Micro-controller Based Three-phase Voltage Source Inverter for Alternative Energy Source

M.M. A. Rahman, Kurt Hammons, Phillip Beemer, Marcia Isserstedt, and Matt Trommater

School of Engineering
Padnos College of Engineering and Computing
Grand Valley State University
Grand Rapids, MI 49504
rahmana@gvsu.edu

Abstract

This paper presents a high frequency transformer isolated, micro-controller based, three-phase, ac-to-dc voltage source inverter (VSI) for ac motor drives and uninterruptible power supply applications. The proposed converter produces a 3-phase sinusoidal ac output voltage from alternative energy sources (converted to a 12 V dc voltage source) while output voltage magnitude and frequency can both be controlled digitally using a micro-controller. A 3-leg full bridge converter topology with sinusoidal-triangle pulse width modulation (SPWM) with an amplitude modulation index, \( m_a \leq 1 \) is used. This converter uses a switching frequency of 50-200 kHz. A 3-phase 200 V, 60 Hz VSI is designed. The design work includes design of a control circuit for high frequency switching, regulated logic power supply, magnetic circuits for transformer and filtering, and a 3-leg bridge converter. The designed converter is simulated using PSPICE simulation software and simulation results are obtained. A prototype of the designed converter is built on a PCB and tested in the lab with a 3-phase induction motor load using Atmel micro-controller AT91SAM7S256 and power MOSFET IRFP460. Appropriate thermal distribution was considered and implemented while designing the PCB. An optically isolated gate driver circuit based around International Rectifier driver chip IR2131 was designed and implemented for high frequency switching of the MOSFETs. Experimental results are recorded and will be presented in this paper. This converter can be used as a stand-alone alternative energy source for ac motor drives and UPS application.

I. INTRODUCTION

Nowadays, dc-to-ac voltage source inverters are generally implemented by using the pulse width modulation (PWM) techniques although other techniques like square-wave inverters and voltage cancellation techniques are also available. The main objective of PWM technique is to eliminate or minimize harmonics in the phase voltage to make it.
sinusoidal. Different PWM schemes are available in the literature [1-4] to implement the phase VSI. This work uses the SPWM technique to implement a three-phase VSI.

With the advent of digital technology modern microcontrollers (μC) are being heavily equipped with enhanced resources such as built in flash program memory, extended RAM, timers, ADC, network control etc. These features make μC an effective candidate for implementing embedded application of complex PWM scheme. This work uses Atmel microcontroller AT91SAM7S256 to implement a VSI for 3-phase induction motor load.

Typical applications of this converter includes but not limited to: (i) power electric motor vehicle, (ii) solar, wind or other alternative energy source based domestic use, (iii) back up power supply in UPS system and (iv) sell back power to utility grid.

Objectives of this work are obtained in this paper outlined as follows: Section II explains the operation of the VSI with circuit diagram. Control scheme block diagram is presented in Section III. PSPICE simulation result of the control scheme is given in Section IV. Section V presents prototype experimental results. Section VI concludes this paper with future recommendations.

II. SCHEMATICS AND OPERATION

A detailed schematic diagram of the proposed voltage source inverter is shown in Fig. 1 where the VSI drives a star connected motor load with insulated neutral. The converter switches S1 to S6 are controlled appropriately with SPWM pulse control signals obtained from the microcontroller so that three phase ac voltage is obtained at terminals A, B and C with minimized harmonic contents. The anti-parallel diodes to six switches are required to handle reactive and live loads while anti-parallel capacitors are required as snubbers to the switches. Inverter ground is accessed by center-tapping a capacitor parallel to the input dc voltage source.

![Proposed dc-to-ac 3-leg VSI with Y load](image-url)
III. CONTROL SCHEME

The microcontroller based control scheme of the proposed voltage source inverter is shown in the block diagram of Fig. 2. As shown in this diagram PWM gating signals generated by the microcontroller are processed by the MOSFET driver IR2131 to drive the six switches of the VSI. This driver has high and low output for all 3-legs of the VSI shown in Fig. 1. It should be mentioned here that signals generated by microcontroller are about a common digital reference while high switch gate signal to control MOSFET has to be w.r.t. the varying voltage at the center of corresponding leg. This is achieved by using a bootstrap capacitor for each leg. Feedback signals from the output and external sources are used to properly generate the SPWM signals to ensure sinusoidal input voltages at phase A, B and C.

![Control scheme of the proposed VSI](image)

**Figure 2** Control scheme of the proposed VSI

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IV. PSPICE SIMULATION RESULTS

The SPWM control scheme of the proposed VSI is simulated in PSPICE using the circuit shown in Fig.3 where $v_{con}$ is the sinusoidal control signal and $v_{tri}$ is the triangular signal. The results of this simulation are presented in Fig.4. These results clearly explains proposed control scheme. Fig. 4(a) shows the simulated SPWM (bottom window) and Fig. 4(b) shows the sinusoidal output voltage from one phase (Line-to-neutral) of the voltage source inverter. When sinusoidal control input, $v_{con}$ is higher than the triangular carrier signal, $v_{tri}$ ($v_{con} > v_{tri}$) a positive pulse (‘1’) is generated. Whereas for $v_{con} < v_{tri}$ a zero (‘0’) is generated. In this way, the width of the pulse has a sinusoidal variation throughout the period of control signal. While generating SPWM it was made sure that amplitude modulation ratio, $m_a$ is kept less than 1.0. This is required as over-modulation ($m_a > 1$) will cause (i) output to contain more harmonics in the sidebands, and (ii) PWM to be non-linear i.e. amplitude of the fundamental frequency component is non-linear with modulation ratio. Fig. 4(a) shows the simulated SPWM (bottom window) and Fig. 4(b) shows the sinusoidal output voltage from one phase (Line-to-neutral) of the voltage source inverter with very small total harmonic distortion.

![Op-Amp circuit to simulate SPWM.](image)

**Figure 3** Op-Amp circuit to simulate SPWM.

![PSPICE simulation results (a) generation of PWM signal, (b) output voltage of one phase (line-neutral voltage)](image)

**Figure 4** PSPICE simulation results (a) generation of PWM signal, (b) output voltage of one phase (line-neutral voltage)
V. EXPERIMENTAL RESULTS

The VSI proposed in the preceding sections was implemented by designing a 12 V dc to 200 V ac 3-phase VSI with a switching frequency varying from 50-200 kHz. This was done as a part of the course project on contemporary alternative energy issues. There was a significant amount of student involvement from concept to implementation of this project. A PCB was designed to implement a laboratory model of the proposed inverter. The laboratory prototype was built on the PCB using power MOSFET IRFP460 driven by 6-channel gate driver IR2131. A snapshot of this prototype model is shown in Fig. 5. Appropriate thermal distribution was considered and implemented while designing the PCB so that power loss in the MOSFET switches due to conduction loss, switching loss etc. dissipates through natural cooling. It was also made sure that the power circuit is optically isolated from the micro-controller circuit using opto-coupler. This prototype was tested in the lab with an induction motor load. Some of the test results recorded are shown in Fig. 6. In Fig. 6(a) PWM signal for one switch generated by microcontroller is shown. This PWM signal is processed by the MOSFET driver IR2131 to boost the power required to turn on a MOSFET. As explained in Section V, this signal is generated using a feedback, along with other inputs, from the output voltage of the VSI. Fig. 6(b) shows the filtered ac output of phase A (line-to-neutral) of the voltage source inverter with an induction motor load. This sample voltage waveform shows that the inverter can generate three-phase clean sinusoidal output with very small (less than 5%) total harmonic distortion.

Figure 5 Snapshot of the prototype VSI built and tested in laboratory
VI. CONCLUSIONS

A micro-controller based three-phase dc-to-ac voltage source inverter has been presented. Operation of the inverter is explained. Power switches of the VSI are controlled with sine-triangular PWM from an I/O pin of a μ-controller. A design example is presented and simulation results are recorded. A prototype laboratory model of the designed VSI is built and tested for switching frequency within a range of 50-200 kHz. Some of the experimental results with ac motor load are presented in Section IV. Results show that the VSI can generate sinusoidal 3-phase output with very small total harmonic distortion. This converter can be used as a stand-alone alternative energy source for ac motor drives and UPS application.

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BIBLIOGRAPHY


BIOGRAPHY

M.M. AZIZUR RAHMAN

Dr. Rahman is an assistant professor of engineering at Grand Valley State University, Allendale, MI. He earned his Ph.D. in electrical and computer engineering from University of Victoria, Canada. He has been teaching and doing research since 1994. His research interests include power electronics, electronic circuit design and electrical drive systems. He is a Commonwealth Scholar and member of ASEE and IEEE.

KURT HAMMONS, PHILLIP BEEMER, M. ISSERSTEDT AND M. TROMMATER

Kurt Hammons, Phillip Beemer, and Marcia Isserstedt were undergraduate students in the School of engineering at Grand Valley State University during this research work. They are working on their B.S.E degree. Mr. M. Trommater graduated in summer 2006.