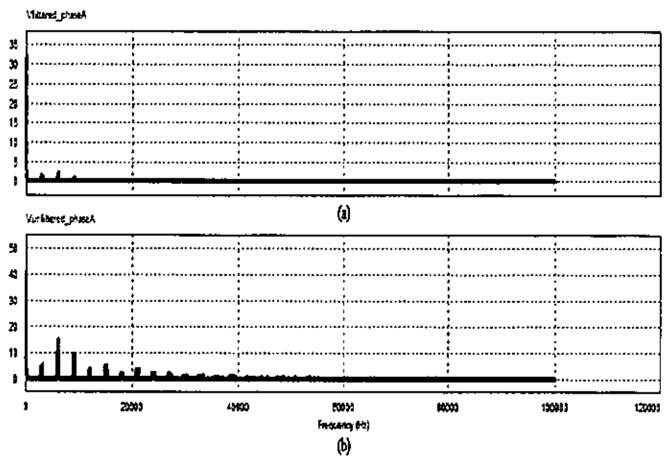

Figure 10. Harmonic Spectrum from FFT at Phase A with Load Resistor with Switching Frequency of 3kHz (a) Filtered Output Voltage (b) Unfiltered Output Voltage

Figure 11 shows the comparison the output voltage with different carrier frequency. It illustrates that the ripple is decreased.

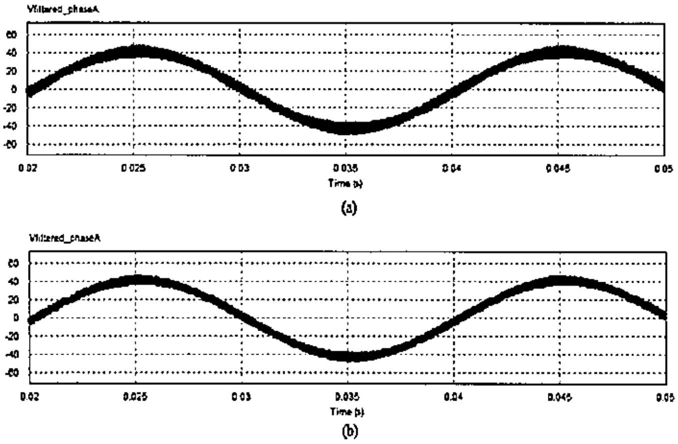

Figure 11. Output Voltage Phase A at Load Resistor with Switching Frequency of (a) 6kHz (b) 9kHz

Figure 12 is picturized filtered and unfiltered output voltage waveform from resistive-inductive load respectively. From the result obtained, fewer ripples existed in the output voltage waveform. Figure 13 is illustrated the harmonic spectrum by doing the FFT analysis.

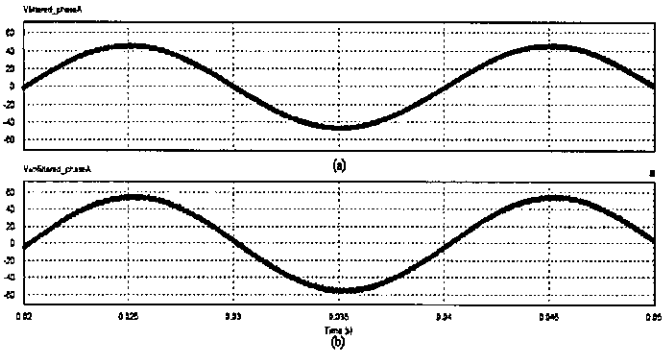

Figure 12. Output Voltage Phase A with RL Load with Switching Frequency of 3kHz (a) Filtered Output Voltage (b) Unfiltered Output Voltage

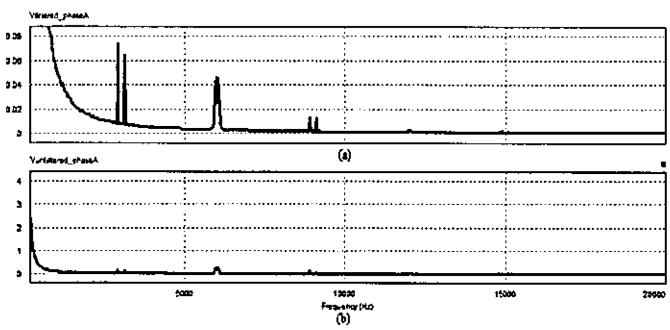

Figure 13. Harmonic Spectrum from FFT at Phase A with RL Load with Switching Frequency of 3kHz (a) Filtered Output Voltage (b) Unfiltered Output Voltage

From Figure 13, the voltage amplitude of unfiltered load is much higher than filtered load

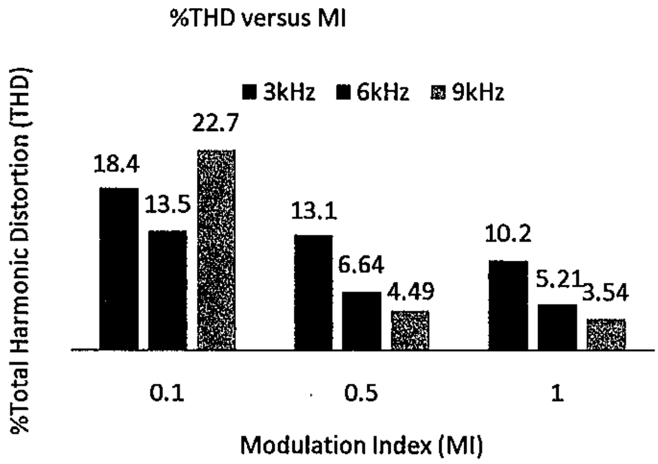

Figure 14. Comparison of THD of Output Voltage versus MI with Carrier Frequency of 3 kHz, 6 kHz and 9 kHz for Pure Resistive Load

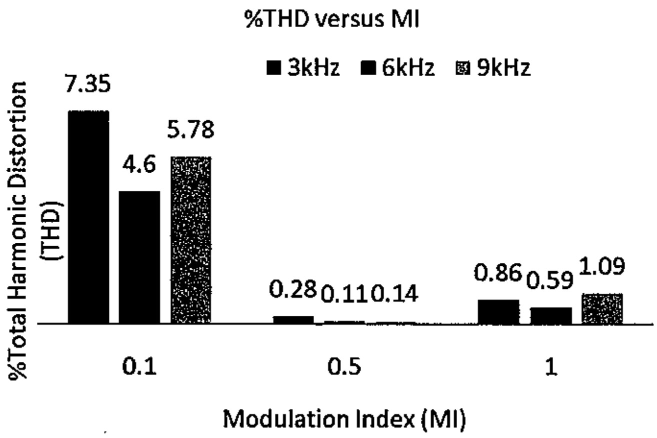

Figure 15. Comparison of THD of Output Voltage versus MI with Carrier Frequency of 3 kHz, 6 kHz and 9 kHz for Resistor-Inductor Load

From the results achieved in Figure 14 and Figure 15, both of them show that when MI is increased, the THD will decrease depends on carrier frequency applied. From the result gained, the best MI is at 1 at carrier frequency of 9 kHz since the THD of voltage is complied with the IEEE Standard where must be less than 5%.

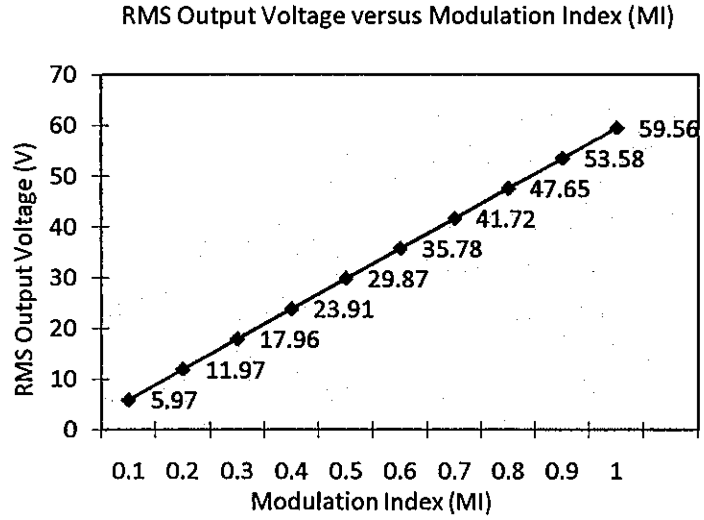

Figure 16. Variation of RMS output voltage versus MI for 3 kHz carrier frequency with Pure Resistive Load

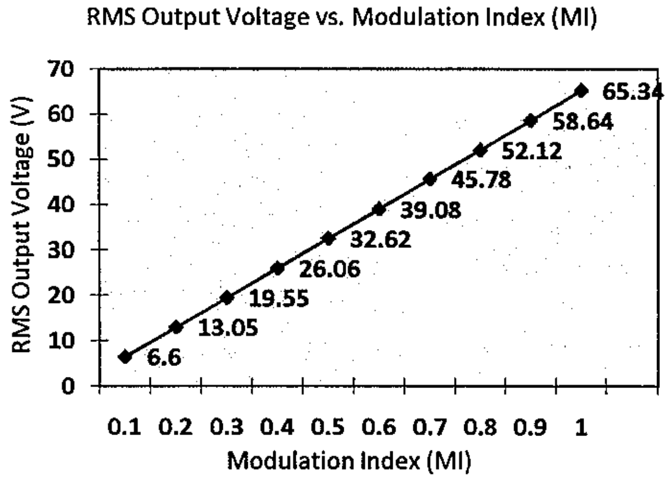

Figure 17. Variation of RMS output voltage versus MI for 3 kHz carrier frequency with Resistor-Inductor Load

Figure 16 and Figure 17 show the relation between the output voltage and MI which can be concluded that output voltage is increased proportionally to the increased MI.

IV. CONCLUSION

The simulation results have been presented for VSI using SPWM scheme. Modulation index of 0.1, 0.5 and 1.0 were used at 3 carrier frequencies of 3 kHz, 6 kHz and 9 kHz. A DC input of 200 V and a resistor load at 3.5 Ω were used for pure resistive load while in RL load a 3.87Ω of resistor and a 7.7mH of inductor are used. It is observed that the output voltage is increased proportionally with an increase the modulation index. In this work, SPWM switching technique is used to control the operation of DC-AC converter has been developed and the results are obtain from simulation are realized. A computer simulation model was then successfully developed using Powersim PSIM to investigate the behavior of the VSI. It is important to predict the behaviors of this inverter using simulation tool.

V. RECOMMENDATION

This project can be improved as listed below:

1. LC filter can be used to reduce the harmonic content at the load side.
2. VSI can interface with chopper for power factor correction application.
3. Space Vector Pulse Width Modulation (SVPWM) technique can be used to replace SPWM technique due to its advantages.

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REFERENCES

[1] Afarulrazi, A.B.; Zarafi, M.; Utomo, W.M.; Zar, A.; , "FPGA implementation of Unipolar SPWM for single phase inverter," Computer Applications and Industrial Electronics (ICCAIE), 2010 International Conference on , vol., no., pp.671-676, 5-8 Dec. 2010

[2] Kai Zhang; Yong Kang; Jian Xiong; Jian Chen; , "Direct repetitive control of SPWM inverter for UPS purpose," Power Electronics, IEEE Transactions on , vol.18, no.3, pp. 784- 792, May 2003

[3] Padimiti, D.S.; Chowdhury, B.H.; , "Superconducting Magnetic Energy Storage System (SMES) for Improved Dynamic System Performance," Power Engineering Society General Meeting, 2007. IEEE , vol., no., pp.1-6, 24-28 June 2007

[4] Halasz, S.; Csonka, G.; Hassan, A.A.M.; Huu, B.T.; , "Analysis of the unipolar PWM techniques," Electrotechnical Conference, 1996. MELECON '96., 8th Mediterranean , vol.1, no., pp.353-356 vol.1, 13-16 May 1996

[5] Hongyan Xu; jianlin li; , "FPGA Based Multiplex PWM Generator for Multilevel Converters Applied Wind Power Generator," Power and Energy Engineering Conference, 2009. APPEEC 2009. Asia-Pacific , vol., no., pp.1-4, 27-31 March 2009

[6] Deshpande, V.; Chaudhari, J.G.; Jagtap, P.P.; , "Development and Simulation of SPWM and SVPWM Control Induction Motor Drive," Emerging Trends in Engineering and Technology (ICETET), 2009 2nd International Conference on , vol., no., pp.748-752, 16-18 Dec. 2009

[7] Tunyasrirut, S.; Srilad, S.; Suksri, T.; , "Comparison power quality of the voltage source inverter type SVPWM and SPWM technique for induction motor drive," *SICE Annual Conference, 2008* , vol., no., pp.241-246, 20-22 Aug. 2008

[8] Woei-Luen Chen; Chun-Hao Pien; Yung-Ping Feng; , "Design of an FPGA-based space vector PWM generator for three-phase voltage-sourced inverters," *Power and Energy Conference, 2008. PECon 2008. IEEE 2nd International*, vol., no., pp.584-588, 1-3 Dec. 2008

[9] Won-Sik Oh; Sang-Kyoo Han; Seong-Wook Choi; Gun-Woo Moon; , "Three Phase Three-Level PWM Switched Voltage Source Inverter With Zero Neutral Point Potential," *Power Electronics, IEEE Transactions on* , vol.21, no.5, pp.1320-1327, Sept. 2006

[10] Ismail, B.; Taib, S.; Saad, A.R.M.; Isa, M.; Hadzer, C.M.; , "Development of a Single Phase SPWM Microcontroller-Based

Inverter," Power and Energy Conference, 2006. PECon '06. IEEE International , vol., no., pp.437-440, 28-29 Nov. 2006

[11] [11] Tajuddin, M.F.N.; Ghazali, N.H.; Daut, I.; Ismail, B.; , "Implementation of DSP based SPWM for single phase inverter," Power Electronics Electrical Drives Automation and Motion (SPEEDAM), 2010 International Symposium on , vol., no., pp.1129-1134, 14-16 June 2010

[12] From website: http://ethesis.nitrkl.ac.in/1133/1/Control_of_Voltage_Source_Inverters_using_PWM.pdf

[13] From website: http://www.arpnjournals.com/jeas/research_papers/rp_2010/jeas_0710_362.pdf

[14] From website: http://www.iaeng.org/publication/WCECS2011/WCECS2011_pp200-205.pdf