CPLD BASED CONTROLLER FOR SINGLE PHASE INVERTERS

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ABSTRACT

The DC-AC converter, also known as inverter, converts DC power to AC power at desired output voltage and frequency. The DC power input to the inverter is obtained from an existing power supply. Nowadays inverters use high power switching transistors either IGBT's and/or MOSFETs. In addition, the voltage and frequency of the source can be adjustable. These single phase inverters and their operating principles are analyzed in detail.

In this project, a full-bridge, single phase inverter that uses a digital Pulse Width Modulation (PWM) to control the power switches at 18 kHz was constructed. The concept of PWM with different strategies for inverters is described. A type of filter is used to improve the distortion in the output waveform.

A design and implementation of PWM by using complex programmable logic device (CPLD) from Altera MaxPlus II is constructed and programmed. The involved software, hardware, and suitable algorithm to implement and generate the PWM are developed in details. To verify the significant of this single phase inverter, the output voltage will be tested with resistive load and inductive load.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols:

μ	Micro (10^{-6})
Ω	Ohm
π	Pi (180^{o})
$\sum$	Sum
ω	Omega
φ	Phase displacement
C	Capacitance
f	Frequency
k	Kilo (10^{3})
L	Inductor
m	Mili (10^{-3})
M	Mega (10^{6})
T	Switching period

Abbreviations:

AC	Alternating Current
DC	Direct Current
THD	Total Harmonic Distortion
UPS	Uninterruptible Power Supply
CVCF	Constant Voltage and Constant Frequency
KV	Kilo-Volt
BJT	Bipolar Junction Transistor
TTL	Transistor-transistor Logic
MOS	Metal Oxide Semiconductor
CMOS	Complementary Metal Oxide Semiconductor
MCT	MOS-controlled Thyristor
IGBT	Insulated Gate Bipolar Transistor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PWM	Pulse Width Modulation
ASIC	Application Specific Integreter
DSP	Digital Signal Processor
PAL	Programmable Array Logic
GAL	General Array Logic
CPLD	Complex Programmable Logic Device
FPGA	Field Programmable Gate Array.
VHDL	Very High Digital language.

HVDC	High Voltage Direct Current
M_a	Modulation Index
GTO	Gate Turn-Off
EDA	Electronic Design Automatic
SRAM	Static Random Access Memory
UP	University Program
LED	Light-emitting diode
ADC	Analog to Digital Converter
PID	Proportional Integral Derivative
RAM	Random Access Memory
RMS	Root mean square
THD	Tottal Harmonics
U/D	Up Dawn
MOD	Modulus
VFI	Voltage Fed inverter
CFI	Current Fed inverter

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CHAPTER 1

INTRODUCTION

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1.0 Introduction to power electronics

Power electronics can be defined as the use of electronic devices to control and convert electric power. Power electronics combine power, electronics and control. It may be defined as the applications of solid-state electronics for the control and conversion of electric power. It is based on the switching of power semiconductor devices whose power handling capabilities and switching speeds have improved tremendously over the years. The switching characteristics of power devices permit the control and conversion of electric power from one to others. Versatile circuit topologies can be found in the power electronics for different applications [1.1].

Power electronics have already found an important place in modern technology and are now used in a great variety of high-power products, including motor controls, power supplies and High Voltage Direct Current (VHDC) systems [1.1].

Power electronics is the technology associated with the efficient conversion, control and conditioning of electric power by static means from its available input form into the desired electrical output form. The goal of power electronics is to control the flow of energy from an electrical source to an electrical load with high efficiency, high availability, high reliability, small size, light weight, and low cost [1.7].

1.1 Significance of power electronics

The demand for control of electric power exits for many years. The generation, transmission, and distribution of electric power are almost AC today, but industry, transportation, agriculture, and everyday life often demand DC power. In any technically and economically defined situation, it is necessary to provide the most suitable form of energy to meet the demand of user [1.3].

Power electronics can process the power in two forms, AC and DC. For AC, it can process by magnitude and frequency and for DC by only magnitude [1.4].

1.2 Power semiconductor devices

Power semiconductor devices play a crucial role in the regulation and distribution of power and energy in the world. In power electronics, it is well recognized that improvement in system performance in terms of efficiency, size and weight are driven by enhancement made in semiconductor device characteristics. Overall system reliability and efficiency depends on the quality of semiconductor switches and how these devices are used. Throughout the last 50 years, power electronics technology mostly evolved with the availability of new and improved power semiconductor devices. With the development of power semiconductor technology, the power handling capabilities and the switching speed of the power devices have improved tremendously [1.1].

The most important elements of power electronics are the power semiconductor devices. A wide variety of devices are available, which made it difficult to compare them. Their numerical ratings that include voltage ratings, current ratings and switching frequency vary widely from one device type to another and also there may be a wide variation of ratings within one type of device. Manufacturer's specification sheets show a considerable amount of tolerance of parameters for a particular device [1.5].

The first power semiconductor switches since the evolution of power electronics systems was dominated by thyristors, developed in the 1950s. The first thyristor SCR was developed in late 1957. Since then, there have been tremendous advances in the power semiconductor devices. Until 1970s, the conventional thyristors had been exclusively used for power control in industrial applications [1.1].

Presently available power semiconductor devices can be classified into three groups according to their degree of controllability [1.3]:

(i) Diodes – ON and OFF states controlled by the power circuit

(ii) Thyristors – latched on by a control signal but must be turned OFF by power circuit.

(iii) Controllable switches – turned ON and OFF by control signals.

The controllable switch category includes several device types including bipolar junction transistors (BJTs), metal-oxide-semiconductor field effect transistors (MOSFETs), gate turn off (GTO) thyristor, and insulated gate bipolar transistors (IGBTs) [1.3].

Ever since their introduction in the 1950's, bipolar junction transistors (BJTs) were favored for low and medium power applications because of their faster switching capability. High-power bipolar transistors are commonly used in power converters at a frequency below 10 kHz and are effectively applied in the power rating up to 1200V and 400A. The bipolar transistor requires a high base current to turn on, and has relatively slow turn off characteristics and is liable for thermal runaway due to a negative temperature co-efficient. Bipolar transistor was the only 'real' power transistor until the MOSFET came along in the 1970s for low power applications and Insulated Gate Bipolar Transistor (IGBT) in the 1980s for medium power applications [1.1].

In the 1970s, the highly anticipated MOS (metal oxide-semiconductor) gate power device was introduced. Later, the power MOSFET (MOS field-effect transistor) was invented and has become the dominant device technology for low power applications. Production of the power MOSFET utilized the cutting-edge semiconductor technology of those days. Power MOSFET has very high input impedance in the steady state due to its metal-oxide-semiconductor (MOS) gate structure, and is classified as a voltage-controlled device. It is used in high-speed power converters and is available at a relatively low power rating in the range of 1000V and 100A at a frequency range of several tens of kilohertz. Different from BJT, MOSFETs have positive temperatures co-efficient which stop the thermal runaway [1.1].

The introduction of insulated gate bipolar transistor (IGBT) in the 1980s has provided the user with a versatile device. This new device combines the MOS input and the bipolar output characteristics into one device. It has gained quick acceptance by users in the off-line, high-power motor drives and in the UPS industry. The insulated gate bipolar transistor (IGBT) is a three terminal device consisting of gate, emitter and collector. It combines the low on-state voltage drop characteristics of the BJT with the excellent switching characteristics and high input impedance of the MOSFET. They are available in current and voltage ratings much higher than those found in MOSFETs. To turn ON the N-channel IGBT the collector must be at a positive with respect to the emitter and a positive gate potential will turn-ON the device. The removal of this positive voltage would turn-OFF the device. The IGBT is a one of several options for designers to choose for the power control in switching applications. The features of the IGBT such as high voltage capability, low on resistance, ease of drive and relatively fast switching speeds makes it a technology of choice for moderate speed, high voltage applications [1.1].

A majority of the semiconductor devices are made of silicon. Silicon carbide, are however, under development to the prototype device. Since the introduction of modern power switches such an IGBT, diodes in many applications are subjected to higher voltage and current levels, and are required to switch at higher speed and frequencies [1.6].

1.3 Power Converters

Power electronics converters are a family of electrical circuits which convert electrical energy from one level of voltage, current or frequency to another level, using semiconductor - based electronic switch. Versatile circuit topologies can be found in power electronics for difference applications [1.2].

The essential characteristic of these types of circuits is that the switches are operated only in one of two states – either fully ON or fully OFF, unlike other types of electrical circuits where the control elements are operated in a liner or nearly linear active region. As the power electronics industry has developed, various families of power electronic converters have evolved, often linked by power level, switching devices, and topological origins [1.2].

In terms of conversion form, four categories can be identified. This conversion can be done by following four ways [1.3]:

(i) AC to AC Converter (cycloconverter)

AC to AC converter controls the rms values of AC voltage applied to the load. This converter converts an AC voltage, such as the mains supply, to another AC voltage. The amplitude and frequency of input voltage tend to be fixed values, whereas both the amplitude and frequency of output voltage tend to be variable without any intermediate conversion link. Single-phase and three-phase cycloconverter is the example of this type of converter. These cycloconverters have a high power output, of the order a few megawatts [1.1].

(ii) AC to DC Converter (rectifier)

AC to DC converter or rectifier changes an alternating voltage to dc voltage. It can classify as uncontrolled and controlled rectifiers. Uncontrolled rectifier circuits are built with diodes, and fully-controlled circuits are built with SCRs, thyristors or power transistors. In AC to DC converter, line frequency diode rectifiers that are increasingly being used to convert the line frequency AC input to an uncontrolled DC output voltage. Primary voltage of a switched mode power supply is the example of uncontrolled DC voltage supply [1.4].

In some application, it is necessary to control the DC voltage. In this case, average DC side voltage can be controlled from a positive maximum to negative maximum. Battery chargers and controlled motor drives use the controlled DC voltage [1.3].

(iii) DC to AC Converter (inverter)

The converter that changes a DC voltage to an alternating voltage is called an inverter. Switch mode DC to AC converter, accepts the DC voltage as the input, and produces the desired AC voltage at the output, whose magnitude and frequency both can be controlled [1.1].

Earlier inverters were built with SCRs. Since the circuitry required turning the SCR off tends to be complex, other power semiconductor devices such as bipolar junction transistors (BJTs), power MOSFETs, insulated gate bipolar transistors (IGBTs) and MOS-controlled thyristors (MCTs) are used nowadays. Currently, only the inverters with a high power rating, such as 500kW or higher, are likely to be built with either SCRs or gate turn-off thyristors (GTOs). There are many inverter circuits and the techniques for controlling an inverter vary in complexity. AC motor drives control and uninterruptible AC power supply widely use this DC to AC converter [1.1].

(iv) DC to DC Converter (chopper)

DC to DC converter circuit was called a chopper. This converter converts a DC supply to another magnitude DC supply. Switched mode DC to DC converters are used to convert the unregulated DC input to a controlled DC output at desired voltage level [1.3].

Nowadays, an SCR is rarely used in DC to DC converter. A power BJT or power MOSFET is normally used in such a converter and this converter is called a switch-mode power supply. The DC to DC converters are widely used in regulated switch-mode DC power supplies and DC motor drive application [1.3].

Buck (step-down) converter, Boost (step-up) converter, Buck-Boost (step-down / step-up) converter, Flyback converter, Forward converter, and Cuk converter are the example of DC to DC converter [1.3].

1.4 Pulse Width Modulation

Pulse Width Modulation (PWM) is employed in a wide variety of application ranging from measurement and communications to power control and conversion. The power semiconductor devices are rapidly gated ON and OFF to vary the effective voltage according to the output frequency. PWM method has been used to describe these kinds of switching pulses. By adjusting the duty cycle of the signal which is modulating the width of the pulse, the average power can be varied. There have been a number of clear trends in the development of PWM concepts and strategies since the 1970s, addressing the main objectives of reduced harmonic distortion and increased output magnitudes for a given switching frequency and the development of modulation strategies to suit different converter topologies [1.2].

This dissertation discussed only the Sinusoidal Pulse Width Modulation (SPWM) and the detail explanation of generating SPWM will be discussed later in the chapter 3.

1.5 Harmonics

Harmonics are defined as the sinusoidal components of non-linear periodic waveform with a frequency that is a whole multiple of the fundamental frequency. These are not apparent but they are harmful. Then we can define the non-linear device as a device that does not draw a sinusoidal current when the sinusoidal voltage is applied [1.8].

All power electronics converters (including those used to protect critical loads) can add to the inherent power line disturbances by distorting the utility waveform due to harmonic currents injected into the utility grid and by producing (EMI). The major harmonic polluters of power system are Diode-rectifiers and Phase-controlled thyristor converters. Due to these harmonics a lot of problem can be found as an increase of overheating of devices, high neutral current, capacitor or transformer failure, power factor reduction, telephone interference, and an increase of power losses [1.8].

The non-fundamental components are called "harmonic distortion". Harmonic distortion can be classified as voltage harmonic distortion and current harmonic distortion. The amount of distortion in voltage or current waveform is quantified by means of an index called the total harmonic distortion (THD). The THD in the voltage is defined as [1.8]:

$$THD_V = \frac{\sqrt{\sum_{n=2}^{\infty} (V_{n,RMS})^2}}{V_{1,RMS}} \quad \text{---} \quad (1.1)$$

Where:

n is the number of harmonics.

Current THD can be obtained by replacing the harmonic voltage with harmonic current.

$$THD_i = \frac{\sqrt{\sum_{n=2}^{\infty}(I_{n,RMS})^2}}{I_{1,RMS}} \quad \text{------------------------} (1.2)$$

Where;

$$I_n = \frac{V_n}{Z_n}$$

Z_n is the impedance at harmonic frequency.

1.6 Objectives of the project

In recent years, much more attention has been paid to find a digitally, flexibility and more efficient solution for controlling the switching devices of converters. The main objectives of this work are:

(i) To design a single phase inverter that converts DC voltage into AC voltage.

(ii) To create the schematic of PWM circuit and inverter circuit by using the Orcad simulation.

(iii) To use the Altera Maxplus II development tool with University Program (UP) board as a programmable logic device to produce a digital PWM signal with frequency 18 kHz to control the power switches in the hardware.

(iv) Lastly, implement the proposed design into hardware.

1.7 Organization of the dissertation

The dissertation is divided into 8 chapters, including this chapter and organized as follows;

Chapter 2 discusses the literature review of the project.

Chapter 3 discusses the Pulse Width Modulation (PWM) and the different types of PWM switching scheme commonly used in power converter.

Chapter 4 briefly discusses the programmable logic device.

Chapter 5 discusses the development of digital PWM. The Altera MaxPlus II software will be used to generate the digital PWM and will be discussed in details. The Altera simulation results are included.

Chapter 6 presents the implementation of hardware.

Chapter 7 presents the results of OrCad simulation, Altera Maxplus II simulation, and hardware implementation of single phase inverter.

Chapter 8 is the conclusion of the research on developing a digital PWM by using Maxplus II for single phase inverter. Some suggestion on further research works related to the main project will also be presented.

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