An FPGA based motor drive for a three-phase induction motor

by

Bhanu Sri Pilla

Submitted in Partial Fulfillment of the Requirements

for the Degree of

Master of Science in Engineering

in the

Electrical Engineering

Program

YOUNGSTOWN STATE UNIVERSITY

Fall 2022

An FPGA based motor drive for three-phase induction motor

Bhanu Sri Pilla

I hereby release this thesis to the public. I understand that this thesis will be made available from the OhioLINK ETD Center and the Maag Library Circulation Desk for public access. I also authorize the University or other individuals to make copies of this thesis as needed for scholarly research.

Signature:

Bhanu Sri Pilla, Student Date

Approvals:

Dr. Frank X .Li, Thesis Advisor Date

Dr. Pedro Cortes, Committee Member Date

Dr. Vamsi Borra, Committee Member Date

Dr. Salvatore A. Sanders, Dean of Graduate Studies Date

Abstract

A three-phase variable frequency drive with field-programmable gate array (FPGA) control is investigated in this study. With increasing demands in electric vehicles, electric aircraft, Unmanned Aircraft Systems, and other applications, the high-performance motor drive employing variable frequency control with higher efficiency and reliability is an indispensable part of the ever-changing technological development. The main variable frequency control is based on the sinusoidal pulse width modulation (SPWM) technique with control hardware implemented by using a single FPGA chip. The proposed SPWM control scheme has been realized using a Xilinx Arty A7 development board. The system was tested with a 3-phase Infineon Trench FREDFET technology based on N-channel IGBTs. The control scheme regulates the AC output voltage precisely with a DC power supply. Depending on the operating voltage and frequency, the motor may be able to run above the rated speed to gain extra power. Both simulations and test measurement results are shown.

List of Figures 6
List of Tables 6
Nomenclature 7
CHAPTER 1 8
Introduction 8
CHAPTER 2 10
The Motor Drive and it's Subsystems 10
2.1 Introduction 10
2.2 Pulse Width Modulation (PWM) 10
2.3 Sinusoidal Pulse Width Modulation (SPWM) 11
2.4 Optocoupler.. 12
2.5 Gate Driver.. 12
2.6 Voltage Source Inverter 13
2.7 Arty A-7 (35T) FPGA 15
2.8 Power Drive Module 15
2.9 Induction Motor 16
2.10 Voltage Variac 17
CHAPTER3 18
FPGA Based SPWM Control Technique 18
3.1 Introduction 18
3.2 FPGA based three phase induction motor control 18
CHAPTER 4 20
Simulation Results 20
4.1 Three-phase System Overview 20
4.2 Three Phase Inverter 21
4.2.1 Inverter Section 21
4.2.2 Comparator for PWM output 22
Figure 4-3 Schematic Section of the Comparator for PWM output 23
4.2.3 Load Section 23

4.3 Simulation Waveforms 25
CHAPTER 5 29
Experimental Setup and Results 29
5.1 Experimental Apparatus 29
5.2 Different Load Conditions 31
5.3 Applications 33
CHAPTER-6 34
Conclusion & Future Works 34
References 35

List of Figures

Figure 2-1 Pulse Width Modulation signal

Figure 2-2 Sinusoidal Pulse Width Modulation Signal

Figure 2-3 Optocoupler.

Figure 2-4 Structure of three phase voltage source inverter

Figure 2-5 Structure of three phase current source inverter

Figure 2-6 Arty A-7 (35 T) Board Figure 2-7 Power Drive Module

Figure 2-8 Four-Pole Squirrel Cage Induction Motor

Figure 2-9 Voltage Variac

Figure 3-1 FPGA based speed control of Induction Motor

Figure 4-1 Schematic of the three-phase inverter Figure 4-2 Schematic of Inverter Section

Figure 4-3 Schematic of Comparator for PWM output

Figure 4-4 Schematic of Load Section

Figure 4-5 Three phase output voltage without insertion of 200 Ω Figure 4-6 Three phase output current without insertion of 200 Ω Figure 4-7 Three phase output voltage with insertion of 200 Ω

Figure 4-8 Three phase output current with insertion of 200 Ω

Figure 5-1 Experimental Setup

Figure 5-2 Three phase output voltage and current with 225 Ω,330 µH load

Figure 5-3 Three phase output voltage and current with 1350 Ω,70 µH load

List of Tables

Table 1: Current & power comparison for different line resistance

Nomenclature

PWM- Pulse Width Modulation

SPWM- Sinusoidal Pulse Width Modulation

VSI- Voltage Source Inverter **IGBT-** Insulated Gate Bipolar Transistor **IGCT-** Integrated Gate-Commutated Thyristor **IEGT-** Injection-Enhanced Gate Transistor **FPGA-** Field-Programmable Gate Array **VHDL-** VHSIC Hardware Description Language **ADC-** Analog-to-Digital Converter

IC- Integrated Circuit

PMOD- Peripheral Module Interface

VSD- Variable Speed Drive

TTL- Transistor–Transistor Logic

GK- Gate Kill Signal

CHAPTER 1

Introduction

1.1 Background

The benefits of using a three-phase induction motor are well demonstrated in industry. It is important to develop a new digital controller to improve motor efficiency. This will result in economic savings and reductions of environmental pollution [1]. To achieve proper functionality, the induction motor's speed must be controlled precisely. There are a variety of induction motor speed control techniques that do not always achieve the desired results. To increase efficiency, an improved approach is implemented using sinusoidal pulse width modulation. This involves a three-phase power supply circuit, IGBTs, gate drivers, optocouplers, and an induction motor.

The scopes of this study are as follows:

i. In the project, a voltage source inverter converter is used. It includes a Gate driver, an Arty A-7 35T FPGA board, optocouplers, and a power drive module.

ii. An optocoupler isolator Si8065 (QSOP-16) is used to protect the control circuit for the power circuit on an Arty A-7 FPGA board. The EVAL-M1-05-65D is used by Infineon for power module.

iii. The PSpice and Simulink software are used to simulate a proposed circuit based on the theories and methods. The simulated output waveforms are analyzed and compare with the experimental data.

iv. Construct the circuit on the protoboard using the information gathered from simulation and testing of an induction motor.

1.2 Objective of the Study

The objective of this project is to develop a prototype of an FPGA based motor drive for three-phase induction motor, to change the motor drive algorithm, and to observe the impact while running the motor. A soft start conditions were generated to reduce the initial in-rush current while increasing power. A variable duty cycle SPWM was implemented utilizing a variable output frequency. The effects in the motor were also observed in relation to a changing voltage range.

The configurable frequency and voltage of a three-phase power supply that was researched, designed, constructed, tested and, operated with both an inductive and a resistive load are within the scope of this research. Methods developed during previous research for fixed frequency were adapted for variable frequency control. In addition, required adjustments to the inverter output voltage were considered for variations in the operating frequency. A control program was used to produce an output voltage waveform from a voltage source inverter. The oscilloscope display showed the result of this controller action.

CHAPTER 2

The Motor Drive and it's Subsystems

2.1 Introduction

This chapter describes each of the subsystems, system components and their operation. It covers pulse width modulation (PWM), sinusoidal pulse width modulation (SPWM), gate driver, optocoupler, voltage source inverter, Arty A-7(35T) FPGA, power drive module and a voltage variac.

2.2 Pulse Width Modulation (PWM)

The use of switching power converters in modern motor drives has led to the implementation of pulse width modulation (PWM) signals. These signals are used to control the energy delivered to a motor by a power converter. PWM signals have set frequencies, magnitudes, and pulse widths that are constant during each period. The pulses in a motor's output are wider at certain times due to the way a PWM signal is applied. This happens because when a PWM signal is sent to the gate of a power transistor, it affects how often that transistor turns on and off. A higher frequency PWM signal will deliver more energy to the motor and load than lower frequency signals [2].

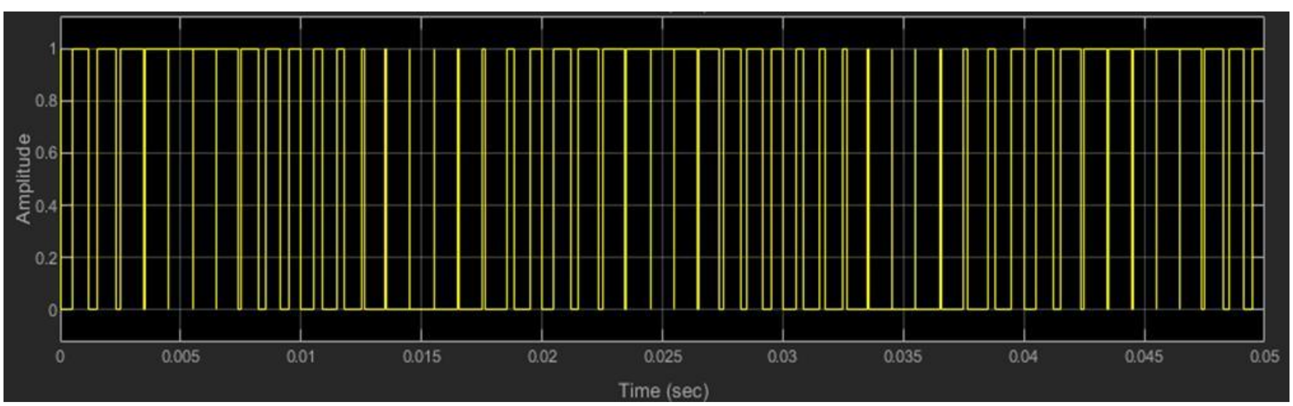


Figure 2-1 Pulse width modulation signal

There is an efficient way to produce intermediate levels of electrical power between fully on and fully off. Based on Figure 2-1, by using pulse width modulation, a power source can deliver the average amount of power needed without wasting energy because it is limited by resistive means. This occurs because the duty cycle determines how much power will be delivered [3].

2.3 Sinusoidal Pulse Width Modulation (SPWM)

Sinusoidal PWM is generated by modulating a sine wave with the reference signal. Pulse width modulation (PWM) is a phenomenon that can be described by a sinusoidal function of angular position. In this example, on and off times for a PWM signal are determined by comparing the reference sine wave with a high frequency triangle wave. Figure 2-2 , illustrates how this works. In industrial applications, the sinusoidal PWM technique is often utilized. The frequency of the output voltage is determined by the amplitude modulation wave. The modulation index is based on the peak amplitude of the modulating wave, which dictates how much RMS power will be produced from it.

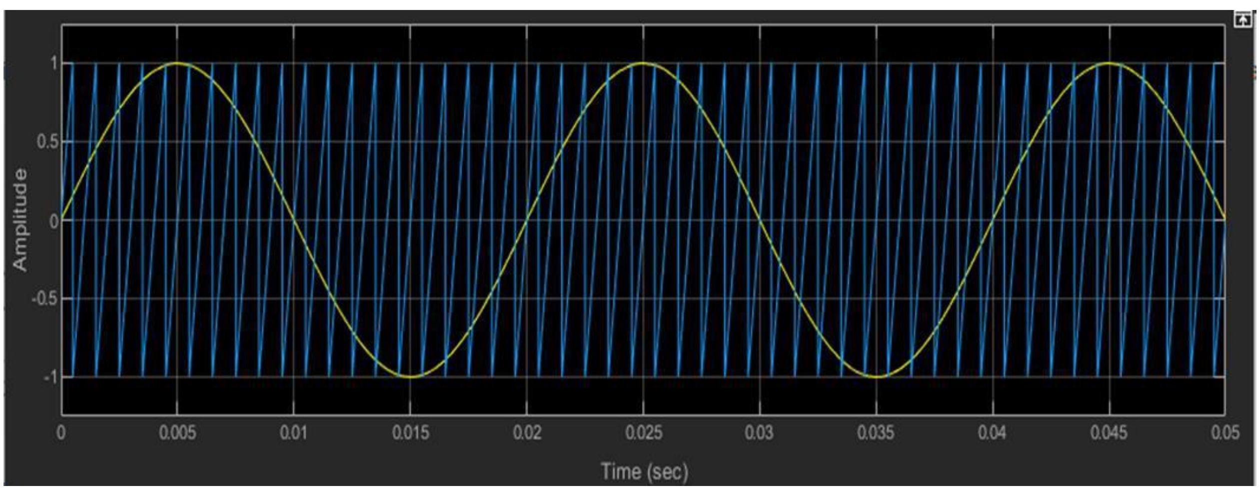


Figure 2-2 Sinusoidal pulse width modulation

By changing the modulation index, the output voltage magnitudes can be altered. Multi-phase modulation techniques achieve a higher distortion factor than other methods by suppressing harmonic waves in the inverter's output voltage. However, the harmonics are pushed to the range around the carrier frequency and its multiples [2]. The fundamental frequency SPWM control approach was proposed to decrease switching losses. By operating the PWM at a higher frequency, less voltage is required to maintain the output level and reduce power consumption [5-7].

2.4 Optocoupler

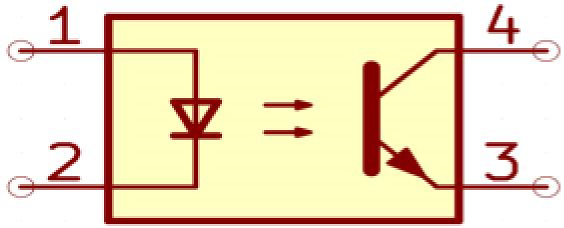


Figure 2-3 Optocoupler

In electronics, an optocoupler is a device that uses light to transfer electrical impulses between two circuits that are isolated from each other. The optocoupler's internal circuit is shown in Figure 2-3. Optocouplers maintain high voltage levels across systems when the input signal stays within acceptable limits. Typical optocouplers can sustain Input-to-Output voltages up to 5.5 volts and voltage transients of up to 50 kilovolts per microsecond (KV/µS). An optocoupler consists of a phototransistor and LED packaged together as one component; it can communicate both digital (on/ off) and analog signals.

2.5 Gate Driver

A gate driver is a device that can amplify high-current drive inputs for gates of power transistors. This allows them to control circuits with higher powers than traditional PWM signals can provide. Additionally, these drivers increase the input capacitance of the power semiconductor associated with their circuit placement. By exploiting this property, gate drivers can be combined with other discrete transistors to create more powerful circuitry. There are two types of gate control systems that can be found in electronic devices: low-voltage and high-current on-chip drivers, and higher voltage and current off-chip drivers. On-chip controllers operate at lower voltages and currents, while off chip controllers have more robust performance for applications requiring high voltage or current levels. This increases galvanic isolation, which helps prevent the device from failing due to electrical or mechanical failures.

2.6 Voltage Source Inverter

Motor drives systems that utilize pulse width modulation voltage sources (PWM-VSI) are commonly found in variable speed industrial applications such as aerospace, railroad traction and robotics.

Several factors contribute to the widespread use of PWM-VSI technology; these include high switching frequency and the use of speed controllers [3], [5]. Furthermore, there is a growing market for medium voltage adjustable drive components with various topologies. Voltage source inverter (VSI) and current source inverter (CSI) are the most popular types of variable frequency drives.

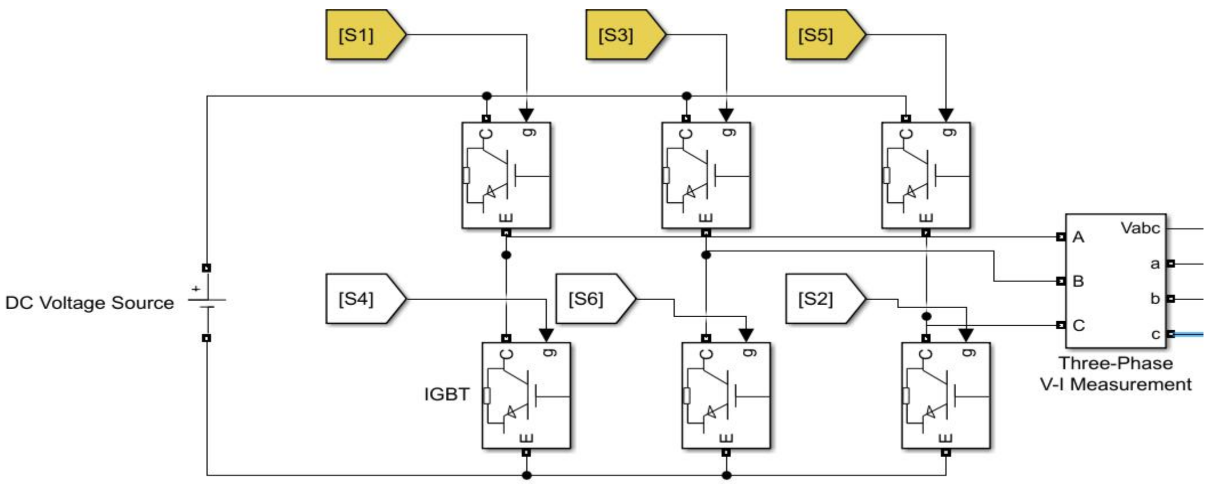


Figure 2-4 MATLAB Simulink diagram of a three-phase voltage source inverter

In Figure 2-4 and Figure 2-5, the VSI design has demonstrated efficiency in industrial markets, with increased stability and response speed. In addition to this, it is also capable of running motors without degradation. This saves money by increasing efficiency and cutting installation time down as well as reducing the amount of power needed for interconnection between machines. The efficiency is 97% with a good power factor throughout all load and speed levels [9]. A wide range of applications can be enabled with a quick dynamic response time. This allows for rapid changes in motor torque and speed, which improves mean time to failure (MTTF), an important factor during critical downtime scenarios.

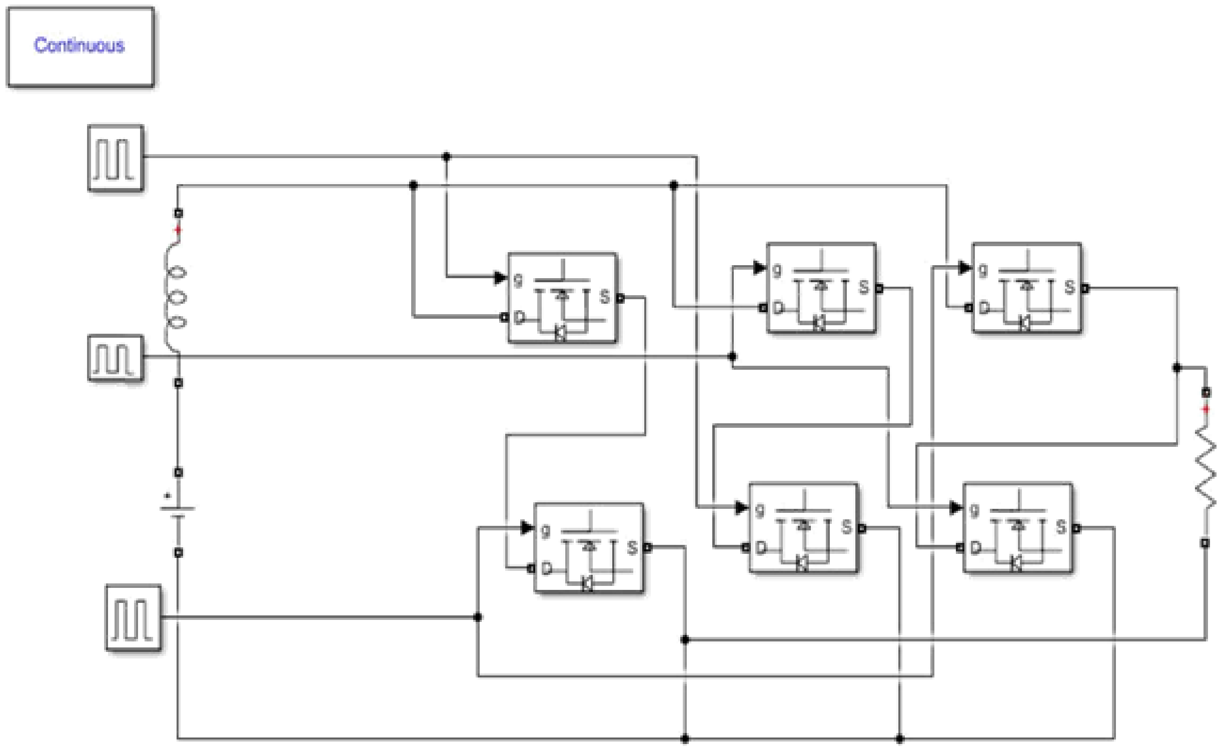


Figure 2-5 MATLAB Simulink diagram of three phase current source inverter

The industrial design of the replacement motor for retrofit applications is high quality and robust. It employs a voltage source inverter topology that uses a diode rectifier bridge to convert utility, line AC voltage (60 Hz) to direct current (DC). The converter is different from the CSI drive in that it does not have electronic firing control. Parallel capacitors in the DC link store energy for system use and reduce the DC bus voltage ripples. In addition, there are insulated gate bipolar transistors called IGBTs, which are the power semiconductors used in this study.

The IGBT switches used to generate power for a motor control the motor's voltage and frequency. A filtering inductor will prevent powerful currents from spiking when a capacitive load is connected to an AC power source. Various modulation strategies are used in order to control the inverter and determine its efficiency. The fundamental frequency and high switching frequency provide the basis for controlling inverters [10-12].

2.7 Arty A-7 (35T) FPGA

The Arty A7 or Artix-7 Field Programmable Gate Array (FPGA), is a ready-to-use development platform that was specifically developed for use with Micro Blaze Soft Processing Systems. The board requires 5 volts of power to operate and has a power good LED indicator which confirms the power supply is working as expected.

The A7 Art Board has four tri-color LEDs, four switches, four push buttons, and four individual LED lights. Each button is connected to the FPGA with a series resistor so that accidental short circuits are prevented. The slide switches generate high or low levels of input depending on their position. When they are pressed, this causes a moment where the switch output is at its highest level. After that, it returns to its original state of being low level. When resetting the processor in Micro Blaze designs, you can use this button as well. Pmod connectors are female right-angle connectors with a 100-mil spacing that pair well with a conventional 2X6 pin header.

Figure 2-6 Arty A-7 (35 T) Board

2.8 Power Drive Module

The Modular Application Design Kit for drives includes the EVAL-M1-05-65D evaluation board is a necessary component for sensorless field oriented control (FOC). The product includes all required assembly components, as well as a single AC connector and rectifier as shown in the figure 2-7. Additionally, it features a DC link and three-phase power output. Infineon provides the EVAL-M1-05-65D evaluation board**.** Infineon's boards are only subject to functional testing.

Figure 2-7 Power Drive Module

2.9 Induction Motor

A three-phase squirrel cage induction motor is an induction motor without rotor coils. In the figure 2-8, the design of the rotor resembles a squirrel cage, making it one type of motor that does not use this technology. This rotor is made with a laminated steel cylinder that has metal embedded on its surface which makes it highly conductive.

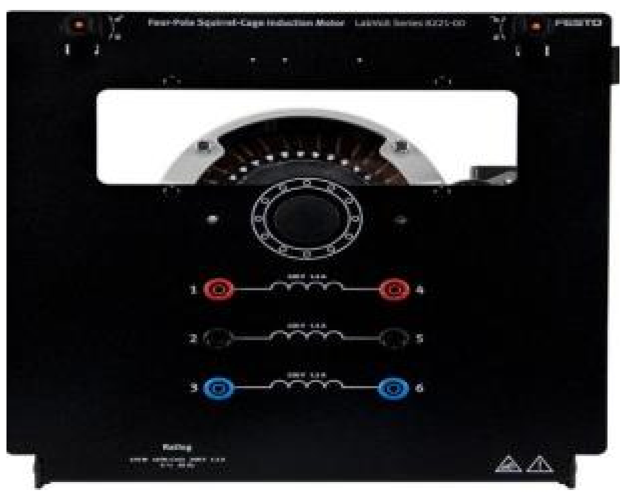


Figure 2-8 A 1-kW Induction Motor used in this study

A rotating magnetic field is produced when an AC runs via the stator windings. A squirrel cage motor consists of a stator and rotor, both made from magnetic materials. When the stator and rotor windings are in contact with each other, they create a torque that can be used to rotate the rotor. This type of motor is reliable because it starts easily and has adjustable speed-torque characteristics. It is commonly found in industrial applications where flexibility is important.

2.10 Voltage Variac

In figure 2-9, the variable voltage transformers are devices that allow for quick and easy adjustment of the voltage supplied to a load. They're widely accessible, simple to use and can be quite intuitive. One of their main benefits is keeping the secondary voltage regulated when the incoming line voltage changes.

Figure 2-9 Voltage Variac

CHAPTER3

FPGA Based SPWM Control Technique

3.1 Introduction

An inverter uses six switches to control the power supply to a motor. To do this, an SPWM method is used which determines the switching of power devices by intersecting a triangle carrier signal and a sinusoidal waveform signal. The output gate pules of this controller has rectangular pulses with varying duty cycles [13].

The switching frequency and modulation index determine the angle at which the switch is operated, and the amplitude of the fundamental wave depends linearly on the modulation index. Changing the switching frequency has no effect on the amplitudes of the harmonics, because it only changes the center of the fundamental wave frequency distribution. The pulses in the output waveform are weighted based on their resemblance to the reference waveform. This concept can be modeled using MATLAB/Simulink and simulated to generate a series of PWM waves.

3.2 FPGA based three phase induction motor control

The control algorithm diagram of an induction motor using a single FPGA chip is shown in Figure 3-1.

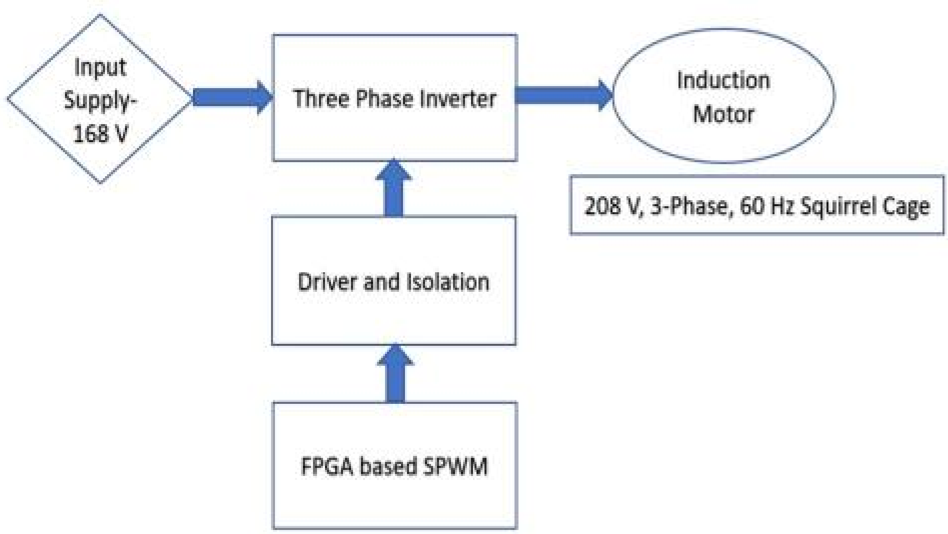


Figure 3-1 FPGA based speed control of Induction Motor

In an inverter using SPWM, a sine wave is used as a reference signal and compared to the triangular carrier signal. When the amplitude of the reference signal is larger than that of the carrier signal, switching pulses are generated. This can be used for the controlled speed of an induction motor [14-16].

The PWM pulses generated by the FPGA controller turn on and off semiconductor switching devices in three-phase inverters The SPWM control module includes six blocks that can be used to adjust the amplitude, frequency, stator phase voltage, PWM switching frequency, and IGBT delay time. External hardware is necessary for these adjustments to take place; this may include analog-to-digital converters (ADCs) and digital switches. The blocks were built on an FPGA with the VHSIC Hardware Description Language [11][12][17]. To control the stator phase voltages, the motor speed is adjusted by manipulating the modulation index. This prevents an uncontrolled shoot-through fault and allows for a delay time between IGBT switches in each of the three phases of an inverter. A discrete sine wave generated as a reference signal is provided by the Discrete Sine Wave module. The sine wave has a voltage range of 80 VAC to 130 VAC and is used to control motor speed [18].

CHAPTER 4

Simulation Results

4.1 Three-phase System Overview

The schematic consists of three main subsystems: a comparator for PWM output, an inverter section, and a load section. PWM inverters are referred to as inverters whose functionality depends on pulse width modulation technology. Depending on the load connected, these can maintain the output voltages at the rated voltages, as shown in Figure 4-1

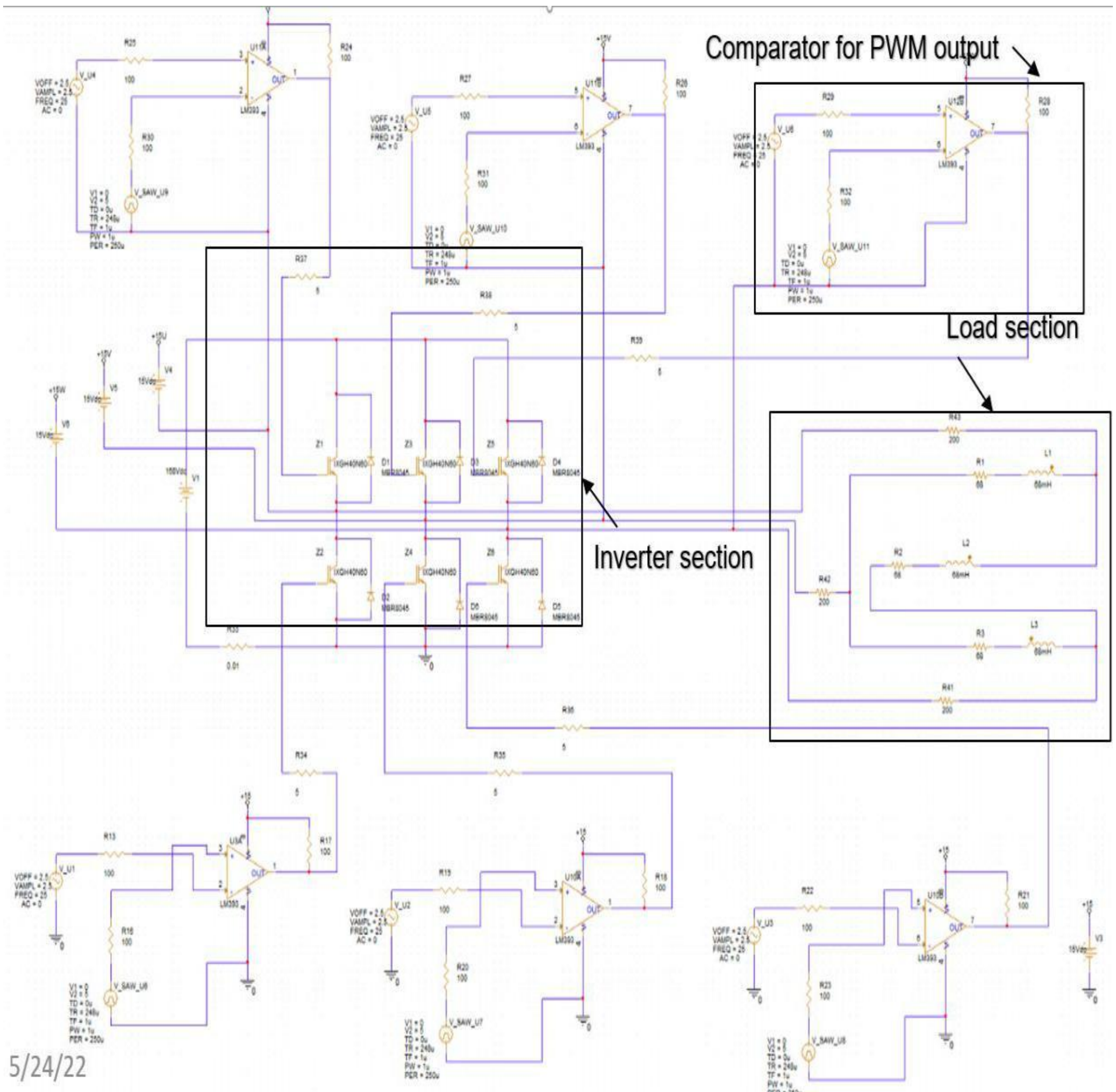


Figure 4-1 the Main Pspice Simulation Schematic of the three-phase inverter

4.2 Three Phase Inverter

Different power circuit topologies and methods for controlling voltage are used when designing an inverter. The most concentrated section of the waveform is formed at the inverter's output. Before being supplied to the connected load, the switching pulses are modulated and regulated. Two signals are used in an inverter's PWM technique. The reference signal is one, and the carrier signal is the other. The comparison between those two signals can produce the pulse required to change the inverter's mode. PWM techniques include modified sinusoidal pulse width modulation (SPWM), and MPWM. In this study, a sine wave is used as a reference in instead of a square wave, and a triangle wave will serve as the carrier. The system output current will be a sinusoidal waveform, and the modulation index will determine the voltage's RMS value.

Three-phase VSIs are widely used in medium to high power applications. The standard three-phase inverter has six power electronic switches that controlled by control gate pulses. Voltage sources use input dc from a three-phase utility power supply to generate controllable voltages using various PWM strategies. The input dc usually comes from Vdc (168 V).

4.2.1 Inverter Section

The resulting high and low-modulated pulses are sent to the six IGBTs to control the power flow**.** Each of the three sinusoidal waves are compared to the triangle wave to determine which set of IGBTs has a pulse width modulation (PWM) that produces the most efficient power transfer. This is done by considering Figure 4-2, which shows how IGBTs are vertically paired and have different phases when their respective waves overlap. When the sinusoidal wave is larger than the triangle wave, IGBT 1 will be high while IGBT 2 will be low. Conversely, when the sinusoidal wave is smaller than the Triangle Wave, then IGBT I will be low while IGBT 2 is high [19].

The phase of the sinusoidal wave is shifted by 120 degrees when compared to the triangle wave. For example, IGBT 3 will be high while IGBT 4 will be low when comparing a larger than triangle-wave to a smaller than triangle-wave. Likewise, IGBTs 5 will be high and 6 will be low for a bigger than triangular wave and IGBT 5 will be low and IGBT 6 will be high for a smaller than triangular wave respectively. The three-phase inverters purpose is to operate three-phase equipment. Three sinusoidal signals with different phase angles—0, 120, and 240 degrees are included in the three-phase design [20]. The three sinusoidal waveforms are compared with a positive and negative carrier waveform to create alternating current (AC) pulses for the inverter. This type of inverter has been popular in power electronics for many years because it is simple to construct, and its control scheme provides strong output signals. In industrial applications, the SPWM switching technique is frequently utilized. The width of these pulses is modulated to obtain inverter output voltage control. SPWM is the most used method in motor control and inverter application [21].

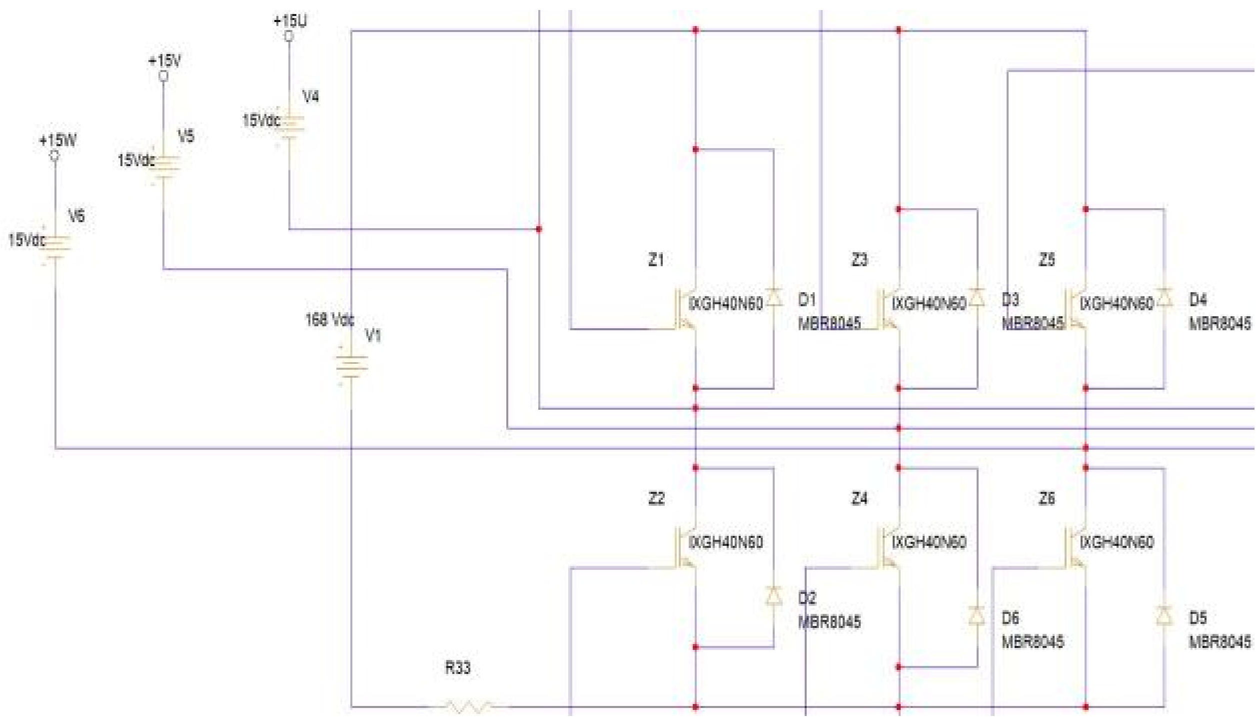


Figure 4-2 Schematic of Inverter Section

4.2.2 Comparator for PWM output

The two signals are compared by a comparator to produce modulated gate pulses. In an inverter, (SPWM) is a technology used to control switches within an inverter. The modulation signal, which is typically known as the sine wave or triangle, determines how often the switch will be turned on. This happens by comparing it with a sinusoidal signal that provides what should be its fundamental frequency. Since there is no continuous power flow through this type of inverter. The inverter's output voltage has a discontinuity waveform, which makes it more likely that the generated energy is accompanied by harmonic frequencies. Unwanted vibrations reduce the efficiency of the inverter. The required inverter output frequency determines the frequency of these sinusoidal waves (25 Hz).

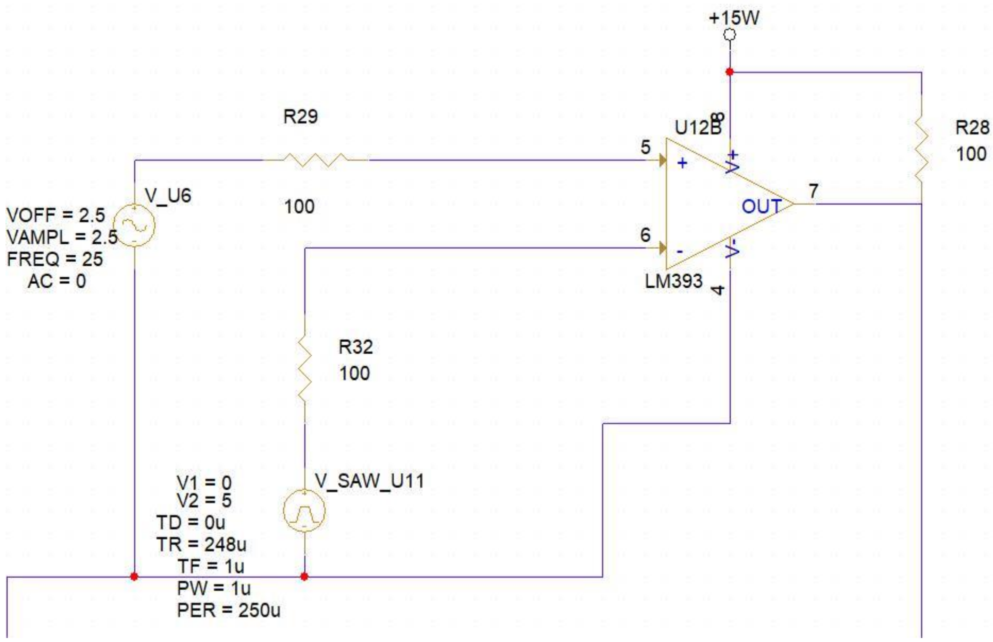


Figure 4-3 Schematic Section of the Comparator for PWM output

Figure 4-3shows a high frequency triangle wave generating circuit that compares the sinusoid waveform and the carrier signals.

4.2.3 Load Section

SPWM is a type of modulation that is necessary to power loads with inductive or resistive characteristics when DC sources are used. Most ohmic and inductive loads can be powered by an SPWM inverter, but only ohmic devices can be driven by a normal PWM inverter. Theoretically, a three-phase SPWM power inverter converts a DC voltage to an AC voltage.

The R-L load is designed to be connected to the delta load as 68 Ω of resistance and 68 mH of inductance,which matches the 3-phase induction motor impedance and later, by insertion of resistance 200 Ω line impedance to the delta load as shown in Figure 4-4.

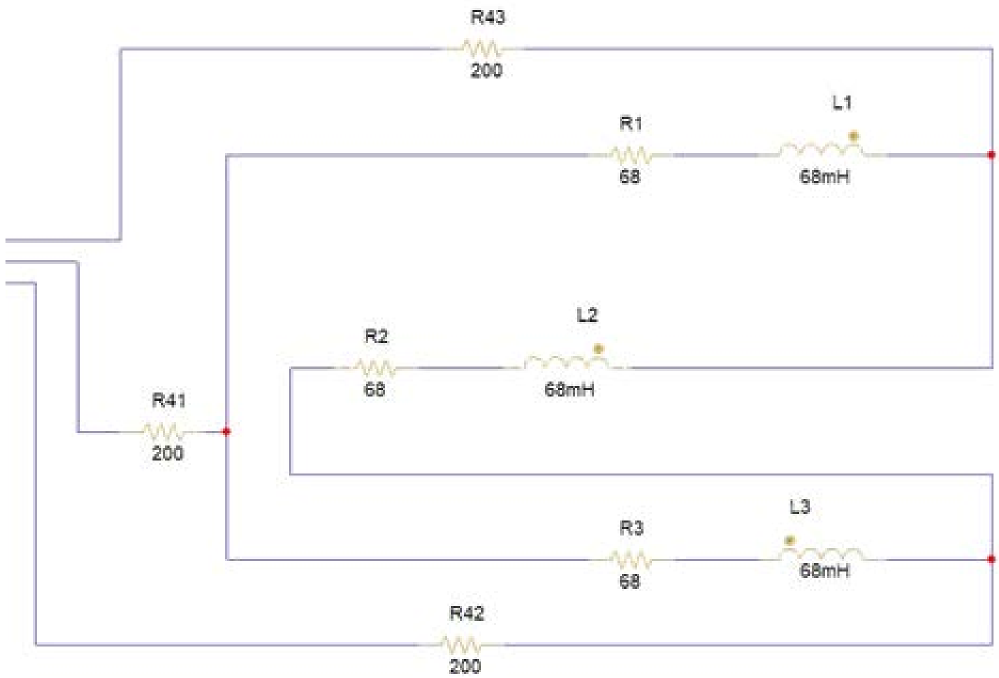


Figure 4-4 Schematic of Load Section

4.3 Simulation Waveforms

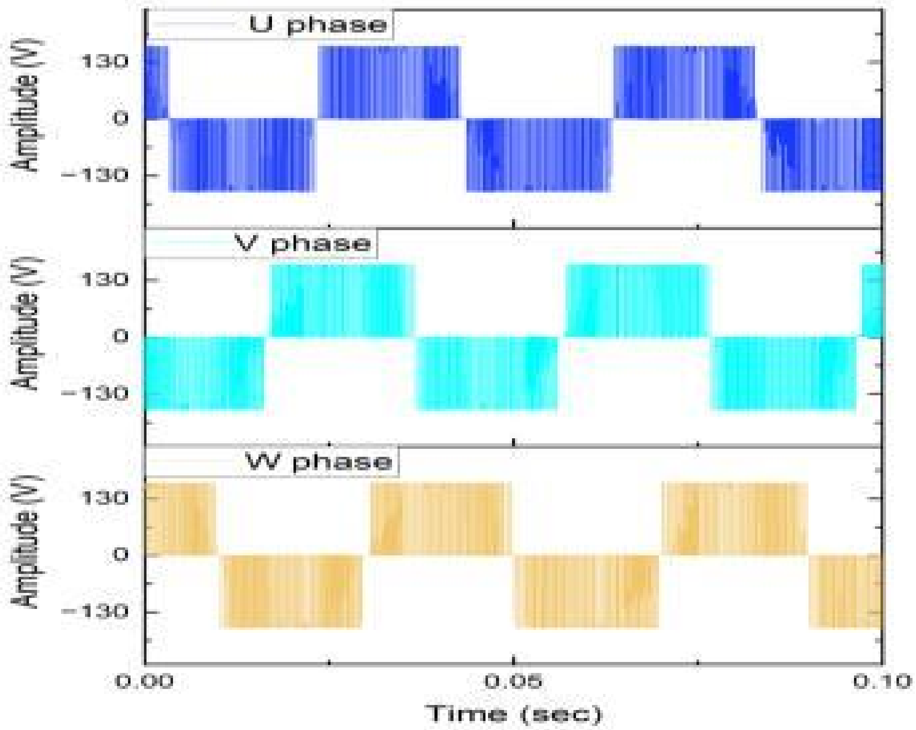


Figure 4-5 Three phase output voltage without insertion of 200 ohm per cycle

The waveforms in Figure 4-5 are the voltage output waveforms of a delta load with 68 Ω resistance and 68 mH inductance, Figure 4-5 displays a waveform with a voltage of 168 V.

Table 1 shows the current drawn and output power for the two different loads set up.

Table 1: Current & power comparison for different line resistance

VOLTAGE	Current	POWER	Comments
168 V	2.3 A	359 W	Without insertion of 200 Ω
168 V	0.39 A	113 W	With the insertion of 200 Ω

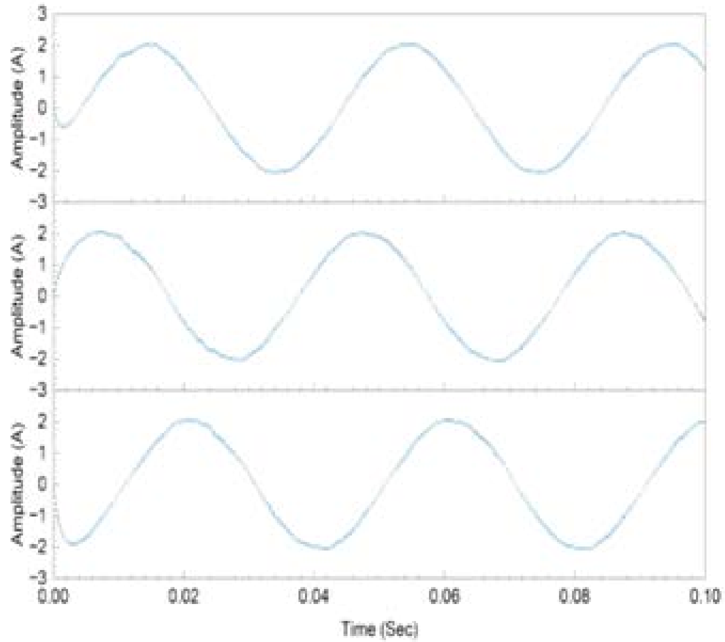
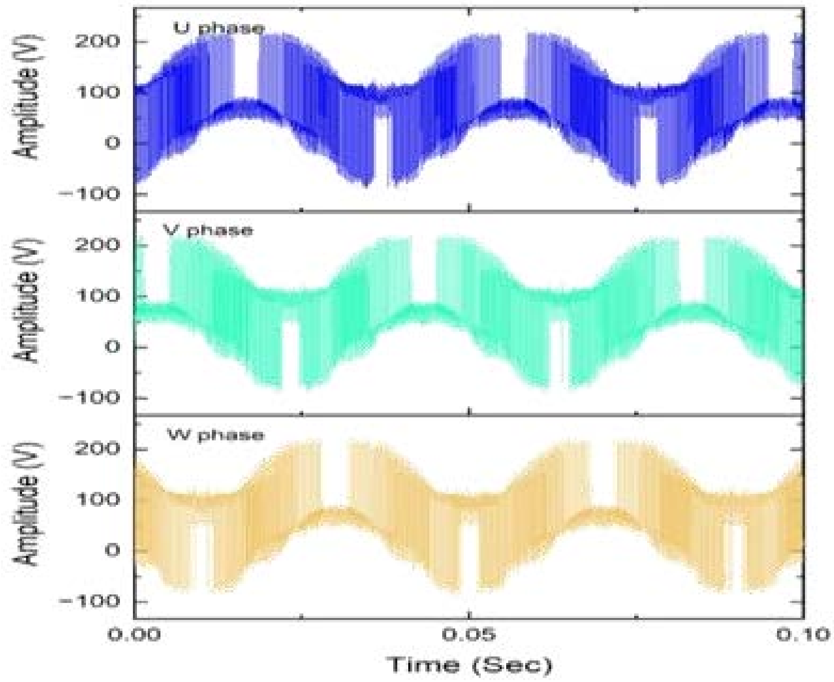
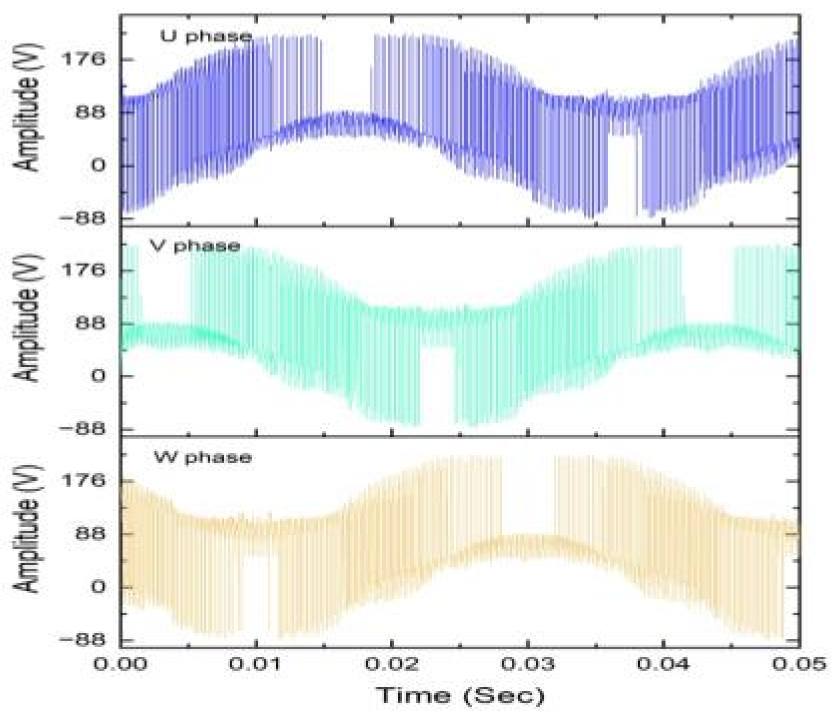


Figure 4-6 Three phase output current without insertion of 200 ohm

The waveforms in Figure 4-6 are the current output waveforms of a delta load with 68 Ωresistance and 68 mH inductance, which displays a waveform with a current of 2.3 A, which exceeds the current rating of the induction motor. The problem was fixed by adding 200 Ω of line impedance to the delta load. The injection of resistance (200 Ω) line impedance is simulated in Figure 4-7 and Figure 4-8.



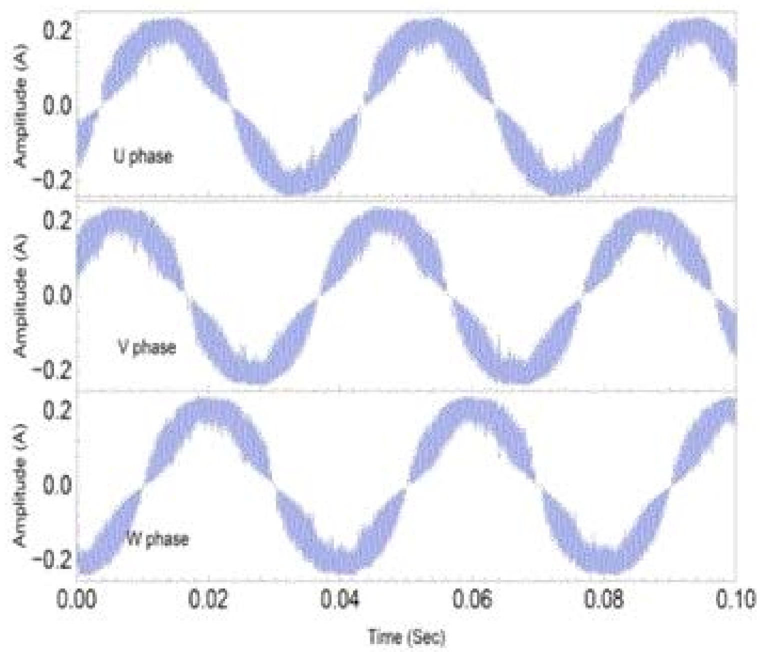
(a)



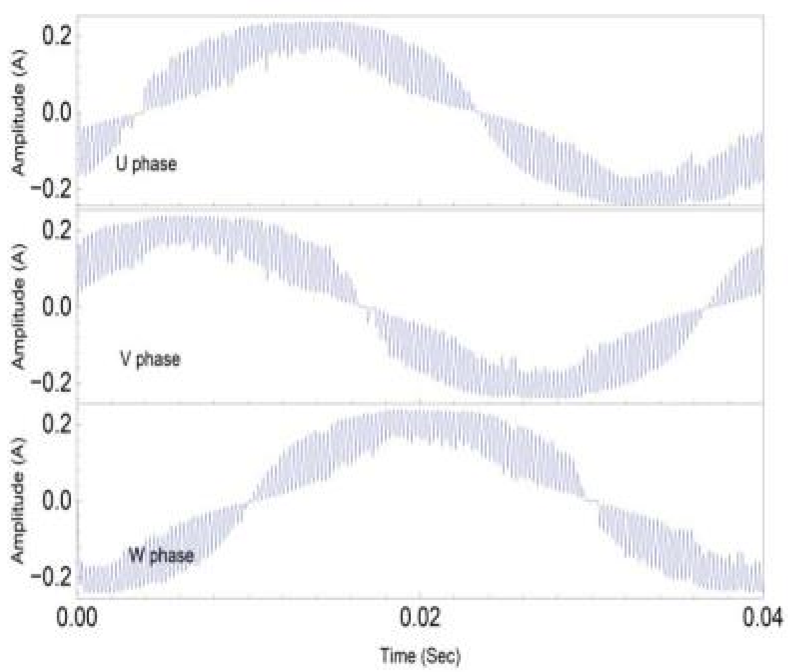
(b)

Figure 4-7 Three phase output voltage (a) with insertion of 200 ohm. (b) Zoomed in graph

Figure 4-7 shows the three-phase output voltage waveforms when the input voltage is at 168 V.



(a)



(b)

Figure 4-8 Three phase output current (a) without insertion of 200 Ω, (b) Zoomed in graph

In Figure 4-8 are the current output waveforms with 200 Ω line impedance. Figure 4-8 shows a waveform with a current of 0.39 A, well within the rated parameter of the induction motor. This confirms the simulation result that combining the proposed technique with the insertion of a 200Ω resistance reduces the over-exertion power to the induction motor.

CHAPTER 5

Experimental Setup and Results

The FPGA-based approach was verified by implementing SPWM modulated VSI in a Xilinx Vivado platform. This method allowed for the control of an induction motor with digital signals and a power electronics module.

5.1 Experimental Apparatus

The experimental setup is shown in Figure 5-1. The six FPGA driving pulses are sent through a PMOD connector to the signal amplification and isolation circuit. An optocoupler is used to isolate the power ground and logic ground. This prevents high-voltage spikes from affecting the FPGA, as well as circulating current that can damage it. Six IGBTs are employed for increased efficiency in this design. A 20V TTL signal from the FPGA is amplified by an International Rectifier driver IC to fulfill switch gate drive requirements [22]. The Propagation delay time of PWM pulses for 5 V according to the Infineon data sheet is maximum (18 ns) and the average of six pulses is 14.774 ns [23].

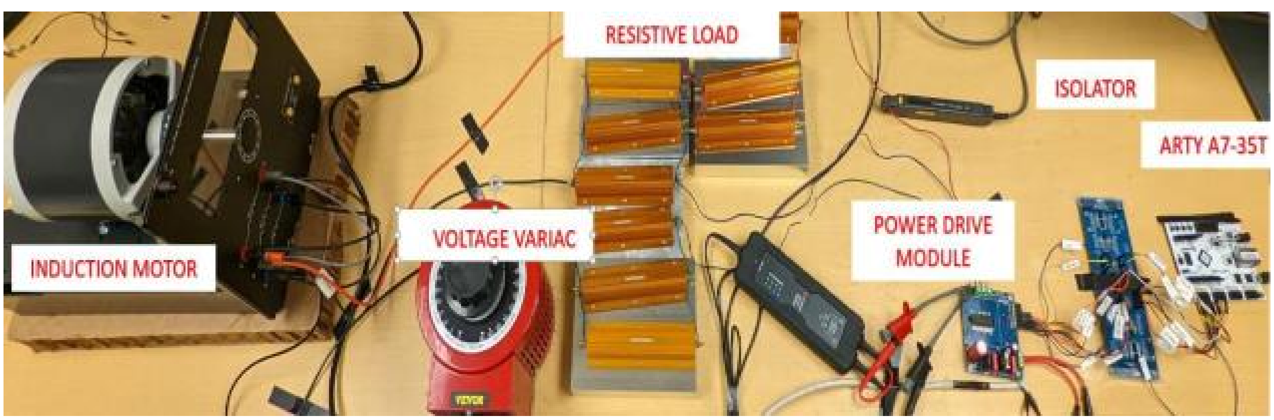


Figure 5-1 Experimental Setup

The propagation delay is the time it takes for an input to change its value and have that effect on the output. This can be caused by a few factors, including the triggering delay of a comparator in PWM mode and the speed at which signals travel through logic gates. There is a possibility that under certain operating conditions, the system may not work correctly because of the propagation delay between different parts of the system. When there is a low-duty cycle, the error amplifier output will be low, and this might cause a switch-on command to be sent to power after the high-to-low transition the of clock signal. It is a high-voltage bridge driver integrated circuit that has three independent output channels with fault protection. The on-board power supply is 3.2 V, and all input signals are active high. If the motor's current is greater than the set value, I will trip and a Gate Kill signal will be activated, causing the machine to stop **[23].** The input signal must be stable during the gate kill filter period in order to trigger the fault condition, and it must also be available to avoid any high-frequency noise. In adjustable voltage transformers, the AC power that's input doesn't automatically turn into DC. Instead, it needs an AC input and the output with the same frequency. This unit has a maximum of 20 Amps or a 2KVA Peak rating. The variac variable transformer is designed with many small holes for heat dissipation while the motor is operating. It can quickly and effectively remove the heat without reaching excessive temperatures and will not damage the transformer. It changes the ac supply to the power board from 80 VAC to 130 VAC. The power system is supplying 60Hz, then a variac variable autotransformer will not change that, the output will be a not distorted 60Hz. This variac variable transformer is the perfect motor speed controller.

To protect switches from shoot-through, the IRSM505-065PA also includes dead time control. The inverter's SPWM switching frequency can be changed, and the dead time is 1µs [24]. In this experiment, the inverter will be loaded with a 68 Ω resistor and 68 mH inductors in each phase. The line impedance is set to 200 Ω. The inverter's performance under loading conditions is also illustrated by the load voltage and current. The experiment employs speed control via voltage and frequency to evaluate the performance of the proposed drive system. The frequency changes from 20Hz to 60Hz in the frequency control technique by adjusting the modulation index (M) in sinusoidal PWM from 0.1 to 1. The experimental results demonstrate that the proposed FPGA-based controller for the motor drive is effective and accurate.

5.2 Different Load Conditions

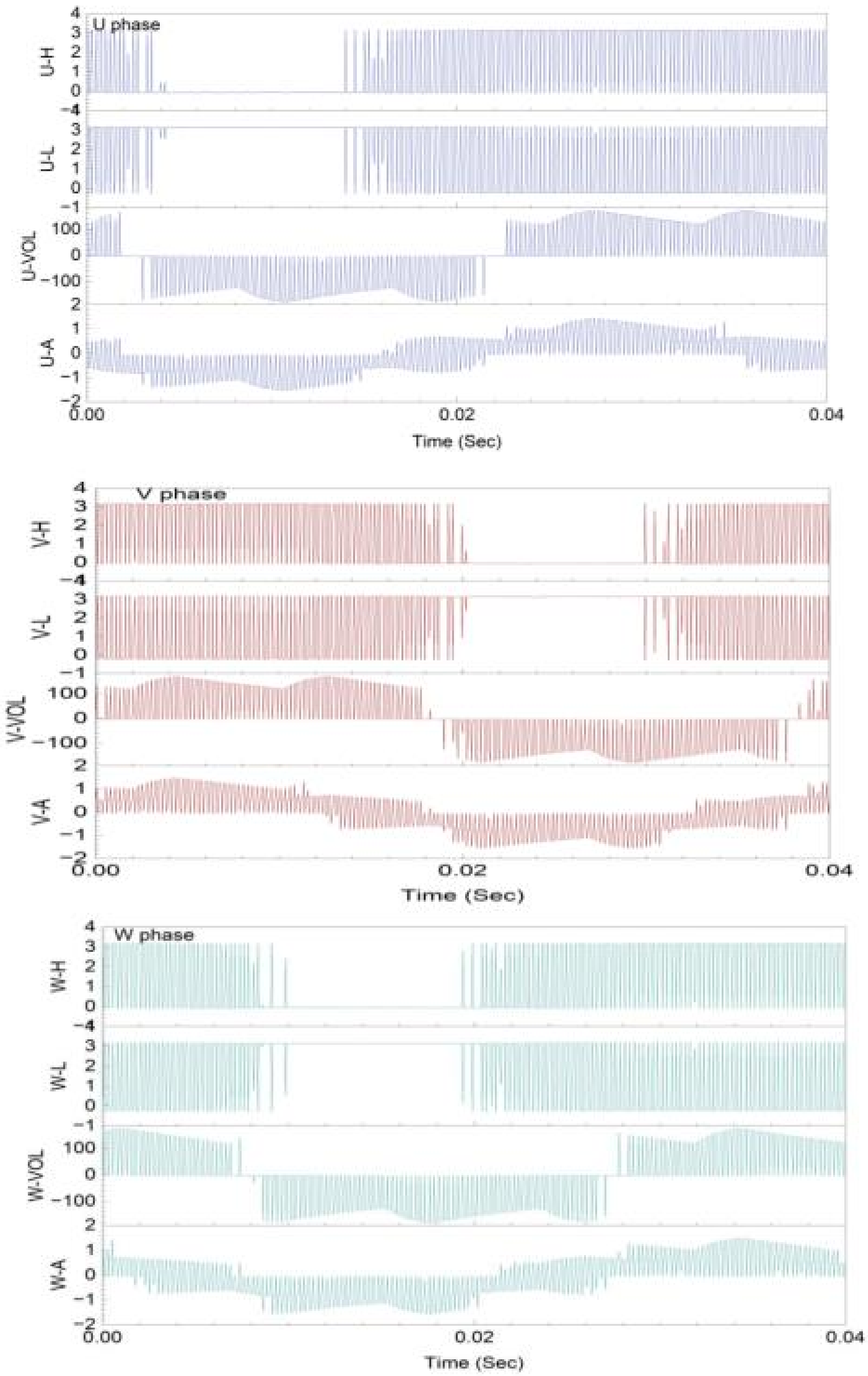


Figure 5-2 Three phase output voltage and current with 225 Ω ,330 µH load (consists of Voltage=168V, Current=0.86A, Power=125.44 Watts)

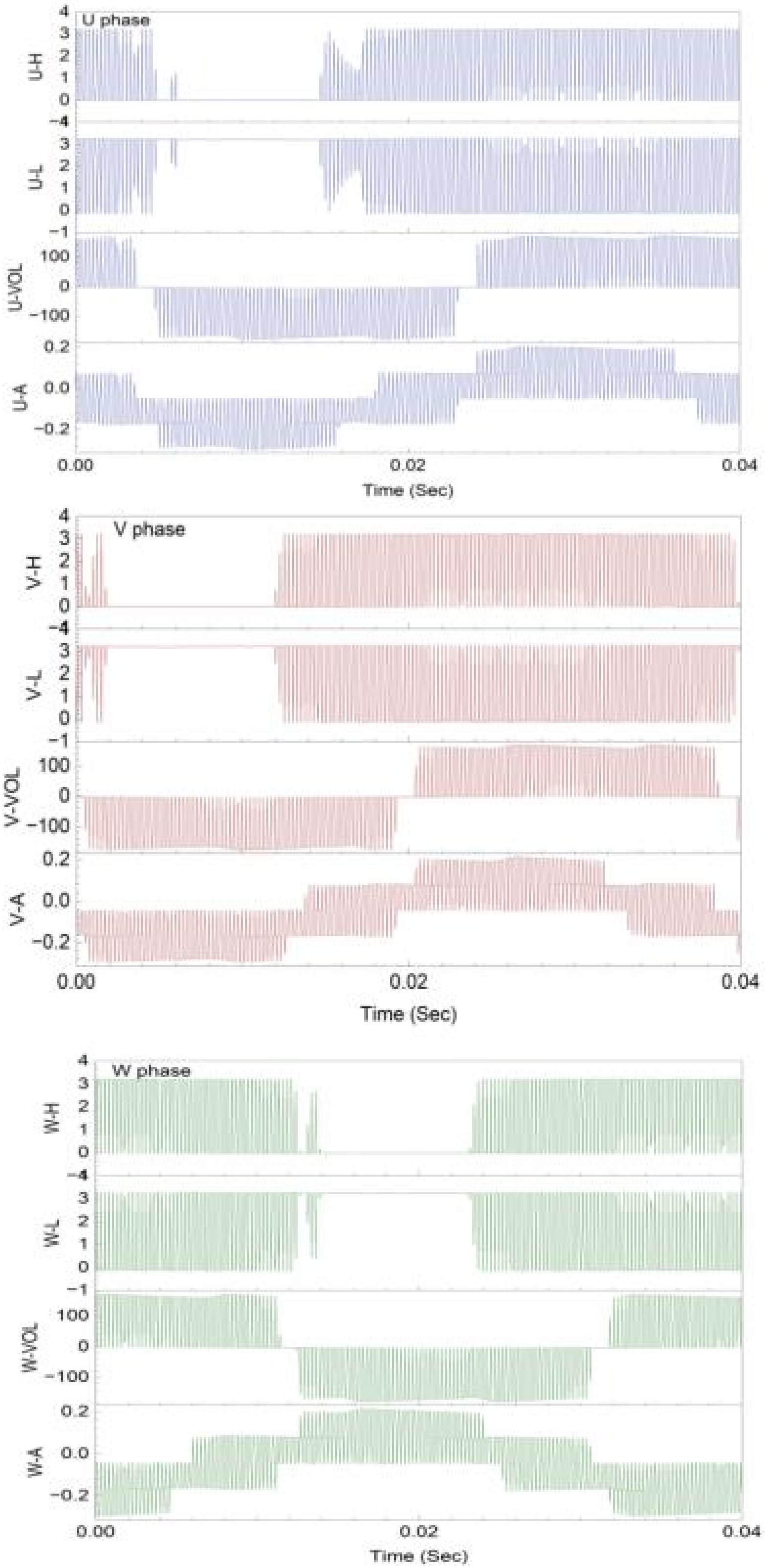


Figure 5-3 Three phase output voltage and current with 1350 Ω ,70 µH load (consists of Voltage=168V, Current=0.124A, Power=20.9998 Watts)

5.3 Applications

For most power conversion applications, a power inverter is a device that helps to convert DC power into the desired AC power. The technics presented in this study, can be used for various applications and industrial machinery, such as UPSs, adjustable speed AC motor drives, induction heating, variable frequency drives, and standalone aviation powers supplies.

CHAPTER-6

Conclusion & Future Works

The represent approach, it is possible to develop and implement digital controllers for power electronic converters and drives. The control algorithm is written in Xilinx Vivado software using HDL code, which was presented in detail. The presented control algorithm is simple and improves the performance of the induction motor SPWM speed controllers using FPGAs**.** The voltage and frequency of the inverter's output controls how quickly an induction motor is speeded up. The inverter operates in a way that simulates sinusoidal waves, which are then used to control the speed of the motor. The three-phase power supply with configurable frequency and voltage that was researched, designed, built, and tested using a resistive and inductive load. To gain extra power, the motor may be able to run above the rated speed. The analysis was verified experimentally on a motor to demonstrate the superior dynamic performance of the proposed ultrafast active inverter. The proposed induction motor drive control is, therefore, more effective and has a smooth speed response. The success of the experiment and simulation is indicative of the effectiveness of the methodology.

Further research into harmonic minimization for three-phase inverter driven induction motors could focus on software, hardware, or a combination of each. Software could be developed that requires motor and operating parameters as inputs and outputs an inverter control program. This method can be translated for higher power induction motors. We can use this implementation for induction motors, with different power output. FPGAs can also be used to drive multiple motors at the same time, with variable output frequency and variable duty cycle. This would implement to an inverter package that could be field configured for a variety of induction motors and operating conditions. The impact of introducing inductance and resistive into the load could be researched. The systems in the future will also cover greater speed and power ranges of induction motor. Devices and components that allow for higher switching frequencies can be used to produce more efficient.

References

[1] Leonhard, W. (2001). Control of electrical drives. *SpringerLink*. Springer Berlin Heidelberg. Retrieved December 12, 2022, from https://link.springer.com/book/10.1007/978-3-642-56649-3

[2] Yu, Z., Mohammad, A., & Panahi, I. (1997). A review of three PWM techniques. *IEEE Xplore*. IEEE. Retrieved December 13, 2022, from https://ieeexplore.ieee.org/abstract/document/611797/

[3] kodavati, B. (2010). automated degaussing of optical gyro. *research gate*. International Journal of Engineering Science and Technology. Retrieved December 13, 2022, from https://www.researchgate.net/publication/50366175_AUTOMATED_DEGAUSSING_OF_OPTICAL_GYRO

[4] Sathish kumar, T., & Gowrishankar, J. (2012). control and modeling of Shaft Generator. *International Journal of Soft Computing and Engineering (IJSCE)*. https://www.ijsce.org/. Retrieved December 13, 2022, from https://www.researchgate.net/publication/336771055_Control_and_Modeling_of_Shaft_Generator

[5] Rodriguez, J., Kouro, S., Rebolledo, J., & Pontt, J. (2005). A Reduced Switching Frequency Modulation Algorithm for High Power Multilevel Inverters. *IEEE Xplore*. IEEE 36th Power Electronics Specialists Conference. Retrieved December 13, 2022, from https://ieeexplore.ieee.org/document/1581729

[6] Lopez, O., Alvarez, J., Doval-Gandoy, J., & Freijedo, F. D. (2009). Multilevel Multiphase Space Vector PWM Algorithm With Switching State Redundancy Applied to Three-Phase Converters. *research gate*. IEEE Xplore. Retrieved December 13, 2022, from https://ieeexplore.ieee.org/document/4608737/

[7] Bassi, H. M., & Salam, Z. (2019, March 13). A new hybrid multilevel inverter topology with reduced switch count and DC voltage sources. *MDPI*. Multidisciplinary Digital Publishing Institute. Retrieved December 13, 2022, from https://www.mdpi.com/1996-1073/12/6/977

[8] Vander Meulen, A., & Maurin, J. (2010). Current source inverter vs. voltage source inverter topology. *eaton*. https://www.eaton.com/. Retrieved December 13, 2022, from https://www.eaton.com/content/dam/eaton/products/medium-voltage-power-distribution-control-systems/motor-control/literature/other-docs/sc9000-csi-vs-vsi-topology-white-paper-wp020001en.pdf

[9] Sahu , A. K., & Patel, R. N. (2022). Single-phase Inverter with Common Ground and Voltage Boost Operation. *https://ieeexplore.ieee.org/*. 2022 IEEE Global Conference on Computing, Power and Communication Technologies (GlobConPT). Retrieved December 13, 2022, from https://ieeexplore.ieee.org/abstract/document/9938335

[10] Ebrahimi, J. (2011). A New Multilevel Converter Topology With Reduced Number of Power Electronic Components. *IEEE Xplore*. IEEE Transactions on Industrial Electronics. Retrieved December 13, 2022, from https://ieeexplore.ieee.org/document/5764521/

[11] Ghaemia, A. H., Abyaneha, H. A., & Mazlumib, K. (2011, July 15). Harmonic indices assessment by wavelet transform. *International Journal of Electrical Power & Energy Systems*. Elsevier. Retrieved December 13, 2022, from https://www.sciencedirect.com/science/article/pii/S0142061511001293

[12] Ramasamy, M., & Thangavel , S. (2012). Photovoltaic based dynamic voltage restorer with energy conservation capability using fuzzy logic controller. *IEEE Xplore*. International Conference on Emerging Trends in Science, Engineering and Technology (INCOSET). Retrieved December 13, 2022, from https://ieeexplore.ieee.org/document/6513953/

[13] Pei, Z., He, J., Guo, T., Zhu, J., & Sun, W. (2009). Research on the application of CPS-SPWM technology in cascaded multilevel inverter. *IEEE Xplore*. International Conference on Electrical Machines and Systems (ICEMS). Retrieved December 13, 2022, from https://ieeexplore.ieee.org/document/5382769/

[14] Tzou, Y.-Y., & Kuo, T. S. (1997, November 14). Design and implementation of an FPGA-based motor control IC for permanent magnet AC Servo Motors. *IEEE Xplore*. National Yang Ming Chiao Tung University Academic Hub. Retrieved December 13, 2022, from https://scholar.nycu.edu.tw/en/publications/design-and-implementation-of-an-fpga-based-motor-control-ic-for-p

[15] Kim, S. J., Lee, H. J., Kim, S. K., & Kwon, Y. (2001, January 1). ASIC design for DTC based speed control of induction motor. *IEEE Xplore*. IEEE International Symposium on Industrial Electronics (ISIE). Retrieved December 13, 2022, from https://www.semanticscholar.org/paper/ASIC-design-for-DTC-based-speed-control-of-motor-Kim-Lee/12fe49baeaae981fd6a011f0679e96463c7b9034

[16] Poure, P., Aubépart, F., & Braun, F. (2000, January 1). A design methodology for hardware prototyping of integrated AC Drive Control: Application to direct torque control of an induction machine. *IEEE Xplore*. International Workshop on Rapid System Prototyping (RSP). Retrieved December 13, 2022, from https://www.semanticscholar.org/paper/A-design-methodology-for-hardware-prototyping-of-AC-Poure-Aub%C3%A9part/233e8f9d8e524ea01471f5903b9d28df1c990041

[17] Ahmed, Z. (2019, April 30). Power Electronics Circuits Devices and applications. *Choice Reviews Online*. academia. Retrieved December 13, 2022, from https://www.academia.edu/38989807/Power_Electronics_Circuits_Devices_and_Applications_By_Muhammad_H_Rashid

[18] Ismail, B., Taib, S., Saad, A., Isa, M., & Hadzer, C. M. (2006, January 1). development of a single phase SPWM microcontroller-based inverter. *research gate*. Power and Energy Conference, 2006. Retrieved December 13, 2022, from

https://www.semanticscholar.org/paper/Development-of-a-Single-Phase-SPWM-Inverter-Ismail-Taib/b8f5d3084bc901cbda41af68eab78c6daebaea3b/figure/8

[19] Gupta, A. (2017). Three phase inverter using sinusoidal PWM. *https://www.ijareeie.com/*. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. Retrieved December 13, 2022, from https://www.mathworks.com/matlabcentral/fileexchange/103240-three-phase-inverter-using-sinusoidal-pwm

[20] Buswig, Y. M., Affam, A., Albalawi, H., bin Julai, N., Hj Othman, A.-K. bin, & Qays, O. (2019). Development and Modelling of Three Phase Inverter for Harmonic Improvement using Sinusoidal Pulse Width Modulation (SPWM) Control Technique. *research gate*. International Journal of Recent Technology and Engineering. Retrieved December 13, 2022, from https://www.researchgate.net/publication/327980748_DEVELOPMENT_AND_MODELING_OF_THREE_PHASE_INVERTER_FOR_HARMONIC_IMPROVEMENT_USING_SINUSOIDAL_PULSE_WIDTH_MODULATION_SPWM_CONTROL_TECHNIQUE

[21] Colak , I., & Kabalci, E. (2013, September 25). Developing a novel sinusoidal pulse width modulation (SPWM) technique to eliminate side band Harmonics. *International Journal of Electrical Power & Energy Systems*. Elsevier. Retrieved December 13, 2022, from https://www.sciencedirect.com/science/article/pii/S0142061512004723

[22] International rectifier. (1947). IR2233 Datasheet (PDF) - international rectifier. *ALLDATASHEET.COM - Electronic Parts Datasheet Search*. Google. Retrieved December 13, 2022, from https://www.alldatasheet.com/datasheet-pdf/pdf/84516/IRF/IR2233.html

[23] Infineon Technologies, A. G. (2018). Eval-M1-05-65D user manual. *Infineon Technologies*. Google. Retrieved December 13, 2022, from https://www.infineon.com/dgdl/Infineon-AN2016-24_EVAL-M1-05-65D_User_Manual-UM-v02_01-EN.pdf?fileId=5546d4625696ed760156da2dccd96f4a

[24] Nekoei, F., Kavian, Y., & Strobel, O. (2007). FPGA-based Speed Control of Three-Phase Induction Motor. https://bfemu.journals.ekb.eg. Retrieved December 13, 2022, from https://www.researchgate.net/publication/236645340_FPGA_Based_Speed_Control_of_Three-Phase_Induction_Motor_Using_Stator_Voltage_Regulator