Development of A Microcontroller-based Inverter for Photovoltaic Application

by

Sharulnizam Bin Mohd Mukhtar
(0630910133)

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Abbreviations

AC	**A**lternating **C**urrent
ADC	**A**nalog to **D**igital **C**onverter
BJT	**B**ipolar **J**unction **T**ransistor
CSI	**C**urrent **S**ource **I**nverter
DAC	**D**igital to **A**nalog **C**onverter
DC	**D**irect **C**urrent
DMC	**D**ynamic **M**atrix **C**ontrol
EMI	**E**lectro**M**agnetic **I**nterference
EPROM	**E**rasable **P**rogrammable **R**ead **O**nly**M**emory
FPGA	**F**ield **P**rogrammable **G**ate **A**rray
GTO	**G**ate **T**urn **O**ff thyristor
HF	**H**igh **F**requency
IGBT	**I**nsulated **G**ate **B**ipolar **T**ransistor
MBC	**M**ultilevel **B**oost **C**onverter
MCT	**MOS** **C**ontrolled **T**hyristor
MIPs	**M**illion **I**nstruction **P**er **S**econd
MOSFET	**M**etal **O**xide **S**emiconductor **F**ield **E**ffect **T**ransistor
MSPWM	**M**odified **S**inusoidal **P**ulse **W**idth **M**odulation
PCB	**P**rinted **C**ircuit **B**oard
PWM	**P**ulse **W**idth **M**odulation
RAM	**R**andom **A**ccess **M**emory

RC	**R**esistor **C**apacitor
RCD	**R**esistor **C**apacitor **D**iode
RMS	**R**oot **M**ean **S**quare
SHEPWM	**S**elective **H**armonic **E**lemination **P**ulse **W**idth **M**odulation
SIT	**S**tatic **I**nduction **T**ransistor
SPWM	**S**inusoidal **P**ulse **W**idth **M**odulation
SVPWM	**S**pace **V**ector **P**ulse **W**idth **M**odulation
THD	**T**otal **H**armonic **D**istortion
UART	**U**niversal **A**synchronous **R**eceiver **T**ransmitter
UPS	**U**ninterruptible **P**ower **S**upply
VSI	**V**oltage **S**ource **I**nverter

Dedicated to my mom

Pembangunan Penyongsang Berasaskan Mikropengawal untuk Aplikasi Fotovoltan

Abstrak

Dibentangkan dalam tesis ini, pembangunan sebuah penyongsang berasaskan mikropengawal untuk sistem fotovoltan. Sebuah mikropengawal 8-bit tunggal telah digunakan untuk menghasilkan dedenyut pensuisan untuk kedua-dua tahap di dalam penyongsang tersebut, yang merupakan penukar dc-dc dan penyongsang dc-ac. Suatu algoritma yang sederhana, berkesan, dan sesuai dilaksanakan dalam satu mikropengawal 8051 telah dibangunkan, mengawal tahap kuasa penyongsang itu. Strategi pensuisan untuk PWM dan SPWM diperincikan, manakala lebar dedenyut pensuisan untuk PWM dan SPWM ditentuukur lalu dibentangkan. Sebuah penyongsang berkapasiti 500W telah dibina, menguji dedenyut pensuisan yang dihasilkan mikropengawal. Alatubah berfrekuensi tinggi jenis satah telah digunakan untuk menaikkan voltan masukan ke tahap yang diperlukan penyongsang, juga bertujuan mengasingkan, dan menangani kerumitan menghasilkan alatubah konvensional buatan tangan. Experimen ini dijalankan didalam persekitaran makmal dimana voltan masukan penyongsang ialah daripada bekalan kuasa DC dan beban penyongsang ialah rintangan tulin. Analisis prestasi prototaip mendapati hasil yang serupa dengan pengiraan. Prototaip penyongsang menunjukkan prestasi yang baik, dapat menghasilkan voltan keluaran yang stabil pada 240V 50Hz, dapat menangani beban sehingga 500W, dan THD yang rendah.

Development of A Microcontroller-based Inverter for Photovoltaic Application

Abstract

Presented in this thesis is the development of a microcontroller-based inverter for photovoltaic systems. A single 8-bit microcontroller generated switching pulses for both stages of the inverter's dc-dc converter and dc-ac inverter. A simple, effective algorithm suitable for implementation in a single 8051 microcontroller was developed, for control of the inverter's power stage. The thesis explained details on the PWM and the SPWM switching strategies including calculation to presents their switching pulse widths. An inverter of 500W capacity was built to test the switching pulse generated by the microcontroller. A high frequency (HF) planar transformer raised input voltage to the inverter's required level and provided isolation and solving difficulties in producing a handmade conventional HF transformer. The experiment were conducted in laboratory environment, where input voltage was taken from DC power supply and the inverter load was purely resistive. The prototype's performance analysis results were found to be similar to those calculated. The prototype inverter performed well that able to produce a stable 240V output voltage at 50Hz, able to handle loads up to 500W, and had a low THD.

Chapter 1

Introduction

1.1 Background

Growing demand for energy has led to depletion of fossil fuels and increase in their prices, creating a need to develop other energy sources. Popular options for energy sources are bio-fuel, fuel cell, hydropower, wind, and solar cell (Tromly, 2006). Among them, photovoltaic-generated solar energy offers the best return on investment and sustainability, as it is inexhaustible and environment friendly.

A main limit of photovoltaic electricity is its low voltage, which must be increased to suitable levels by a converter before being sent to a DC-AC inverter.

Inverter is power converter's most widespread use, converting to AC voltage suitable for home appliances and a DC power supply is usually generated by a renewable energy source.

Sinusoidal pulse width modulation (SPWM) switching technique has become the most popular switching technique for many years which effectively used for the inverter.

SPWM signal generation traditionally uses pure analog component. The generation is via comparison between triangular carrier-signal waveform and sinusoidal signal waveforms. Rapid development in computing technology has made digital implementation of SPWM signal generation becomes more practical. Digital control is advantages over analog control as its design is more flexible.

The method proposed for this research is the replacement of conventional analog controls with an 8-bit microcontroller through which the control algorithm can be more flexibly modified without any changes to the hardware. It reduces the number of components used, so the circuit is more compact and more cost-effective.

1.2 Thesis Objective

This research aims mainly to design and develop a two-stage inverter controlled by the switching signals produced by an 8-bit microcontroller. Its main objectives are:

1. To design and develop a single-phase bridge inverter with gate driver.
2. To design and develop a PWM based microcontroller system that used to control the operation of the inverter.

1.3 Problem Statement

An inverter's output waveforms should be sinusoidal. Practically, though, it is not, and contains harmonics. This research seeks to limit harmonic content to the 5% range.

Drawback in the line-frequency transformer's weight and size will be overcome by use of a high-frequency (HF) planar transformer.

To meet requirements, a simple effective algorithm suitable for implementation in a single 8-bit microcontroller was developed, to control the inverter's first and second stages.

1.4 Scope of Work

Up first was the inverter's design methodology, discovering circuit characteristics and investigating strategies and control methods that, based on theory and literature reviews, have potential to improve the inverter's performance. Up next was simulation of the circuit, done on PESIM software.

Calculations and simulation based the switching pulses' design and development. Simulation and calculation data were then compared to verify the circuit's effectiveness. Laboratory experiments validated the circuit. Switching techniques were then recommended.

1.5 Thesis Outline

The thesis contains seven chapters. The first introduces it generally, including defining the problem, stating the problem, and stating objectives.

In Chapter 2, a brief introduction over-viewing power-inverter circuit topologies, and switching and modulation strategies. Inverter topologies such as half-bridge and full-bridge were described along with their advantages and disadvantages. Suitability of an inverter topology depends on its application and on its dc-source characteristics. Inverter with push-pull topology as front-end dc-dc converter, full-bridge inverter as back-end dc-ac inverter, was found the most appropriate, as among others it needed the fewest components.

Chapter 3's discussion was divided into two main sections, one for the dc-dc converter stage, and another for the dc-ac inverter stage, both including their operating principles. PWM and SPWM switching strategies were detailed, and their switching pulse widths calculated and presented.

Chapter 4 described the prototype inverter's hardware development. A microcontroller was developed, and served as the prototype's main control circuit. Hardware control circuit was thus reduced. Use of planar transformer in this project solved the problem of difficult production of handmade conventional HF transformer. Flux imbalance problem was solved via use of the planar transformer.

Chapter 5 explained the software development. Switching pulses for PWM1, PWM2, SPWM1, and SPWM2 were generated by a single DS89c420 microcontroller board. Use of the microcontroller eased modification of the amplitude modulation ratio and the duty cycle, via software firmware updates.

Chapter 6 set out the results for simulations and experiments. Performance analysis of the prototype found the results to be similar to those calculated. The inverter prototype performed well and was able to produce a stable 240V 50Hz output voltage, could handle loads up to 500W, and had low THD.

The conclusion has been made in Chapter 7 where they discussed the summary of the study with research contributions. Suggestions for Further Work will also be discussed with the proposed use of the load RL and by making both stages on the inverter work in the closed-loop system.

Chapter 2

Review of the Inverter Topologies and their Switching Techniques

2.1 Introduction

This chapter describes topologies and switching strategies, including PWM switching technique for single-phase inverters and types of PWM switching strategies in inverter circuits.

2.2 Overview of Inverter Topologies

Inverters can be broadly divided into two types: single-phase, and three-phase. Inverters with constant input voltage are called voltage-source inverter (VSI), and inverters with constant input current are called current source inverter (CSI) (Rashid, 2004). All the inverters can be operated by controlled turn-on and turn-off semiconductor devices such as BJT, MOSFET, IGBT, MCT, SIT, and GTO.

There are two common inverter topologies used in single-phase or three-phase ac systems. Figure 2.1 shows one, the half-bridge topology, which consists of two semiconductor switches S1 and S2 and whose logic-circuit design should be such that S1 and S2 are not turned on simultaneously; when only S1 is ON, load voltage is half the input-voltage amplitude *Vdc/2*, when only S2 is ON, -*Vdc/2* appears across load. This inverter needs a center-tapped DC source, or it can be simplified by use of well-matched series capacitors providing the center tap. Another topology is the full-bridge inverter, comprising four semiconductor switches. Figure 2.2 shows it with its two inverter legs.

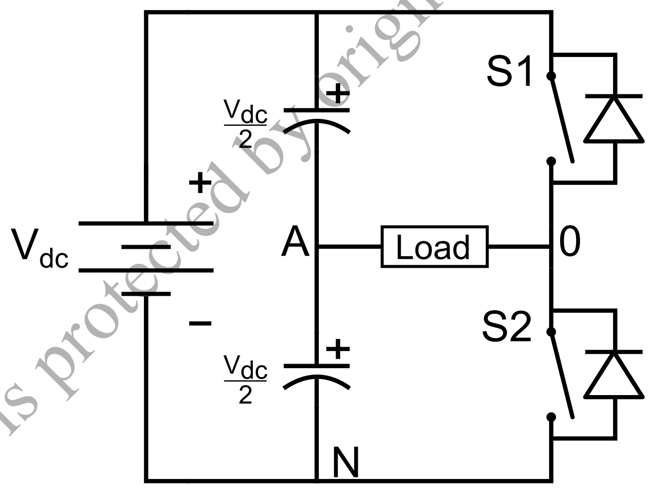

Figure 2.1: Half-bridge configuration

For each leg and to avoid shoot-through, the top and the bottom switches cannot be turned on simultaneously. When switches S1 and S2 are turned on simultaneously, input voltage appears across load. If switches S3 and S4 are turned on simultaneously, voltage across load reverses. Figures 2.3 and 2.4 respectively show output voltage waveforms for half-bridge and full-bridge single-phase inverters.

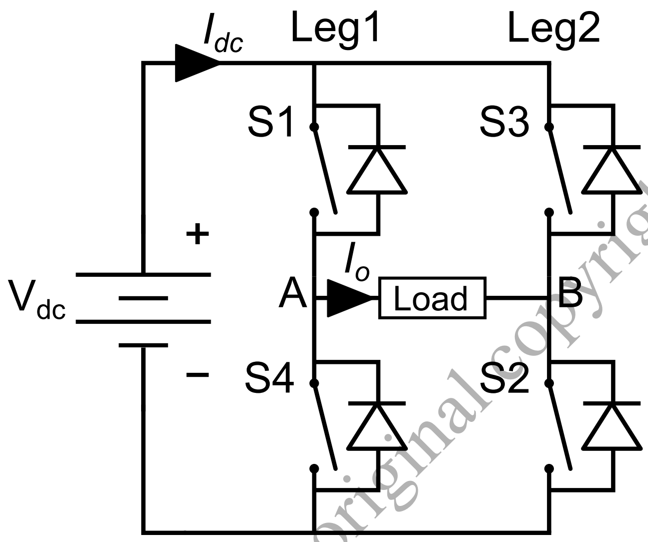

Figure 2.2: Full-bridge configuration

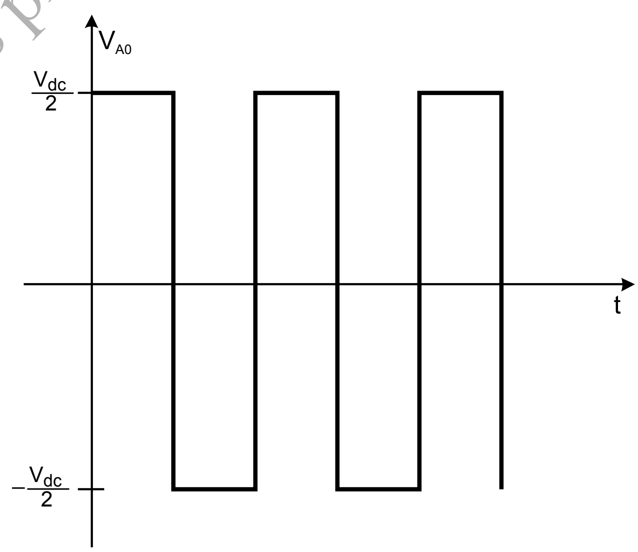

Figure 2.3: The output waveform of half-bridge configuration

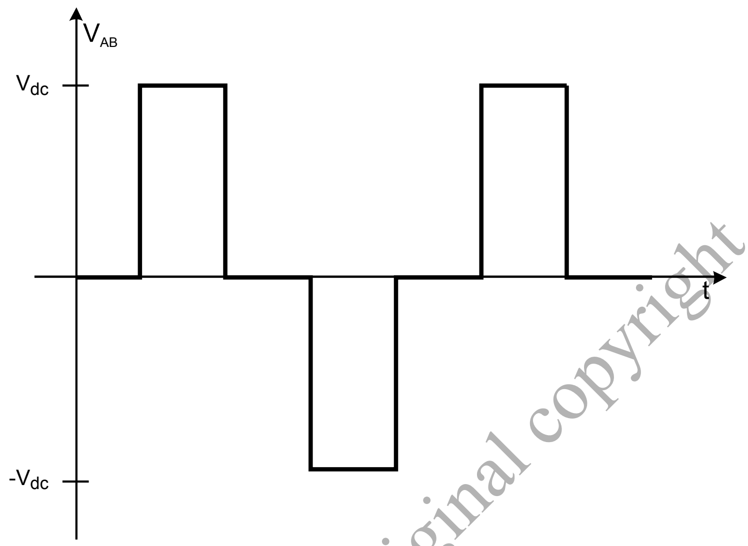

Figure 2.4: The output waveform of full-bridge configuration

2.2.1 Conventional Single-stage Inverter Topologies

Figure 2.5 shows a simple conventional inverter that has found wide use in dc-ac applications such as uninterruptible power supply (UPS) and variable-speed ac motor speed drives (Ismail et al., 2006). Its circuit topology is simple, its performance is good, and it is highly reliable. The circuit consists of power switches, line transformer, and low-pass filter. Step-up line transformer boosts the inverter's output voltage. Line transformer, however, has drawbacks of weight and size (Xue et al., 2004).

Recent years have seen research being devoted to either avoiding use of the transformer or replacing it by a high-frequency (HF) transformer. Increased operating frequency reduces transformer size. With a high-frequency operation, the desired output waveform can be obtained via use of output filter, whose size is greatly reduced. As regards cost and efficiency, various topologies have been proposed (Xue et al., 2004), for power conversions that use high-frequency switching technologies.

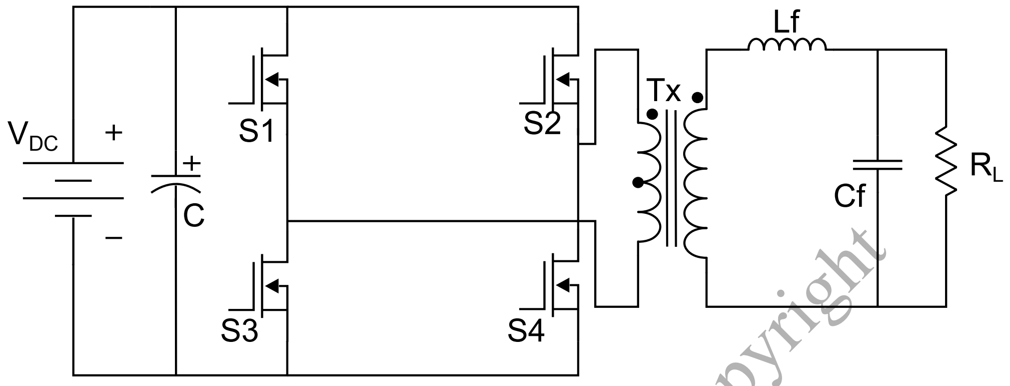

Figure 2.5: A conventional inverter circuit configuration

2.2.2 Two-stage Inverter Topology

The first stage is known also as a front-end converter, a dc-dc converter. It boosts to higher voltage levels, the dc voltage from a low-dc source such as photovoltaic, fuel cell, and battery, via use of HF transformer. Generally, a dc-dc converter either has, or does not have, galvanic isolation between incoming supply circuit and output circuit.

Various dc-dc-converter topologies have been proposed by researchers. Xue et al. (2004) introduced a dc-dc multilevel boost converter (MBC), which is a PWM-based dc-dc converter that uses multilevel-converter principle: each device blocks only one voltage level, achieving high voltage via low-voltage devices. Changchien et al. (2010) proposed a converter that uses a multi-winding coupled inductor and a voltage doubler to achieve high stepped-up voltage gain.

Park et al. (2007) discussed step-up dc-dc converter with resonant voltage doubler which combines an active-clamp circuit and a resonant voltage doubler across a power transformer. Kim and Kwon (2009) discussed high step-up resonant push-pull converter.