Construction of Variable Frequency Drive for Three Phase Induction Motor

Final Year Project Report

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DECLARATION

We hereby declare that this project report entitled "Construction of variable frequency drive for three phase induction motor" submitted to the "Electrical Engineering Department", is a record of an original work done by us under the guidance of Supervisor "Dr. Ammar Hassan" and that no part has been plagiarized without citations. Also, this project work is submitted in the partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering.

Advisor: ____________________________________

(Dr. Ammar Hassan)

Co-Advisor: _________________________________

(Dr. Hasan Arshad Nasir)

Date: _________________________

DEDICATION

We dedicate this project to our parents for being there for us through the thick and thin, the highs and the lows and to our friends, who through the course of these four years have become nothing short of a family. Thank you for believing in us. We love you all.

ACKNOWLEDGEMENTS

We would like to acknowledge the efforts of both our supervisor, Dr. Ammar Hassan, and Dr. Hasan Arshad Nasir for being helpful throughout the project. They have helped us find a way out of the uncertainties and have been of great help throughout the project timeline. We would like to extend this acknowledgement to SEECS and NUST of providing us with an environment, full of opportunities, that was nurturing and providing for us in almost every sense.

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ABSTRACT

In a country like Pakistan, energy conservation is critical. The only cost-effective solution to the energy dilemma is to conserve energy. According to some estimates, AC motors utilize 25% of the world's electricity. Furthermore, there is a significant issue with these motors, namely, a considerable starting inrush current. The motor draws a high current when it first starts up, which is useless until the motor reaches synchronous speed. This high current not only generates heat, but it also shortens the life of electrical equipment and increases power consumption. As a result, there is a need to lower this current in some way. Using a variable frequency drive, this current can be minimized. A technique for controlling the speed and frequency of AC induction motors is variable frequency drive (VFD). This phenomenon is also implemented on electric vehicles to control the speed of electric car motor. This thesis showcases the design and implementation of VFD which uses an interleaved boost converter and an SPWM (Sinusoidal Pulse Width Modulation) based inverter. The voltage and frequency of the motor are controlled using a technique known as SPWM. Renewable energy resources require boost converters with a high step-up conversion ratio and a large input current capability. Interleaved converters, which are made up of many parallel-connected converters, are a good choice for such applications. VFD provides energy to electrical appliances according on demand. It extends the life of equipment, but the most important benefit is that it is an energy-saving gadget, which is critical in a country like Pakistan, where the country's economic wheel has come to a standstill due to an energy crisis.

Chapter 1: INTRODUCTION

1.1 Chapter Overview

This document explains the approach utilized while designing a variable frequency drive for a three-phase induction motor. Because of their wide range of uses, ac induction motors are the most widely utilized of all motors. Variable frequency drives are used in a variety of products, including fans, solar pumps, tower cooling systems, microwave ovens, air conditioners, and electric vehicles. However, there is a need to solve the problem with ac induction motors and run them more efficiently. Many devices are used for this purpose, but the greatest of them all is the Variable Frequency Drive, which is used to change the speed and frequency of the motor and allows motors to run at varying loads by reducing speed. The motor can also be gradually brought up to speed, avoiding large start-up current spikes using VFD. The frequency of motor action is proportional to the speed of the motor. As a result, the motor speed can be modified to a desired value by altering the frequency of ac voltage.

$$N = \frac{120\mathrm{f}}{\mathrm{P}}$$

N = speed of motor (RPM)

f = electrical frequency of motor

P = number of poles of motor

According to some estimates, 10% of the energy consumed by ac motors is wasted and another 12% to 15% is lost when the motor is not running at maximum load. As a result, there is a strong desire among users to reduce energy waste, which can only be accomplished by employing devices such as variable frequency drives, whose primary benefit is energy savings.

1.2 Problem Statement

"*Indigenously built VFDs having high boost capabilities for Electric Vehicles and solar pump*".

1.3 Goals and Objectives

As Pakistan is facing power crisis, most of the energy is consumed by high power induction motors. This can be reduced by using variable frequency drive, as it is not only an energy efficient device, but it also provides a control on speed of motor. Furthermore, as most of the car in Pakistan are working on the principle of combustion engine, which is one of the leading causes of environmental pollution.

Electrical vehicles with Variable frequency drive to control speed of its induction motor which is directly connected to drivetrain using gears proves to be the best replacement to achieve our goal.

Main objectives of project are:

- Controlling speed of motor of Electric Vehicles.
- Reducing energy consumption by induction motor.
- Controlled starting, stopping and acceleration.

1.4 Methodology

Our Variable frequency drive is basically comprising of two portions. These are as follow:

- Boost Converter
- Invertor (DC to AC convertor)

Typical VFDs available in market also utilizes Rectifiers because they are using AC source. But our project presents a model for Electric Vehicles (EVs) and Solar pumps. That is why, we implemented boost converter followed by inverter. So, the basic idea is to take energy from batteries, boost it to desired level and then covert it into AC voltage using inverter to drive the induction motor. Figure 1 shows the block diagram of proposed VFD. Taking 24V input from batteries and boosting it to 400V using interleaved boost converter. We used interleaved boost topology due to its flexible design. It also provides the feature of automatic current balancing. We can increase the output level according to our demand just by adding parallel layers of diodes and capacitors. The invertor is the last and most significant element because it converts DC to AC by averaging the square waveform with a sine waveform whose pulse is changed to control the voltages and frequencies of motors. Then comes the invertor. It converts DC to AC by averaging the square waveform with a sine waveform whose pulse is changed to control the voltages and frequencies of motors. PWM, the key approach for controlling motor speed, is a crucial tool of variable frequency drive. For control purposes, we used Delfino Board by Texas Instrument. A feedback path is used and then PI controller was implemented to get stable output from Boost Converter. Similarly, SPWM is also implemented on this board for inverter.

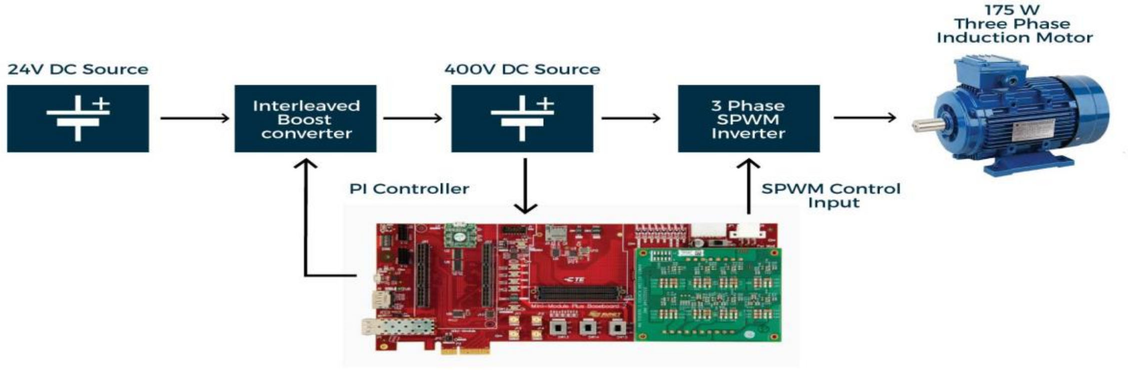

Figure 1: Block Diagram of Proposed VFD

1.5 Novelty

Currently, none of the VFDs work without Rectifiers circuits. Very less amount of VFDs contain Boost Converter. Because usually VFD is used for controlling speed of motor using frequency. Our project is a kind of modification to already present VFDs as it is working on batteries rather than AC source. Due to this reason, it can be employed in Electric Vehicles. This VFD also provide boost capabilities and due to its flexible design, output voltage can be boosted to any desired level.

Chapter 2: LITERATURE REVIEW

The literature review of all the work done or being done in this field can be divided into three different types:

1. Review of different topologies of boost converter.
2. Review of Feedback Controller.
3. Review of SPWM based three phase inverters.

2.1 Review of different topologies of boost converter

2.1.1 Simple Boost Converter

One of the most basic types of switch mode converter is the boost converter. It takes an input voltage and boosts or enhances it, as the name implies. All it consists of is an inductor, a semiconductor switch (usually a MOSFET these days), a diode, and a capacitor. A source of a periodic square wave is also required. This periodic square wave for switching can be given using any microcontroller.

The most significant benefit boost converters provide is their great efficiency - some can even reach 99 percent! To put it another way, 99 percent of the incoming energy is turned into useful output energy, while only 1% is squandered.

The conventional boost converter has voltage conversion ratio of:

$$\frac{Vout}{Vin} = \frac{1}{1-d}$$

V_{in} = input voltage

V_{out} = output voltage

d = duty cycle

We started off reading different research paper on boost converter keeping in mind that our battery source is of 24V, and we need to boost it to 400V. We also get to know that duty cycle should not exceed 0.75 otherwise the switching losses increases. We then implemented circuits of boost converter on simulation software to check whether we are achieving our desired level of 400V or not.

This conventional boost converter operates on very high duty cycle (i.e., $d \geq 0.9$) which causes current ripples, component current strains, and losses. On less duty cycle we were not getting desired voltage boost.

2.1.2 Cascaded Boost Converter

It is design consist of simple boost converter connected in series to create full network of boosting effect. The design used is Double cascaded boost converter in which V_{in} is applied at input voltage is boosted and appeared at the input of Second stage boost converter. Inductor used in the configuration are loaded through supply voltage and supply energy. Two MOSFET are used Q1 and Q2 and they work alternatively when Qi is on Q2 is off and vice versa. The MOSFET are given square wave at its gate input and both waves are inverse of each other.

The cascaded boost converter has voltage conversion ratio of:

$$\frac{Vout}{Vin} = \frac{1}{(1-d)^2}$$

V_{in} = input voltage

V_{out} = output voltage

d = duty cycle

We used source 24V as input and duty cycle was set 0.75 so the output was approximately 384V. We could move to three stage cascade converters but the main problem we were facing that each semiconductor device have high voltage stress. The electronics component used are of high voltage and current rating. Moreover, the output was not that much stable it was affected by increase or decrease of load.

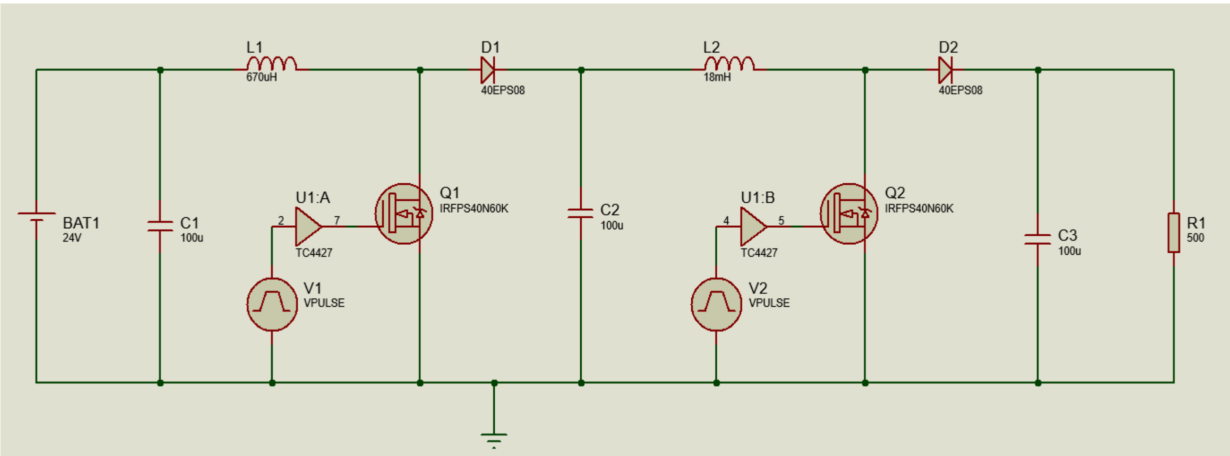

Figure 2: Cascaded Boost Converter Schematic

2.1.3 Quadratic Boost Converter

Quadratic boost converter is a type of cascaded boost converter. It has higher voltage gain ratio than simple boost converter and widely used in many applications. Its main difference from the typical boost converter is that it has only one MOSFT for switching. The operation of circuit is that second inductor current increases with input voltage during period when MOSFET is on and when MOSFET is off capacitor is charged to output voltage.

The quadratic boost converter has voltage conversion ratio of:

$$\frac{Vout}{Vin} = \frac{1}{(1-d)^2}$$

V_{in} = input voltage

V_{out} = output voltage

d = duty cycle

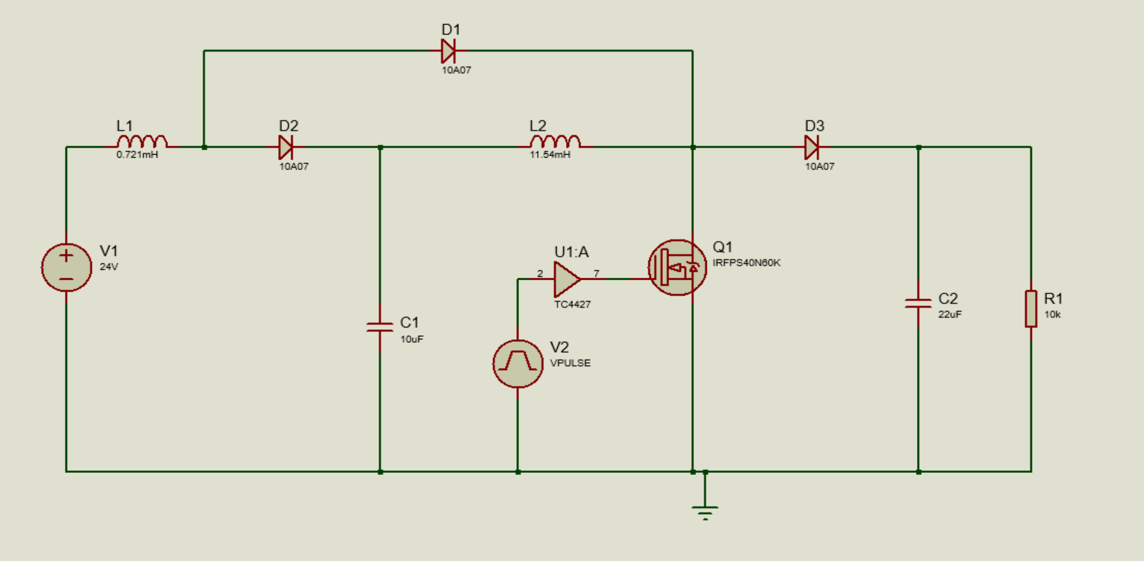

Figure 3: Quadratic Boost Converter Schematics

We used source 24V as input and duty cycle was set 0.75 so the output was approximately 384V. The main problem we were facing that each semiconductor device have high voltage stress. The electronics component used are of high voltage and current rating. Moreover, the output was not that much stable it was affected by increase or decrease of load.

2.1.4 Interleaved Boost Converter

After going through different topologies of boost converter, we finally get to know about interleaved boost converter. We started research on it. We came to know important features of our interleaved boost converter design. Some of them are listed here:

- A high-step-up interleaved boost converter with automatic current balancing and lower voltage.
- Added capacitors reduce stress on semiconductors.

- The suggested converters' step-up conversion ratios and input current capacity can be arbitrarily increased by increasing the number of voltage multiplier (VM) stages and phases, respectively.

Figure shows interleaved boost converter with 3p-4s topology. We implemented the circuit on a simulation software, Proteus. The output conversion ratio for this configuration is:

$$\frac{Vout}{Vin} = \frac{4}{1-d}$$

Which means that its output voltage is four times that of conventional boost converter.

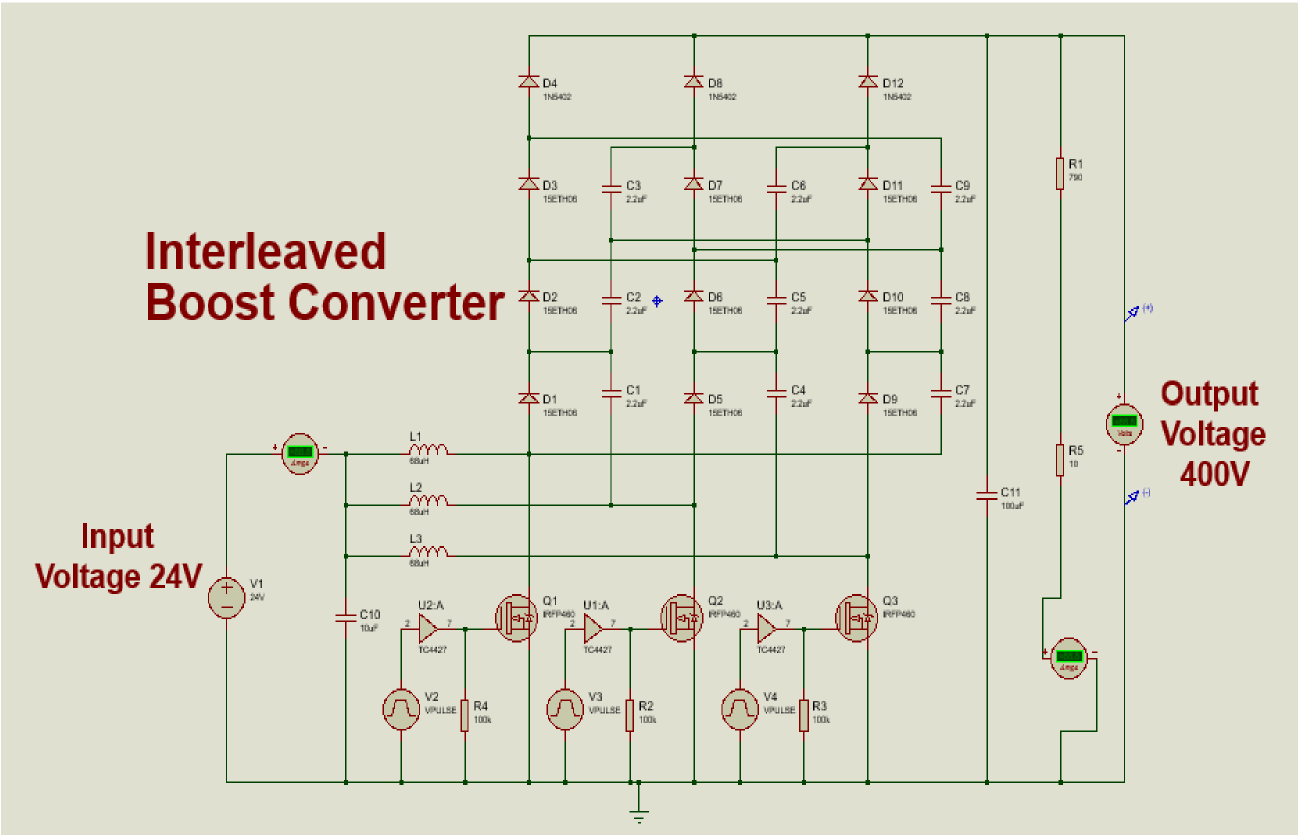

Figure 4: Interleaved Boost Converter Schematic

By expanding the VM stages, the suggested converter could modify step-up conversion ratios at will. In the research paper, multiple topologies are given but based on our design, we choose the 3p-4s topology.

2.2 Review of Feedback Controller

2.2.1 PI Controller

PI controller used in boost converter to get stable output voltage. It specifically consists of two component proportional part and integral part. Proportional controller refers output as proportional to output and integral controller refers output as integral of its output. The Pi controller was first designed on Arduino using Timer and interrupt but we all of challenged that we do not have full control to change its duty cycle. We were able to generate three waves of 120° phase delay but the code was not full customized so than we move to Simulink which provide full control of the system and very effective tool for making PI controller.

Main board on which Pi controller was deployed is DELFINO board and it was interfaced with the Simulink and model was deployed on it.

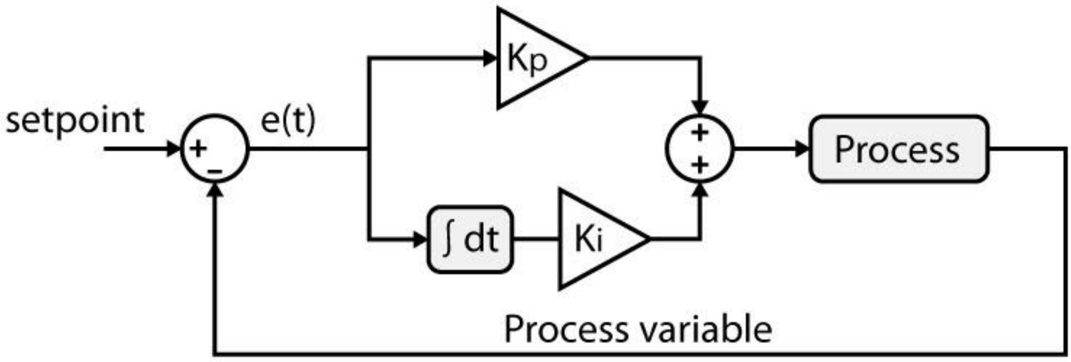

Figure 5: PI Controller

2.3 Review of SPWM Based three phase Inverter

A three-phase inverter transforms a single-phase DC input into a three-phase AC output. To generate a three-phase AC supply, its three arms are generally delayed by an angle of 120°. The switches S1 and S4, S2 and S5, and S3 and S6 are complementary to each other. A three-phase inverter circuit is shown in the diagram below. It's just three single-phase inverters connected to the same DC supply. In a three-phase inverter, the pole voltages are the same as in a single-phase half-bridge inverter.

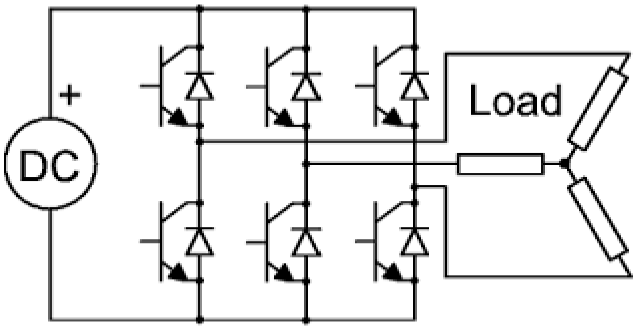

Figure 6: Basic three phase Inverter Model

2.3.1 PWM Technique

PWM (pulse width modulation) is a modulation technique in which variable-width pulses are generated to represent the amplitude of an analogue input signal. PWM (pulse-width modulation) is a powerful approach for manipulating analogue circuits with the digital outputs of a microcontroller. PWM is often used to manage electric motor speed, light brightness, ultrasonic cleaning applications, and many other things.

A PWM is a digital unipolar square wave signal in which the ON time can be varied (or modulated). A microcontroller can manage the amount of power given to the load in this way.

To fully comprehend PWM, we must first comprehend the phrase "Duty Cycle." The duty cycle is measured in percentages ranging from 0% to 100%. 0 percent duty cycle signifies no voltage at output, whereas 100% duty cycle means the power source's maximum voltage. With a microcontroller, the entire voltage is usually 5V, thus at 100% duty cycle, we get 5V; at 50% duty cycle, we obtain average voltage equal to half of the source voltage, which is 2.5V at output.

To summarize, if the pulse width is greater, the average voltage will be higher, and vice versa. We can attain the desired average voltage levels with just two voltage states by adjusting the pulse width.

We started off using hard-coded PWM using Arduino, which is the crude way of doing things, but we just wanted to check whether it is working or not. We have to generate six pulses as there are six switches (MOSFETs) in three phase inverter. On Arduino UNO, we generated three waves having 120 degrees of phase difference with a thought that we would invert these waves to produce another three waves. Using Proteus, we connected Oscilloscope with Arduino and observed the waveform which can be visualized as:

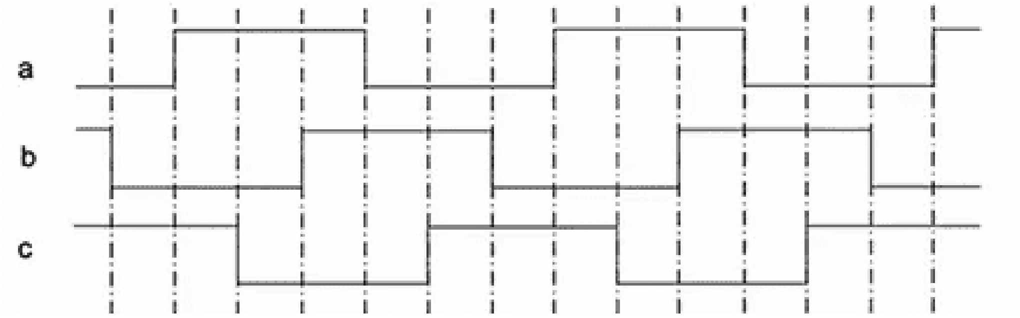

Figure 7: three pulses with 120 degrees phase shift having 50% duty cycle

The drawback of crude PWM technique is that it is not an efficient way of doing things, we have to change code manually every time we need to change duty cycle. Moreover, the hard-coded design is not flexible. We cannot employ feedback to this code, if needed for inverter.

Keeping in mind the drawbacks of hard-coded PWM, we then write code using Arduino timers and interrupts. The Timer/Counter on the ATmega328p microcontroller may create two types of PWM signals:

- **Phase Correct PWM:** The timer counts from 0 to 255 and goes back to 0 in this mode. When the timer hits the output compare register value on the way up, the output switches off, and when the timer hits the output compare register value on the way down, the output turns back on. As a result, the output is more symmetrical. Because the timer runs both up and down, the output frequency will be around half that of fast PWM mode.

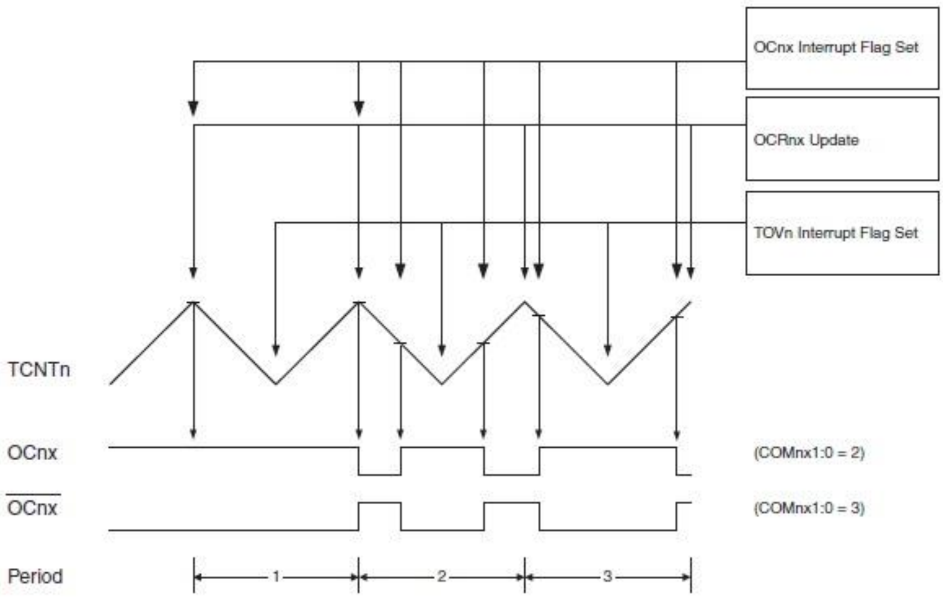

Figure 8: How Phase Correct PWM works

- **Fast PWM:** The timer counts from 0 to 255 repeatedly. When the timer is at 0, the output is turned on, and when the timer matches the output compare register, it is turned off. The duty cycle is proportional to the value in the output compare register. Fast PWM Mode is the name for this mode.

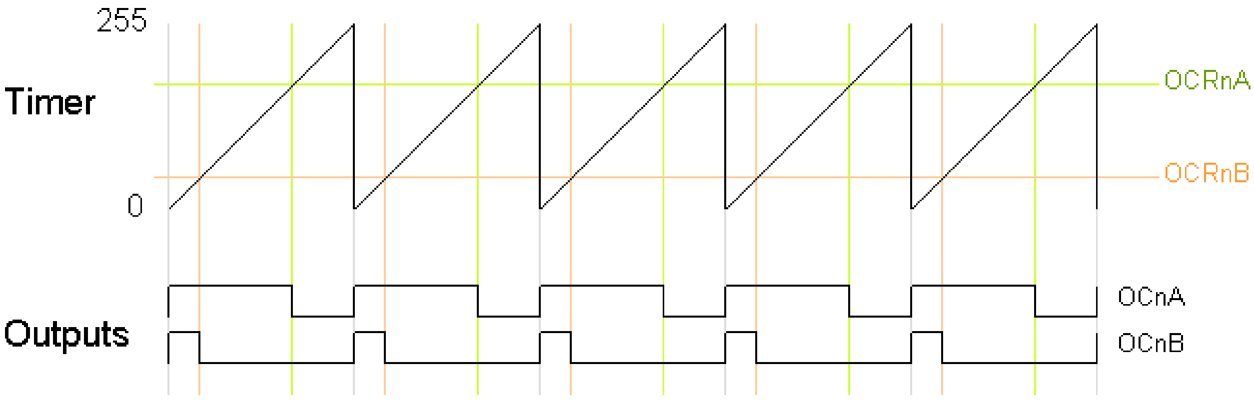

Figure 9: How Fast PWM works

We produced PWM waves using timers and interrupts by implementing both FAST PWM and Phase Correct PWM. We cannot produce more than three signals using Arduino UNO because it has only three timers. The duty cycle of the waves were set to 0.7 having frequency of 100 kHz with 120 degrees phase difference with each other.

2.3.2 SPWM Technique

After learning the PWM techniques for inverter, we then shifted to SPWM technique due to following reasons:

- Switching losses are significant due to the high PWM frequency.
- The output generated using PWM have more jerks as compared to SPWM.
- In SPWM, the output is more like a sine wave.
- SPWM technique has an advantage of having a constant switching frequency as it is equal to that of carrier wave.
- Design of Low Pass Filter for SPWM is easier.

The term "Sinusoidal pulse width modulation" refers to a pulse width modulation technique used in inverters. An inverter uses switching circuits to generate an AC voltage output from a DC input in order to reproduce a sine wave by creating one or more square pulses of voltage each half cycle. If the size of the pulses is adjusted, the output is said to be pulse width modulated. With this modulation, some pulses are produced per half cycle. The pulses close to the ends of the half cycle are constantly narrower than the pulses close to the center of the half cycle such that the pulse widths are comparative to the equivalent amplitude of a sine wave at that part of the cycle. The sinusoidal AC voltage reference V_{ref} is compared in real time with the high-frequency triangle carrier wave V_c to identify switching states for each pole in the inverter in SPWM approach.

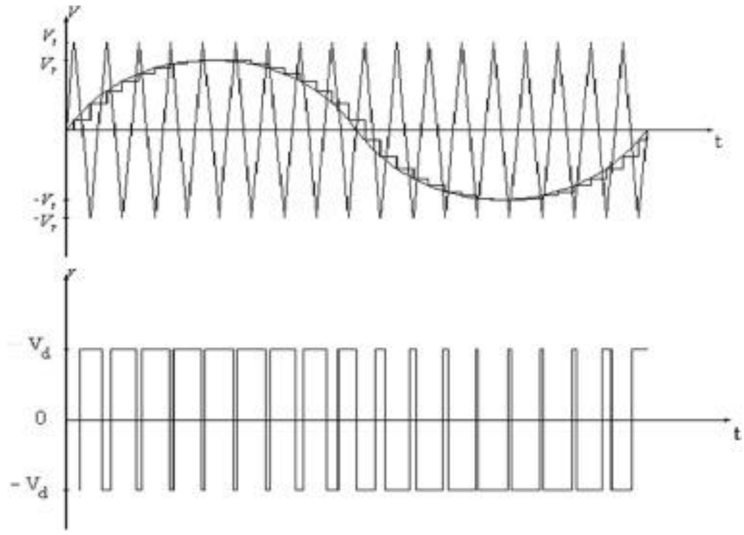

Figure 10: Design of a single phase SPWM Inverter

After comparing, the following rule can be used to calculate the switching states for each pole:

- Reference voltage V_{ref} > Triangular carrier $V_{c:}$ upper switch is turned ON.
- Reference voltage V_{ref} < Triangular carrier $V_{c:}$ Lower switch is turned ON.

This type of PWM technique is known as a carrier-based PWM approach because it uses a high-frequency carrier wave for voltage modulation. We implemented SPWM on Arduino UNO using Arduino timers and interrupts. Three signals were generated with a phase difference of 120 degrees and adjustable frequencies. We set it to 5 kHz. We successfully implemented SPWM and were able to generate three waves. We then tried to invert it in Proteus but failed. It is not inverting accurately. There are some lags in inverting due to which both switch in the same leg become close simultaneously and the leg become short circuited which is not required. They must operate alternatively. We discussed this issue with our advisor and then we came to know about the limitation of Arduino UNO. We researched some other boards such as STM32, FPGA, Arduino MEGA, etc. Our advisor recommended us to use Delfino Board by Texas Instruments. We started working on it. We came to know about its interfacing with GUI of MATLAB, known as Simulink. We then implemented SPWM inverter in Simulink and it is working perfectly here, generating six waveforms with 120 degrees phase difference.

Chapter 3: PROJECT COMPONENTS

3.1 Software and Tools Used

The following software and tools were used throughout the project:

- Proteus
- Power Sim
- Arduino IDE
- Altium
- MATLAB

3.1.1 Proteus

We have used Proteus for simulations. It has helped us in observing PWM and SPWM waveforms using oscilloscope. Arduino UNO and MEGA were available in Proteus. We write code in Arduino IDE and then add file of code to Arduino UNO in Proteus. Right from the start, we started implementing circuits on Proteus. It also give us leverage to work with PCB Layout. We start our PCB Designing in Proteus, then we move to Altium.

3.1.2 Power Sim

Power Sim is easier to use as compared to Proteus in a sense that it contains pre-defined pulses in which you can set duty cycles, frequencies, and phase angle. We use this software for checking our circuit that weather it is giving output or not. It is more ideal model than realistic model. After checking the circuit in Power Sim, we then move to Proteus for implementing the same circuit.

3.1.3 Arduino IDE

Arduino is an open-source hardware and software company, project, and user community that creates single-board microcontrollers for making digital devices that can control items in both the physical and digital worlds. We used Arduino IDE for writing code which is used for implementing switching for MOSFETs, PWM and SPWM techniques for three phase inverter and implementing PI controller for Interleaved Boost Converter.

3.1.4 Altium

Altium is used for PCB designing. Most industries in Pakistan uses Altium for PCB designing. We started off with Proteus to get the know-how of PCB Designing. Then, we shifted to Altium and started designing our PCB. Altium gives us leverage to design our own component if not available on internet, though 99% of the components were available.

3.1.5 MATLAB

We have used MATLAB for implementing SPWM based three phase inverter when we came to know that it can be interfaced with Delfino board. Its large toolset of pre-defined functions has helped with accelerating the process and has helped with faster and more accurate problem solving. Things become very easy when it comes to implement it using GUIs or Blocks.

Figure 11: Software Used

3.2 Hardware Considerations

We started our hardware work by considering small modules of Boost Converter. We first boosted our voltage from 3V to 40V by using one leg of our interleaved Boost Converter. We have done this for the sake of safety reasons as 400V is quite dangerous to deal with. The Details of Hardware are given along with their PCB design.

Chapter 4: CIRCUIT AND LAYOUT OF VARIABLE FREQUENCY DRIVE

In the figure, the circuit starts with a 24V DC source. This voltage goes to boost converter, which boosts it to required voltage level (400V in our case). This section incorporates a PI Controller to reduce oscillations in output voltage. Feedback signal is generated using voltage divider method. We make sure that no current flow through smaller resistor and voltage across smaller resistance be less than 5V. Output side voltage of boost converter is then fed to the H-bridge Inverter that converts the voltage into AC.

4.1 Interleaved Boost Converter

This converter is a DC-DC converter. A DC-DC converter's principal objective is to provide a controlled DC yield voltage to the load from a fixed DC input voltage. The interleaved boost converter design used is highly extendable and flexible. It provides high step-up boost with automatic current balancing and reduces voltage stresses of semiconductor.

The design fundamentally consists of two things interleaved boost converter and VM (voltage Multiplier) stages. Current capacity can be increased by using a greater number of phases and voltage capacity can be increased by increasing VM stages. Various topologies are used in design such as 3p-3s, 3p- 4s, 4p-4s topologies.

The voltage multiplier stages relation is as follows

$$\frac{Vout}{Vin} = \frac{M}{1-d}$$

Where M = Number of Voltage Multiplier stages.

The topology we are using is 3p-4s topology. Design uses three MOSFET Q_A - Q_C as a switch operate with 120 phase delay. Duty cycle for each of the interleaving signal is 0.76 but we can vary it from 0.67 to 1.

Operation mode is divided into four based on operation states.

Mode 1

Q_A, Q_B, Q_C all switches are on. V_{in} is applied to inductors L_A, L_B, L_C phase current increases linearly. All diodes are in reversed biased state and do not conduct. Current to load is supplied by C_{out}.

Mode 2

Q_B, Q_C are still on. Q_A is off. V_{in} is applied to inductors L_B, L_C, there phase current still increases linearly. But L_A phase current decreases linearly. Diode switch there states and capacitor are charge and discharged respectively.

Mode 3

Q_A, Q_C are on. Q_B is off. V_{in} is applied to inductors L_A, L_C, there phase current increases linearly. But L_B phase current decreases linearly. Diode switch there states and capacitor are charge and discharged respectively.

Mode 4

Q_A, Q_B are on. Q_C is off. V_{in} is applied to inductors L_A, L_B, there phase current increases linearly. But L_C phase current decreases linearly. Diode switch there states and capacitor are charge and discharged respectively.

MAXIMUM VOLT-AMP STRESSES OF THE PROPOSED CONVERTER						
		MOSFET	**DIODES**			
3p-4s topology		Q_j	D_{j1}	D_{j2}	D_{j3}	D_{j4}
	V_{max}	$\frac{V_{in}}{1-D}$	$\frac{2V_{in}}{1-D}$	$\frac{2V_{in}}{1-D}$	$\frac{2V_{in}}{1-D}$	$\frac{V_{in}}{1-D}$
	I_{max}	$\frac{7I_{in}}{12}$	$\frac{I_{in}}{12}$	$\frac{I_{in}}{12}$	$\frac{I_{in}}{12}$	$\frac{I_{in}}{12}$

Overall system voltage and current values

Power	192W
Voltage	
Input	24V
Output	400V

Current	
Input	8A
Output	0.48A

4.1.1 Simulations

MATLAB Simulation

Boost Converter Circuit Simulation on MATLAB. Circuit consists of both converter and PI controller which take feedback and maintain voltage to specific value.

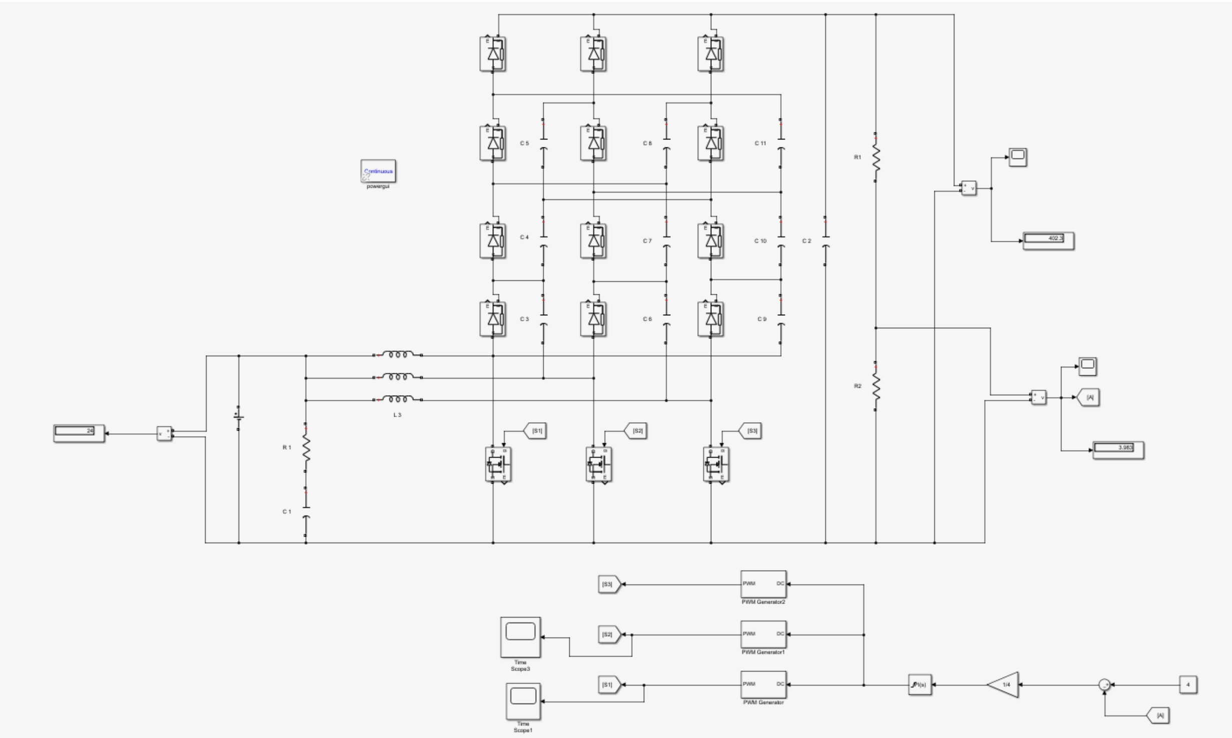

Figure 12: Interleaved Boost Converter

The graph below shows the output voltage of 400V of interleaved boost converter. The y axis represents voltage and x axis represent time.

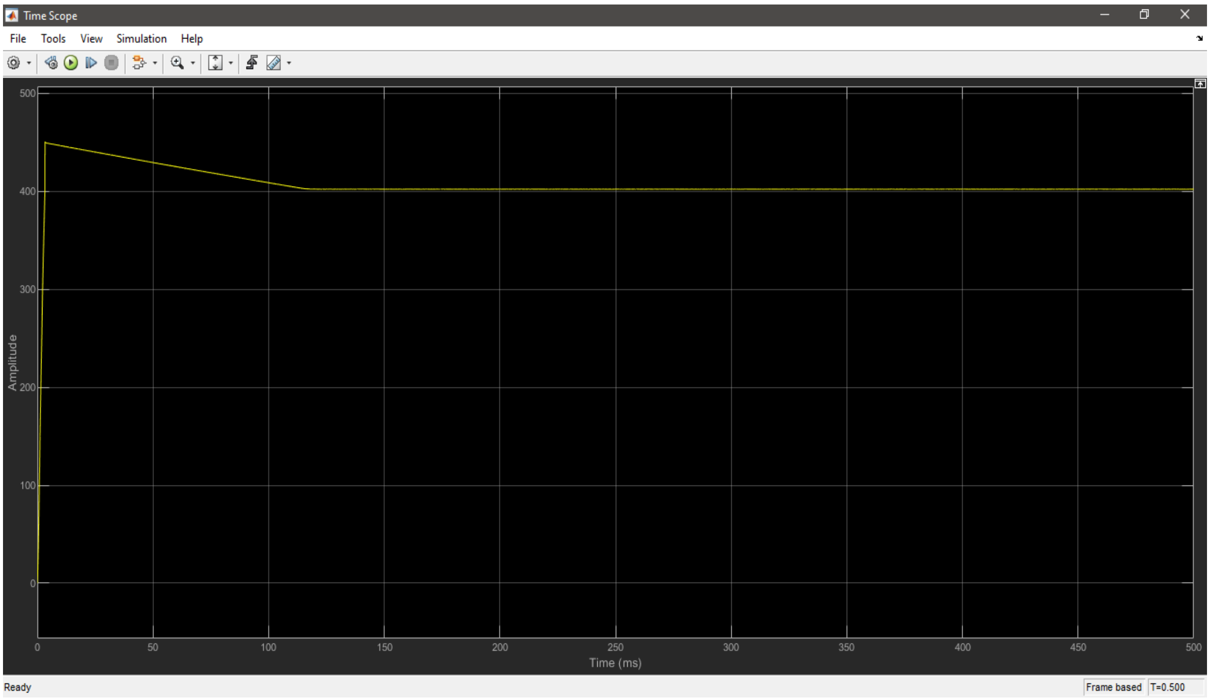

Figure 13: Output Voltage of Converter

Boost converter voltage output given to the PI Controller as Input Voltage. Voltage is approximately 4V the voltage divider circuit set in such a way that this voltage should not exceed 5V on safer side the calculation is done for about 4V.

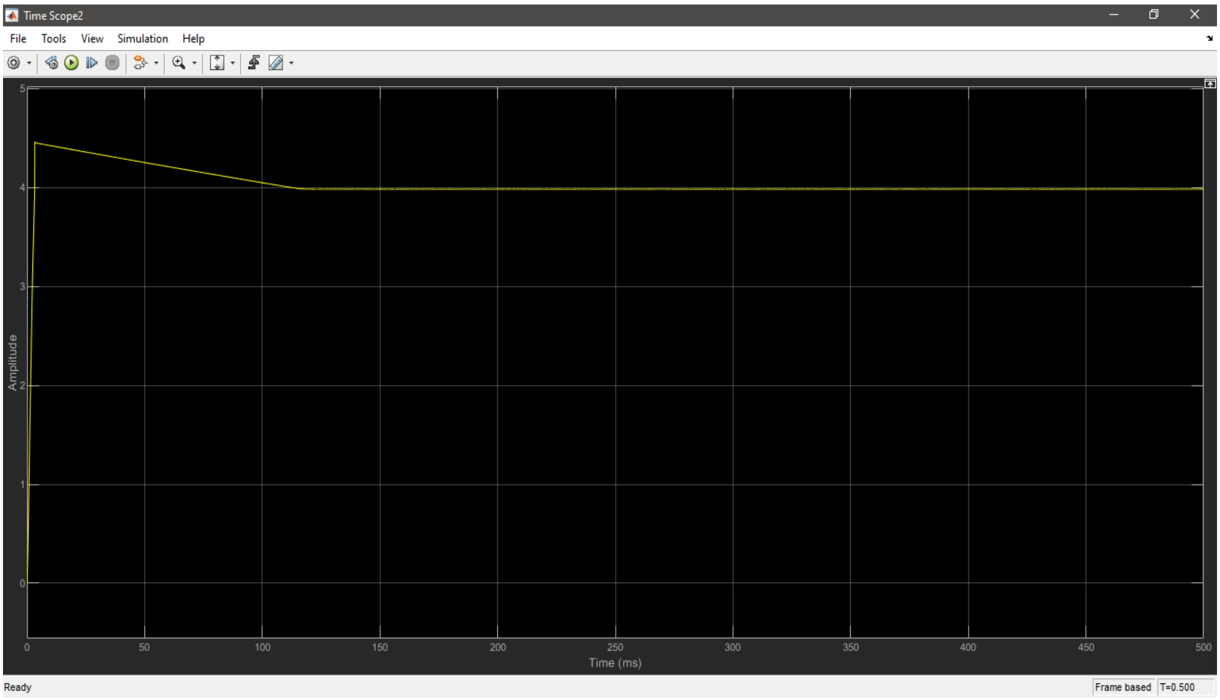

Figure 14: Controller Input

POWERSIM Simulation

Schematic circuit of boost converter to check feasibility of circuit.

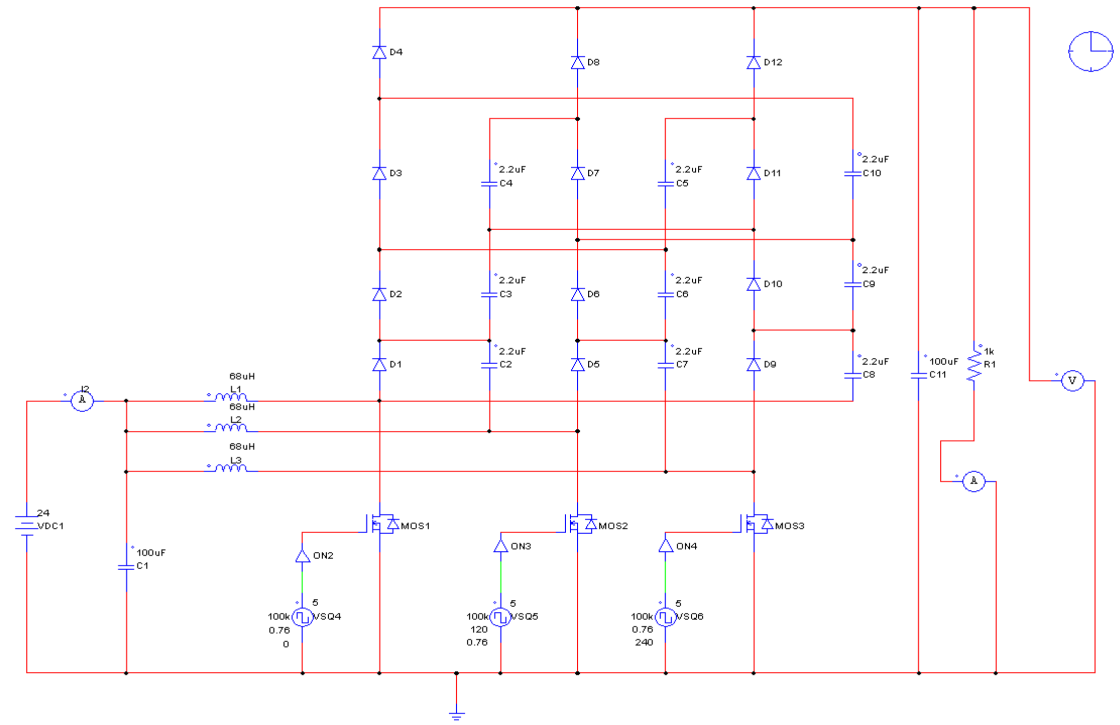

Figure 15: Interleaved Boost Converter

The graph below shows the output voltage of 400V of interleaved boost converter. The y axis represents voltage and x axis represent time.

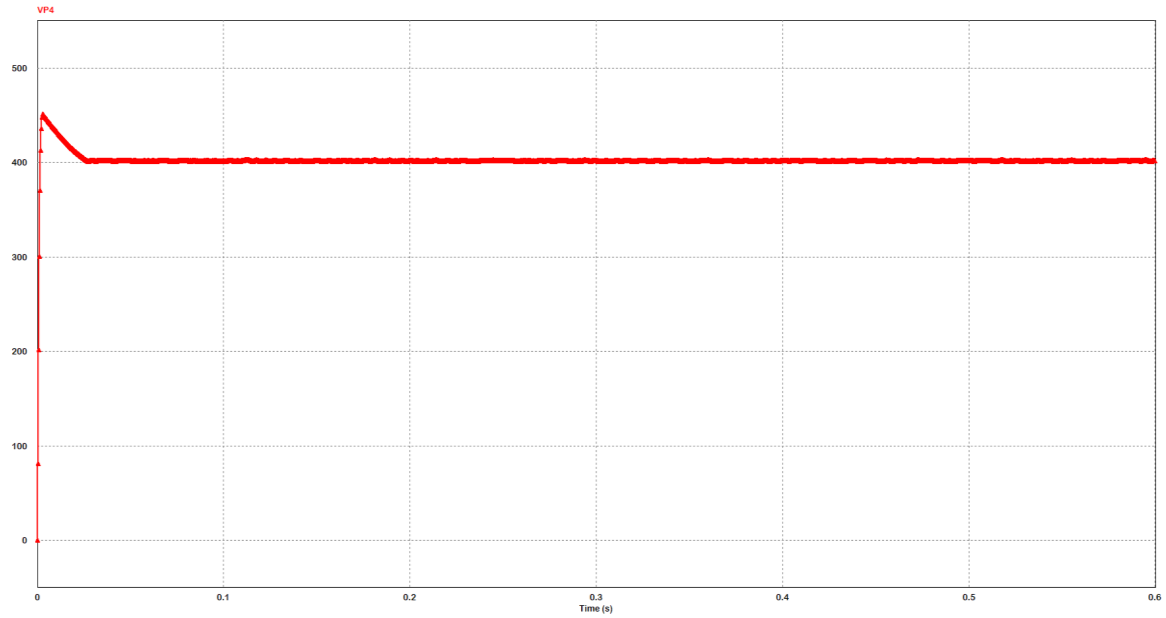

Figure 16: Output Voltage of Converter

The graph below shows the output current of 0.48A of interleaved boost converter. The y axis represents current and x axis represent time.

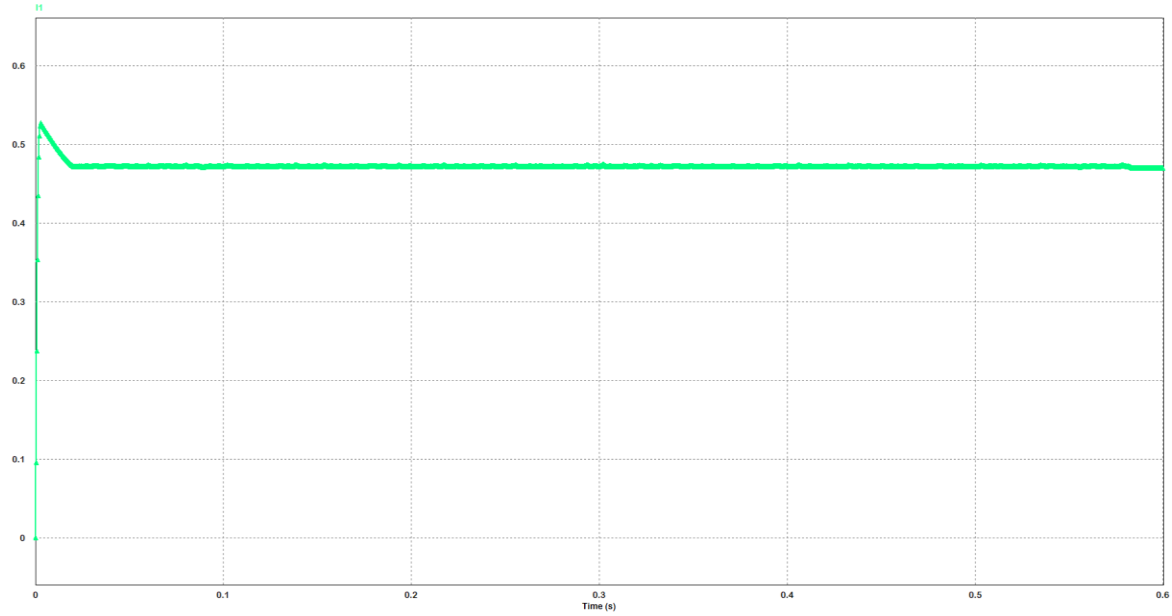

Figure 17: Output Current of Converter

Proteus Simulation

Boost Converter Final Circuit on Proteus.

Component used:

MOSFET	IRFPS40N60K
DIODE	40EPS08
Gate Driver IC	TC4427
Inductor	68uH
Capacitor	2.2uF, 100uF
Resistor	100k, 1k ohm
Frequency	100kHz

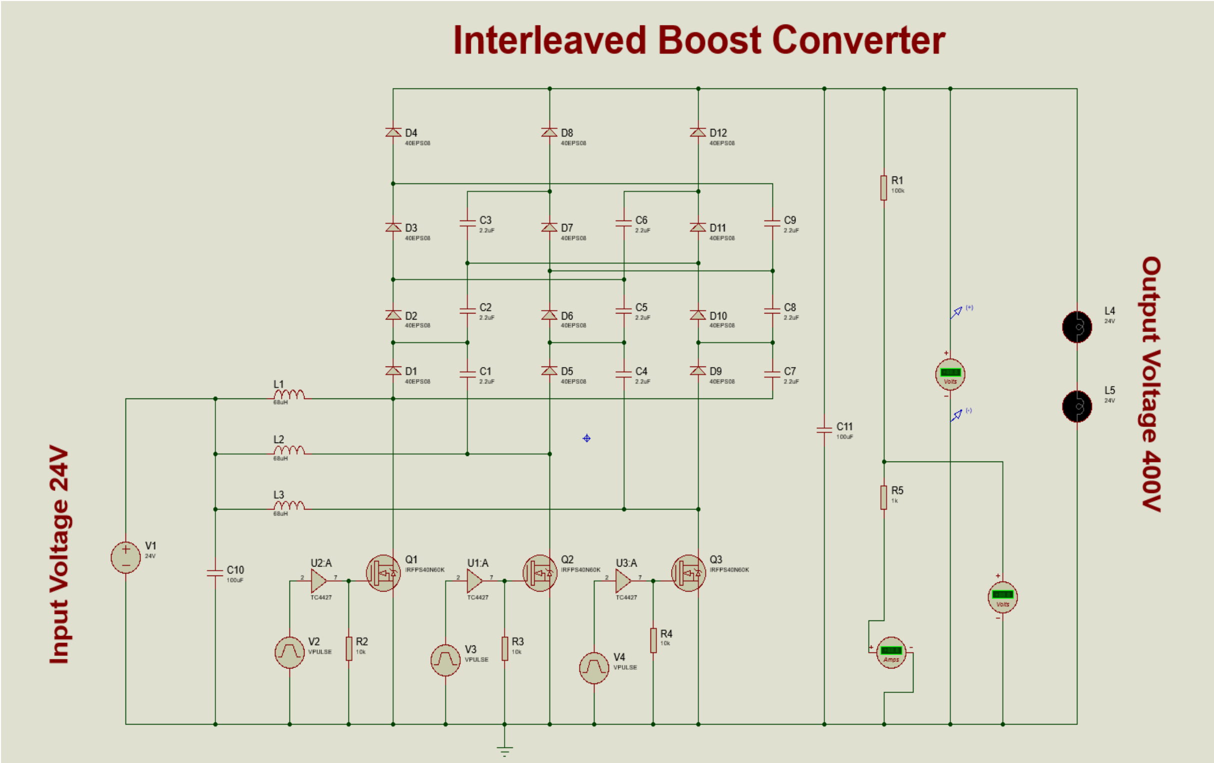

Figure 18: Interleaved Boost Converter Schematic

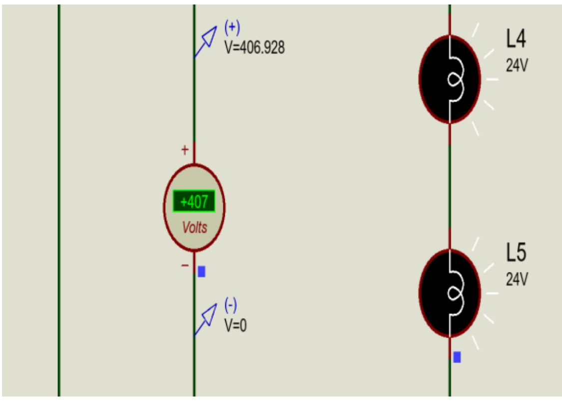

Figure 19: Voltage

4.1.2 PCB Designing and Implementation

Due to lack availability of component we have to move towards alternative components.

MOSFET	20N60
DIODE	FR307
Gate Driver IC	IR2112
Inductor	68uH

Capacitor	2.2uF, 100uF
Resistor	100k, 1k ohm
Frequency	100kHz

PCB layout of Boost Converter

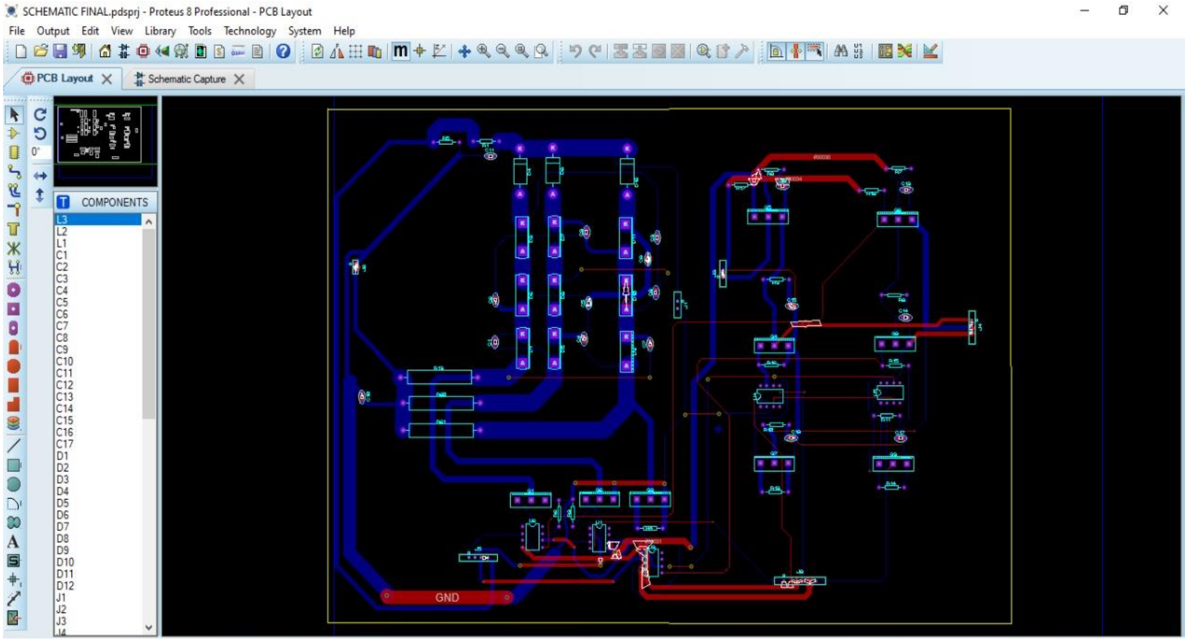

Figure 20: PCB Boost Converter

Circuit prototype implemented for two phase single stage interleaved boost converter.

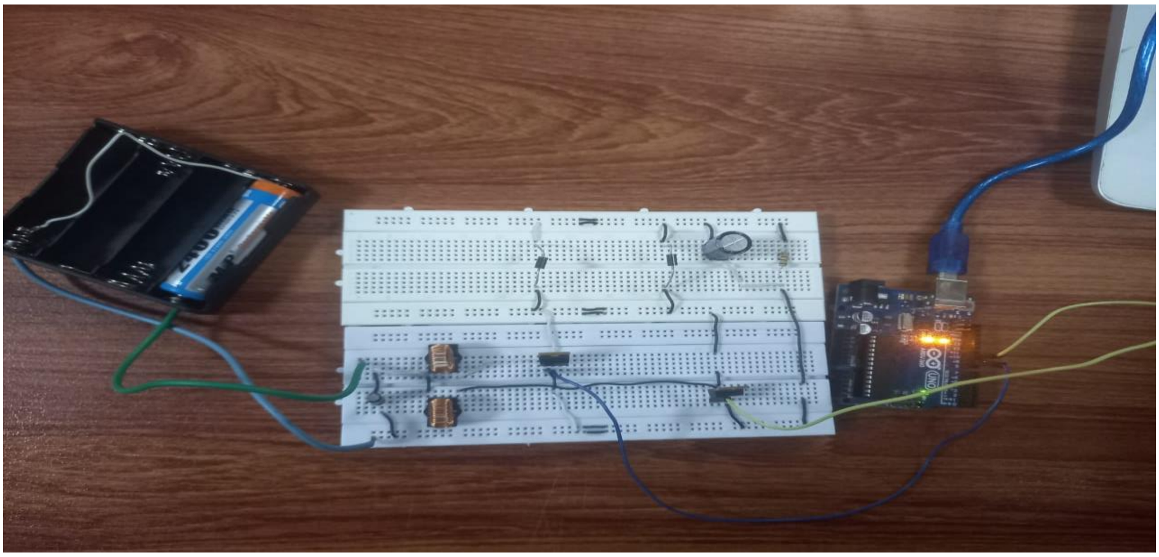

Figure 21: Boost Converter prototype

4.2 Inverter

A sine wave is generated in the microcontroller and superimposed on a triangular wave in the SPWM principle. This produces a square wave, which is then supplied into the inverter. The duty cycles of the pulse can be changed to modify the breadth of this square wave.

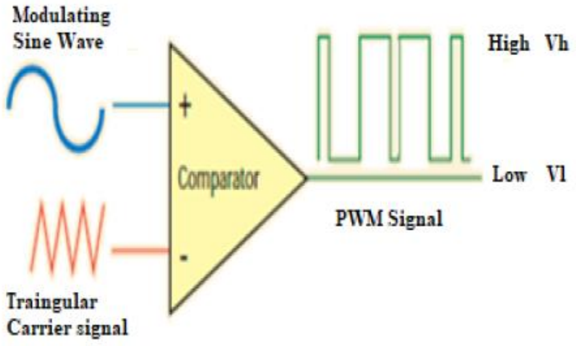

Figure 22: Block Diagram of SPWM

The PWM-generated square wave is then fed into the inverter portion. MOSFETs are semi-conductor switches found in this section. Because of their fast-switching speeds and high voltage and current ratings, these MOSFETs are ideal for variable frequency drives. These MOSFETs are coupled in an H-bridge configuration in the inverter portion. These MOSFETs are powered by two PWMs, one normal and the other complementary. This is because we must first excite the first and fourth MOSFETs, which will result in a clockwise rising waveform. The complement of the PWM is employed to generate an anti-clockwise waveform increase, resulting in a complete cycle of the waveform. Simultaneous switching of any leg in a three-phase inverter is not possible since it will generate a short circuit, and similarly, inverter legs cannot be switched off simultaneously to avoid undefined line voltages and states. Because the pulse width of this square waveform is adjusted by the microcontroller at a very high switching speed, when it is applied at load, it approximates a sine wave. The load's inductance also aids in the shaping of this waveform into a sine wave. Inverters and PWM are used to get the desired result.

4.2.1 Simulations

MATLAB Simulations

SPWM Based three phase inverter implemented in MATLAB’s GUI known as Simulink. One the left hand side of the figure, is the control circuitry of SPWM inverter. It compares a triangular carrier wave with three sine waves having phase difference of 120 degrees with each other. On the right hand side, is the actual circuit having six switches, two in each leg operating alternatively.

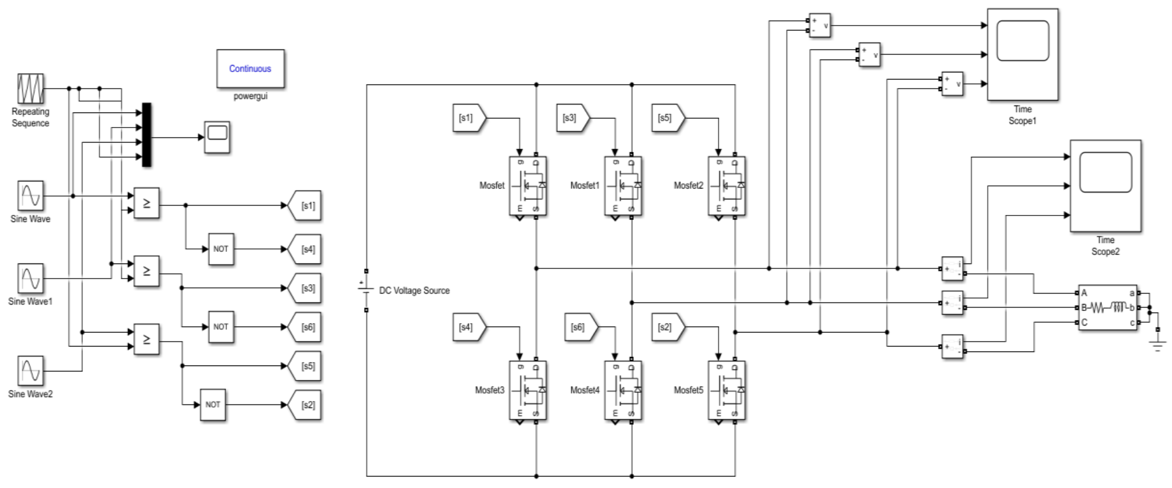

Figure 23: Simulink Model of Inverter

The graph below shows the output voltage. The voltage is a step size sine wave with a value of 400V. It is 120 degrees out of phase with each other. On the y-axis, we have voltage and on the x-axis, we have the time.

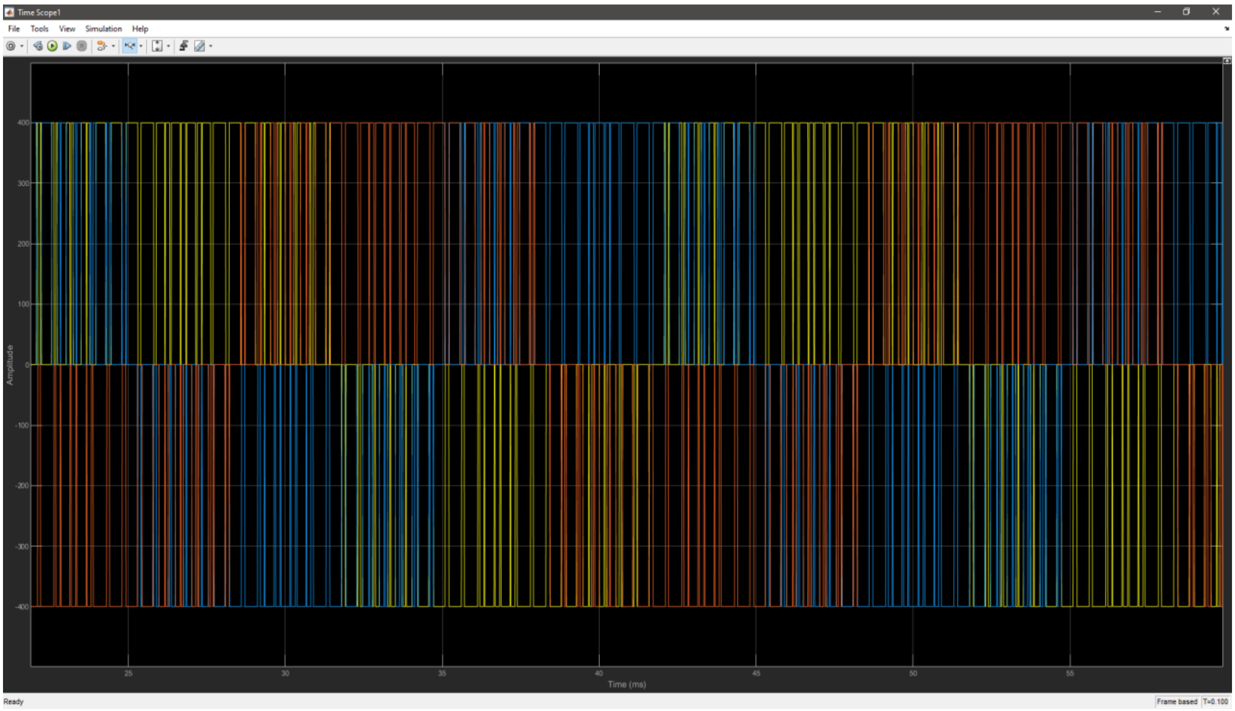

Figure 24: Output Voltage of Inverter

The graph below shows the output current, and it is 120 degrees out of phase. On the y-axis, we have current amplitude, and, on the x-axis, we have the time.

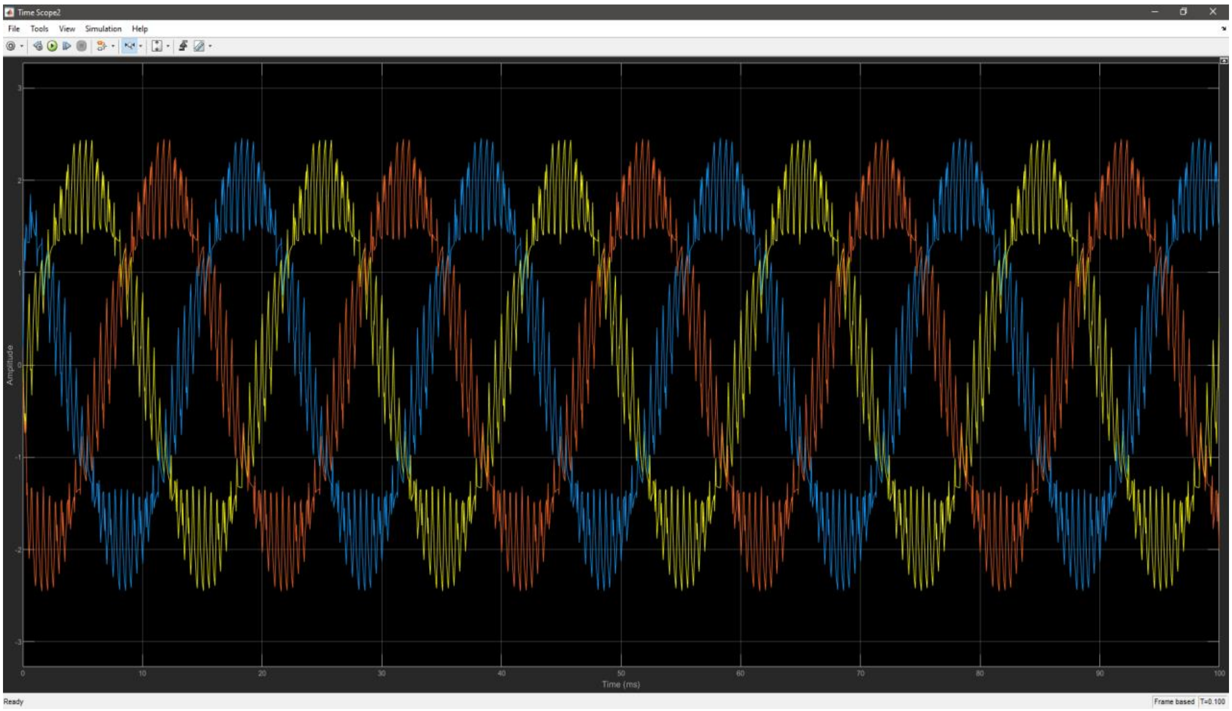

Figure 25: Output Current of Inverter

Power Sim Simulations

We have also implemented inverter in Power Sim. You can see from figure that snubber circuit is also added with MOSFETs.

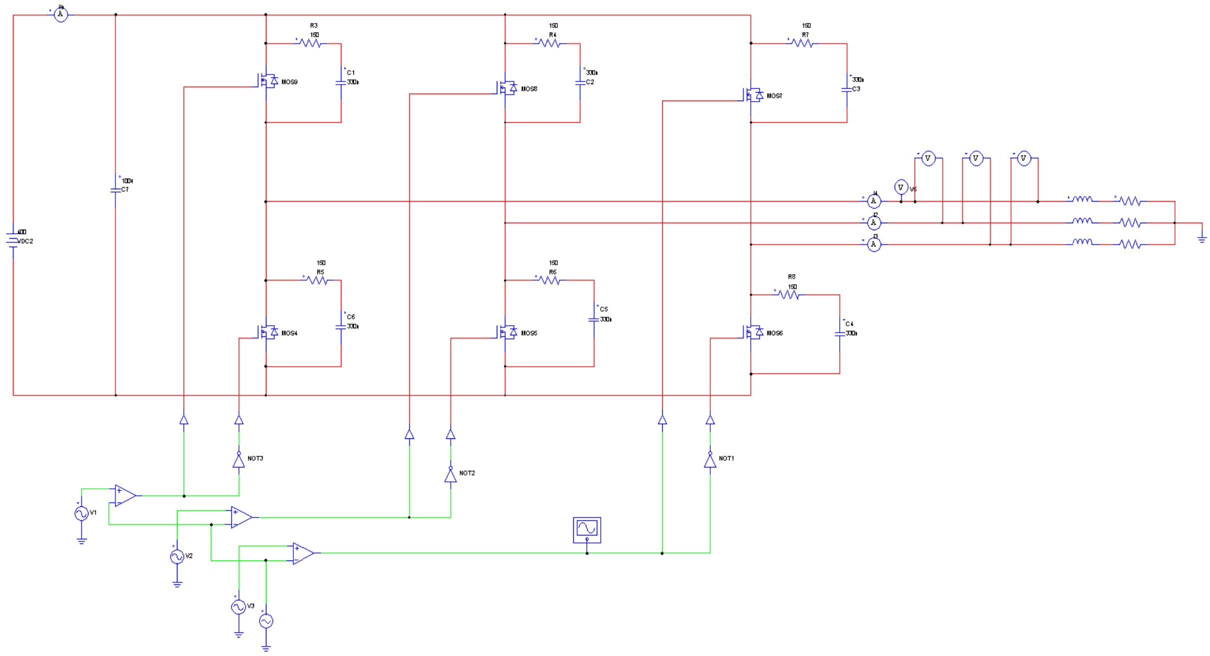

Figure 26: Power Sim Model of Inverter

The graph below shows the output voltage. The voltage is a step size sine wave with a value of

400V. It is 120 degrees out of phase with each other. On the y-axis, we have voltage and on the x-axis, we have the time. First picture is the cumulative picture, while the second one is separation of the three voltages

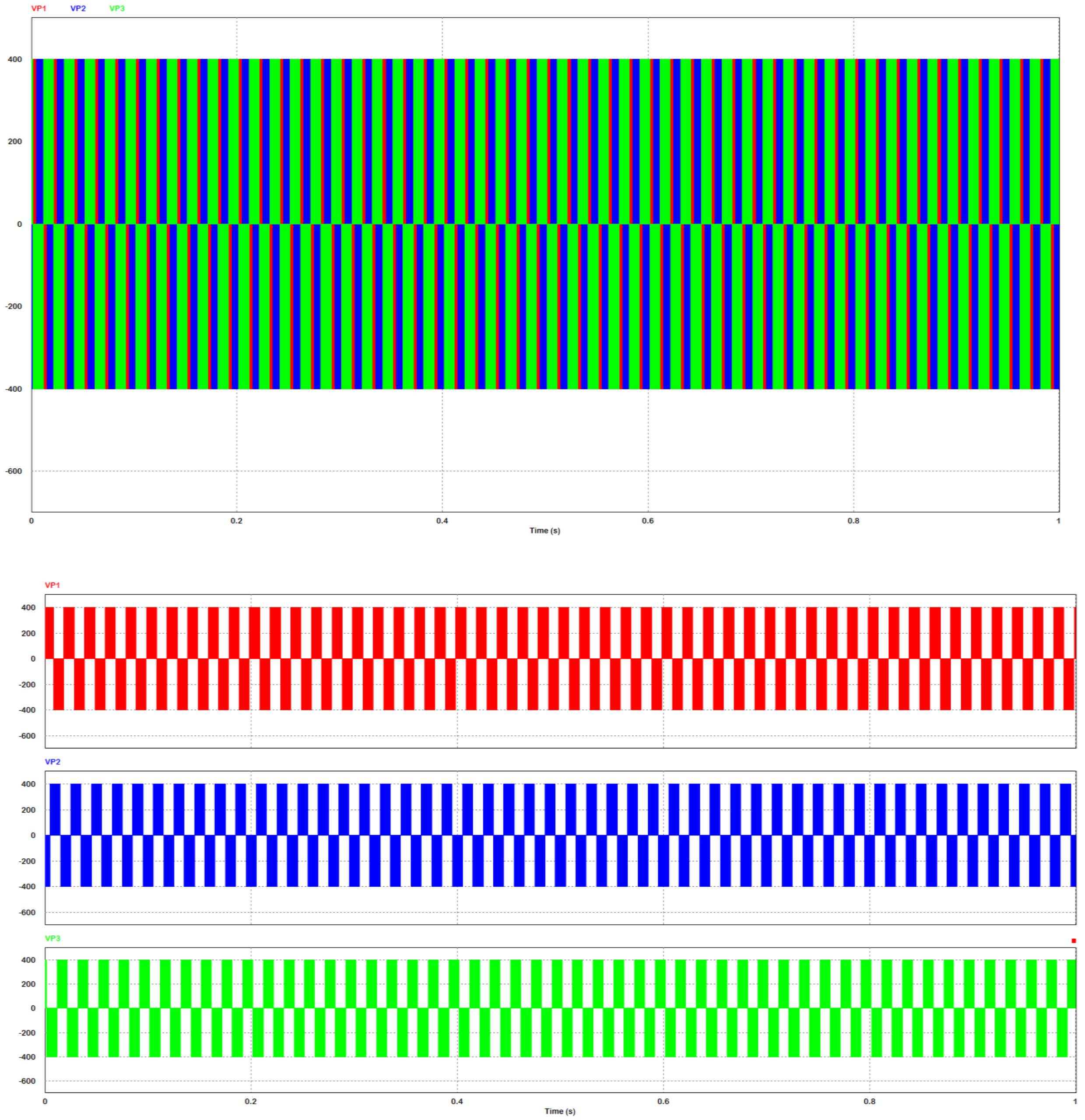

Figure 27: Output Voltage of Inverter a) combined b) separated

If we zoom in the voltage, we get a figure something like the one shown below:

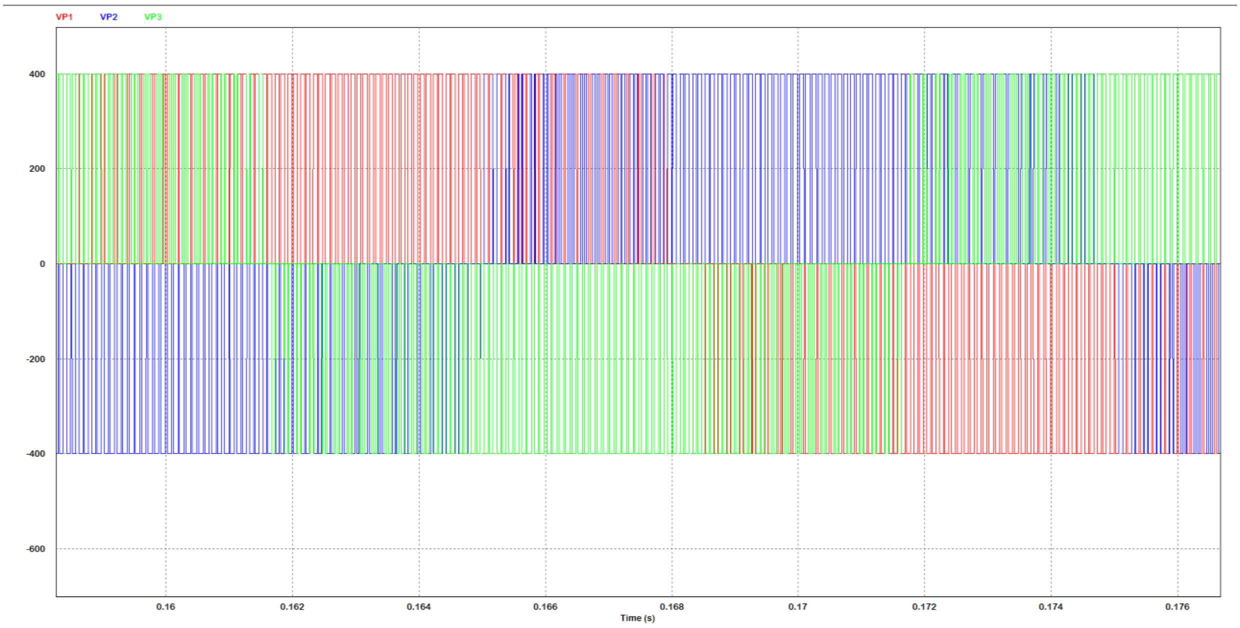

Figure 28: Zoomed In View of Inverter Voltage

The graph below shows the output current and it is 120 degrees out of phase. On the y-axis, we have current amplitude and on the x-axis, we have the time.

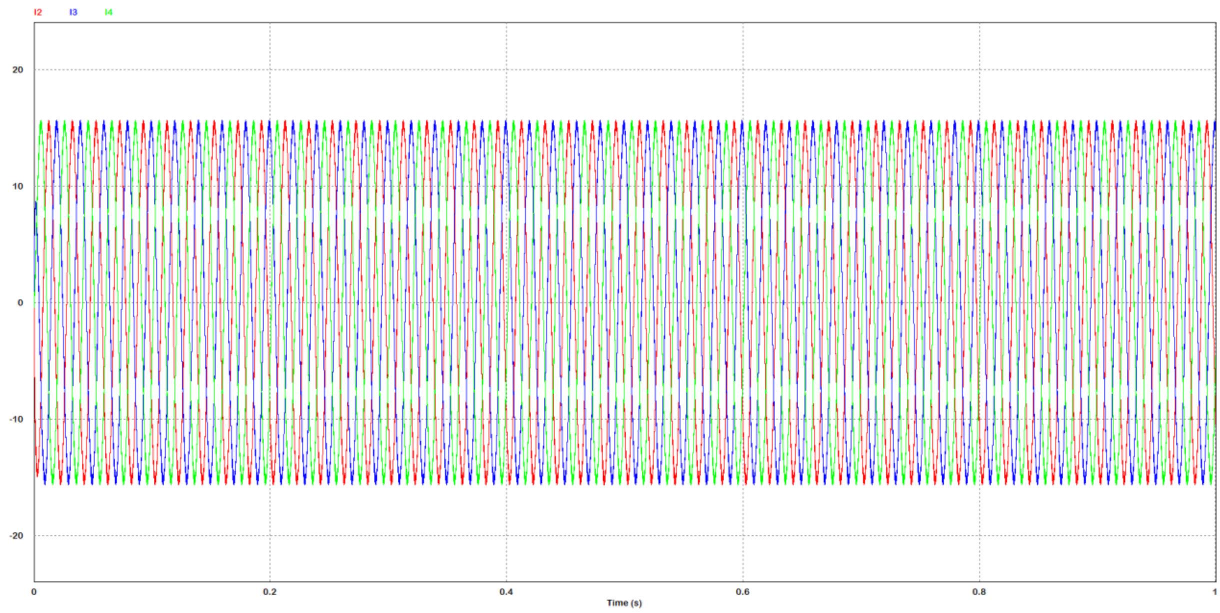

Figure 29: Output Current of Inverter

If we zoom in the voltage, we get a figure something like the one shown below:

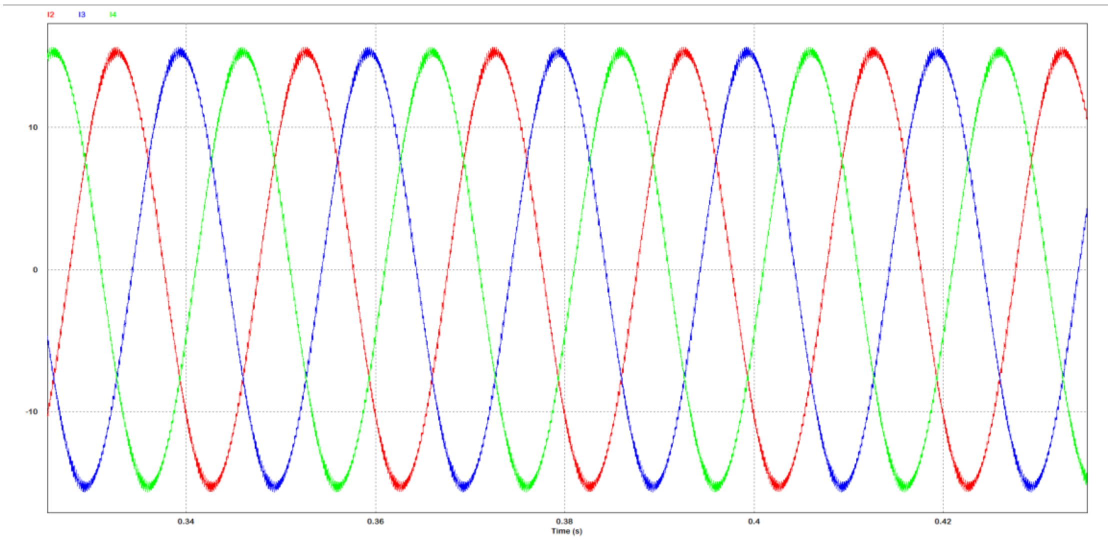

Figure 30: Zoomed In View of Inverter Current

4.2.2 PCB Designing and Implementation

Due to lack availability of component we have to move towards alternative components.

MOSFET	20N60
Gate Driver IC	IR2112
Capacitor	30nF
Resistor	150 ohms

Circuit design of inverter is below. Design is made on proteus.

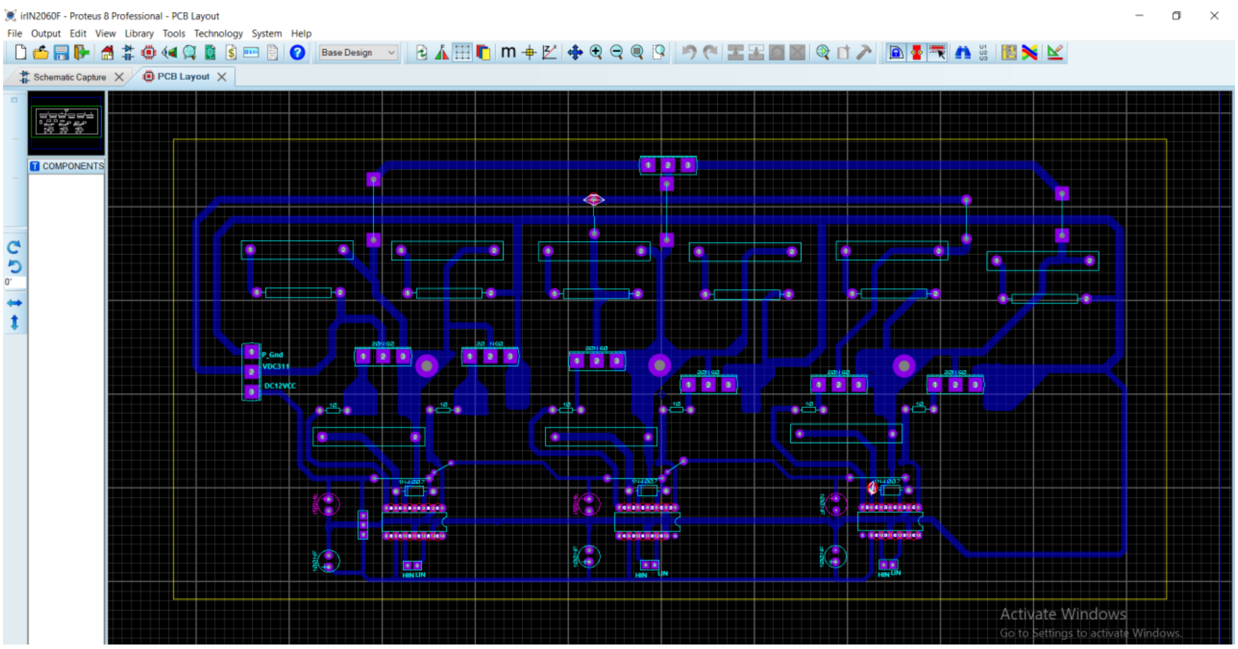

Figure 31: Inverter PCB Design

PCB Hardware

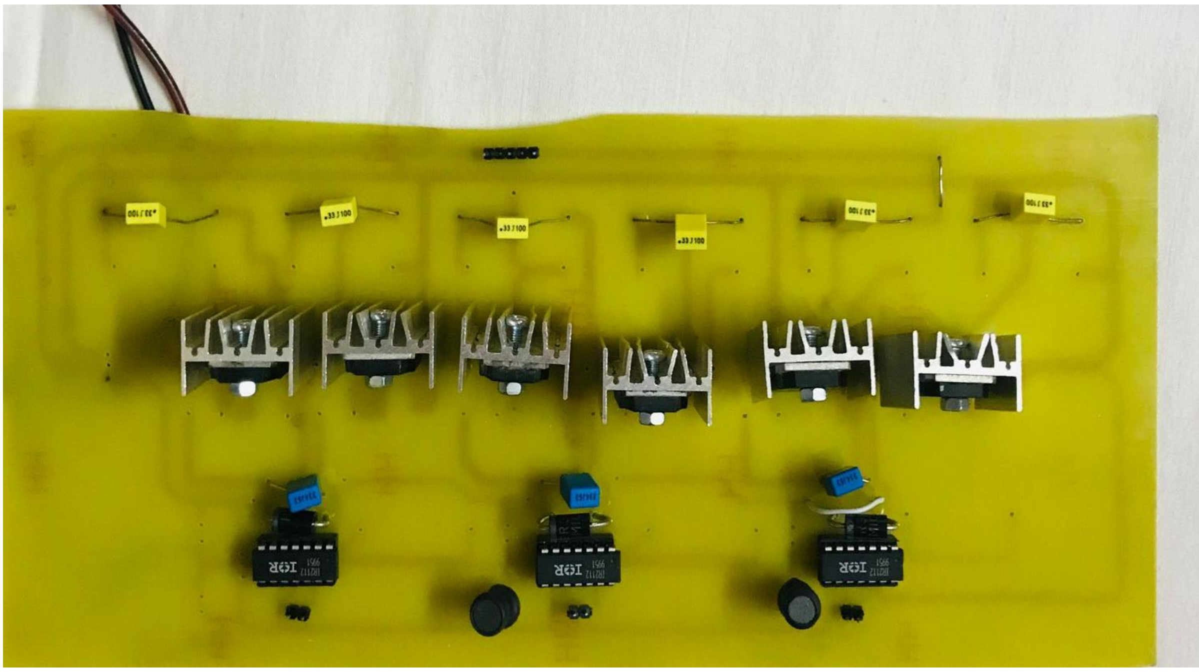

Figure 32a: Printed PCB front

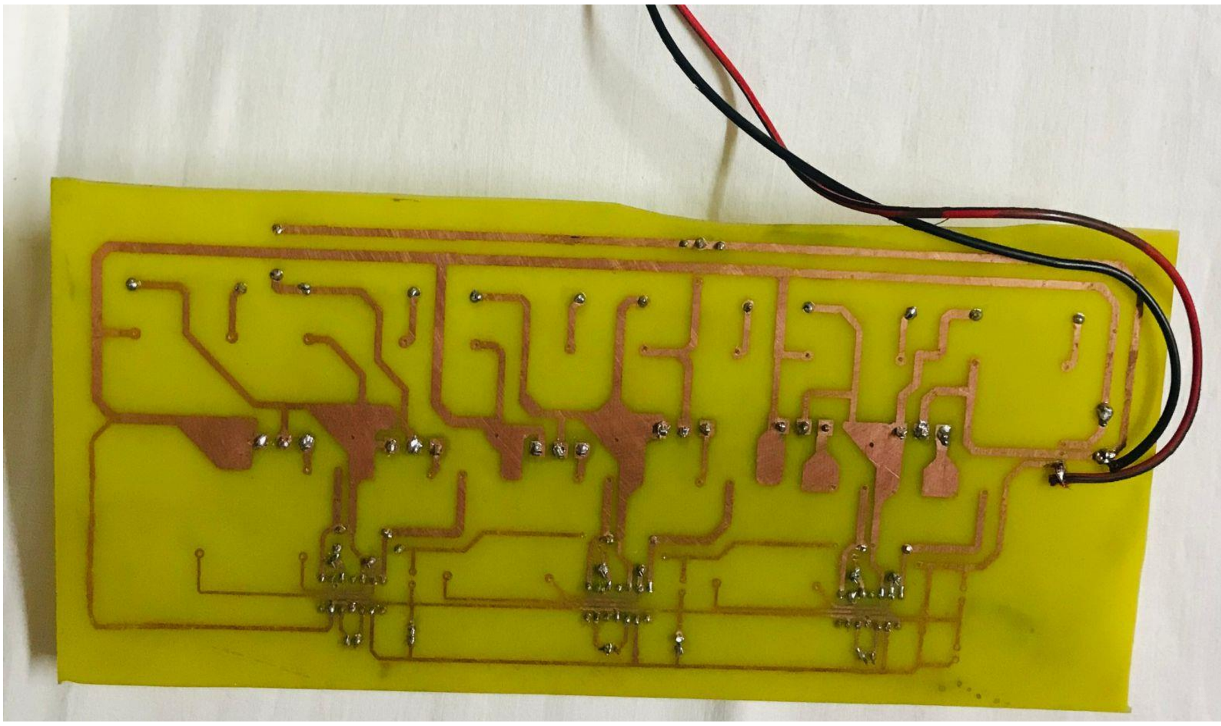

Figure 32b: Printed PCB tracing

4.3 PI Controller

The Proportional & Integration (PI) controller helps to reduce the oscillation on the output side voltage. The goal of PI controllers is to reduce steady-state error. Because the proportional-integral-derivative (PID) controller has noise in the derivative parameter, the proportional-integral (PI) controller will solve the problem of oscillations on the output side. Feedback signal is generated using voltage divider method. The PI controller is attached to the boost converter as feedback to guarantee that the voltage remains constant.

PI controller is implemented on TI Launchpad kit F28379D Delfino board. ADC is used for input voltage detection. PI module is used. Three PWM generator are used each with specific delay as the signal are 120° phase delay with each other. The Digital output is used for giving output from Delfino board.

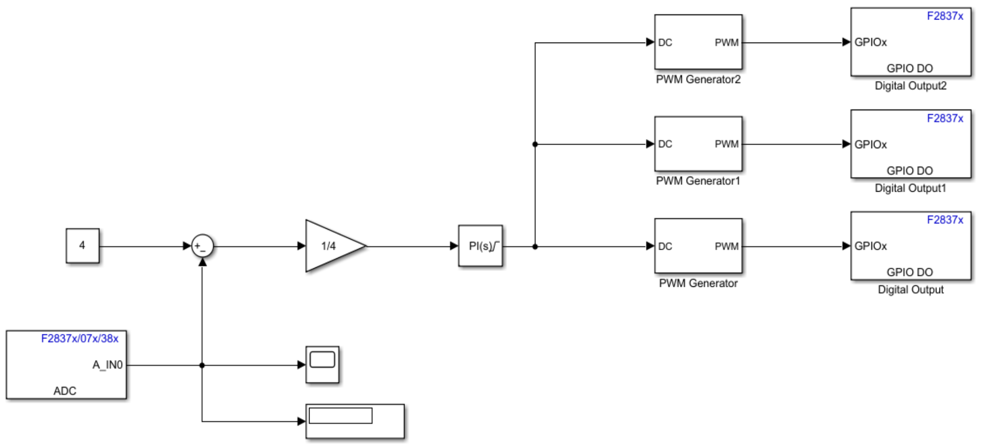

Figure 33: PI Controller

Controller input to MOSFET at early stage when the output is increasing to level of 400V the graph clearly shows the duty cycle is at maximum.

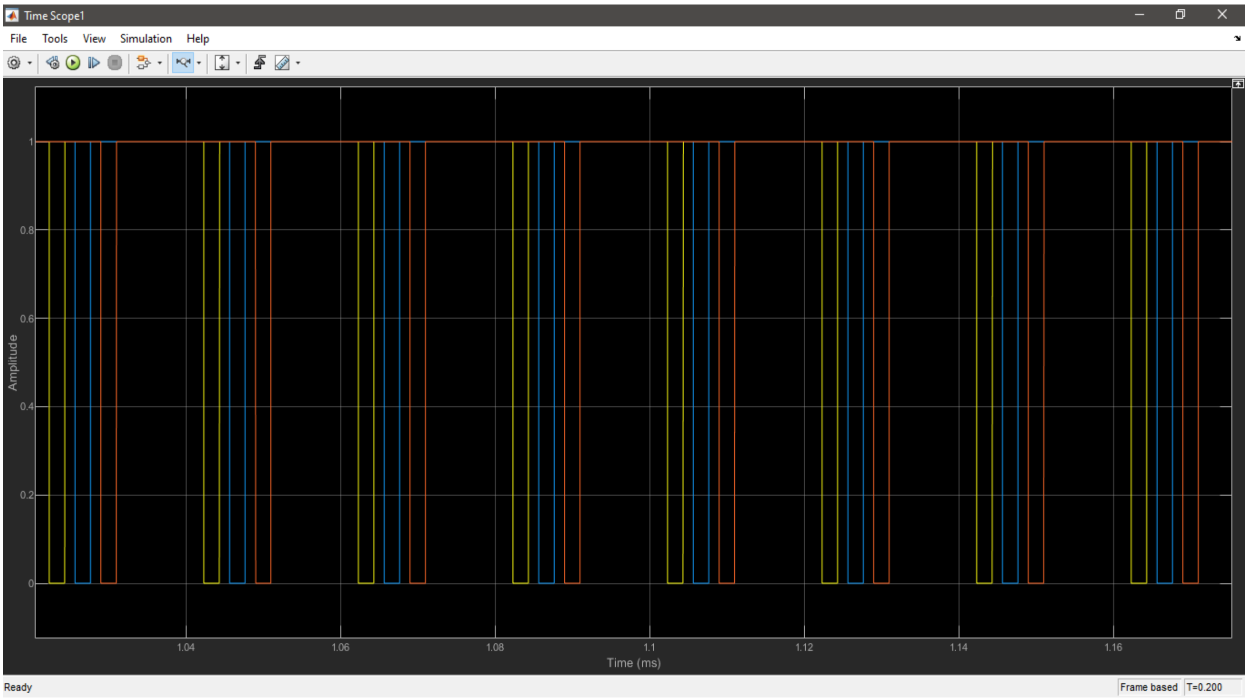

Figure 34: PI Controller MOSFET Input (starting)

Controller input to MOSFET when voltage become stable to 400V. The duty cycle is decreased to its minimum because the required level is reached.

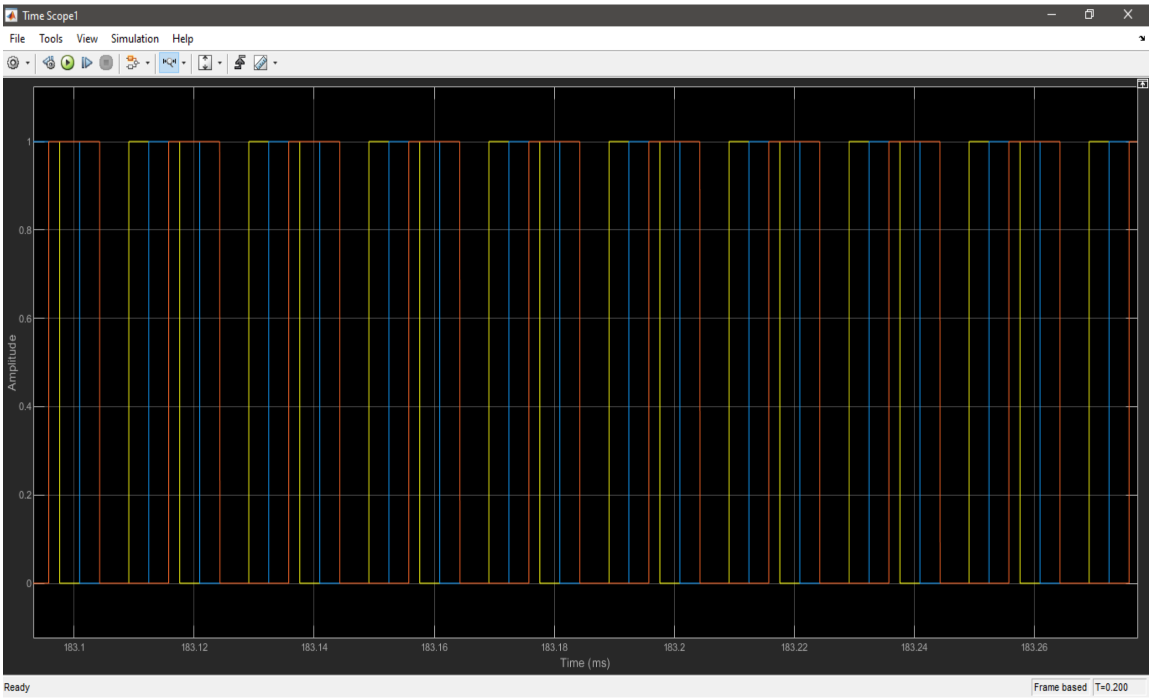

Figure 35: PI Controller MOSFET Input (stable voltage)

4.4 SPWM Controller

SPWM controller model which is implemented on TI Launchpad kit F28379D Delfino board.

(explain component)

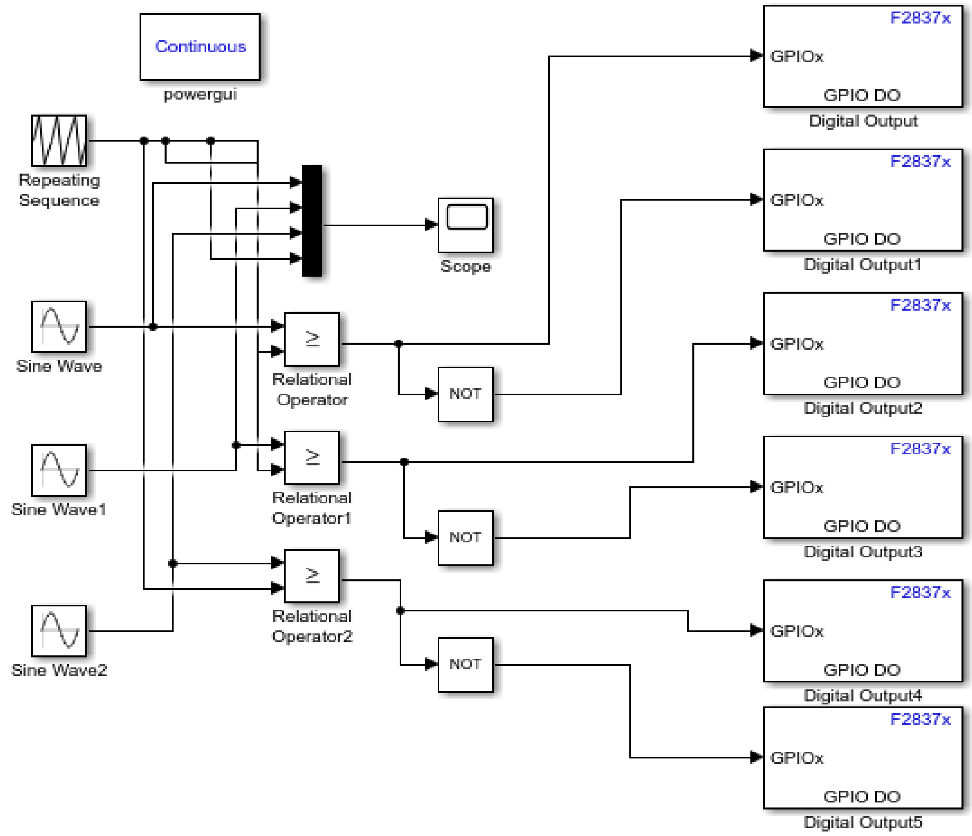

Figure 36: SPWM Controller

SPWM output control signal each with 120 degrees phase difference.

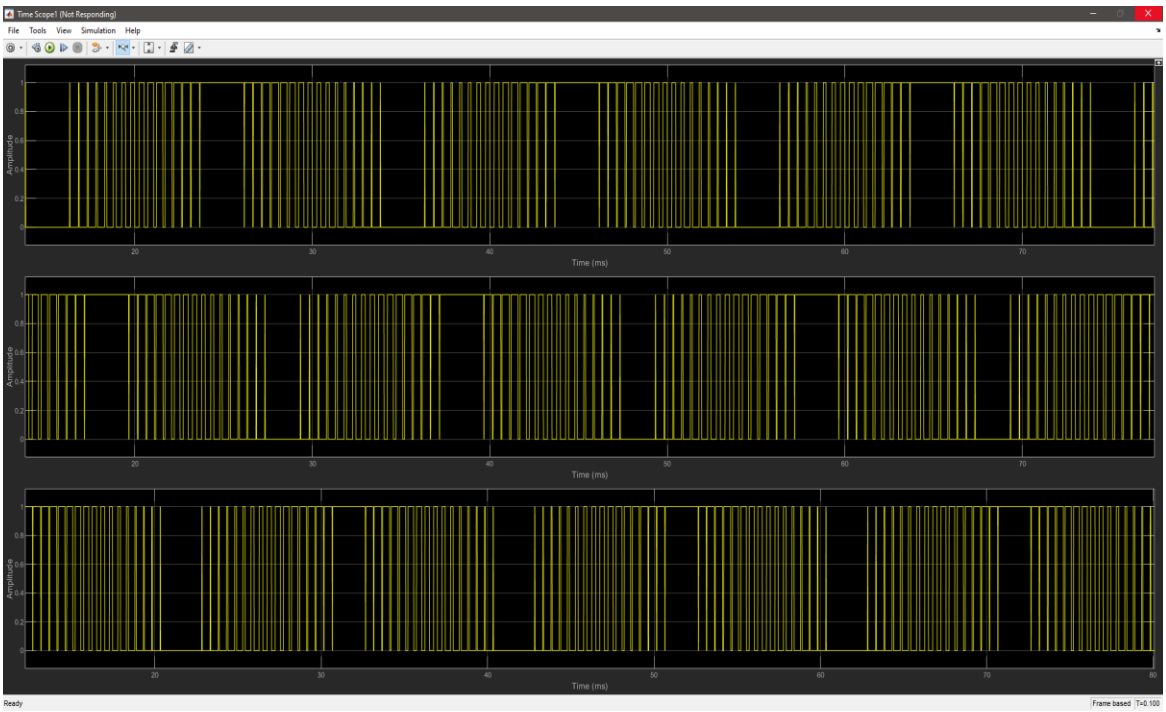

Figure 37: SPWM Waves

SPWM output control signal each with phase difference shown in single graph

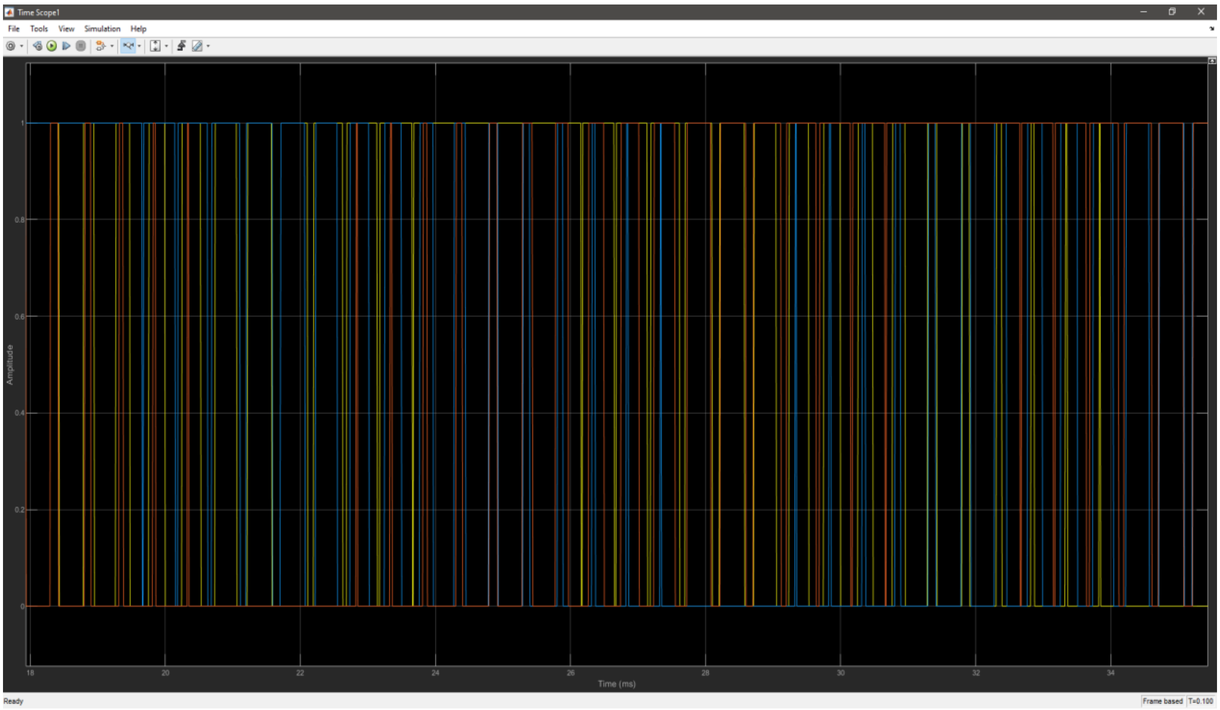

Figure 38: SPWM output control signal

All the six signal of SPWM inverter

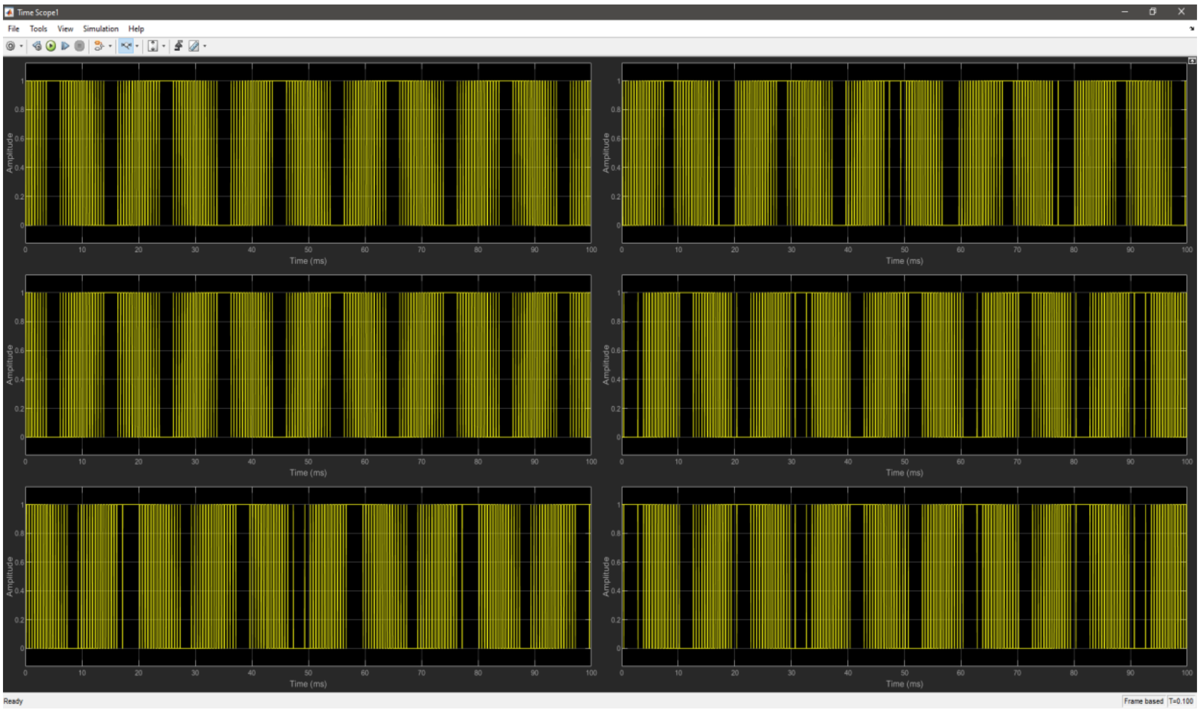

Figure 39: Six pulses of SPWM

Chapter 5: CONCLUSION AND FUTURE WORK RECOMMENDATIONS

Here are a few recommendations for anyone who wants to build upon our work on the problem

5.1 Future Extension

People and organizations are putting up fresh researches as technology advances swiftly. Emerging technologies such as FPGAs, DSP advancements, genetic algorithms, fuzzy logic, creative PWM approaches, and a revolution in the field of power electronics can lead to the experience of any amazing device. NANO technology can also be used to miniaturize VFDs. This smaller type of VFD would be extremely useful in small devices, allowing for energy savings on a small scale. The main goal of the project is to lay down the fundamental hardware for electric car. The design of interleaved boost converter and three phase inverter is designed for this purpose and by modifying the control of SPWM inverter we can design the fully functional mechanism of Electric Car.

5.1.1 Boost Converter

The Boost Converter designed will best work for any voltage rating the only thing we have to modify is the number of stages of Voltage multiplier. The Motor used in Electric Vehicle are of very high horsepower, so they require high voltage. The increase current will result in more phases so that the current is distributed among the components and there is not too much load on individual component.

The component used in Circuit will be modified and we must use vary high voltage MOSFET and if the voltage exceeds above 1000V than IGBT must be used. The circuit analysis will be made for high voltage calculation and value must be modified to get required voltage.

Voltage on output side must be detected using Hall effect voltage sensor or by Mors Smith closed loop voltage sensor because they have high accuracy and precision. Voltage divider circuit lack accuracy and precision, so it is not preferable in high voltage circuitry. The controller design implemented is a PI controller which is effective but not 100% accurate so to get best result we should move towards Nonlinear controller and must design a nonlinear controller for the circuit.

5.1.2 Inverter

The design of SPWM inverter is very effective and if the motor is of very high voltage than IGBT must be used for switching. We can improve output voltage and make it pure sinusoidal using Filter circuit. There are various type filters such as LC filter circuit are used at output for getting specific voltage.

The main improvements which can be made are in control logic of the circuit we can add multiple customized features to make the control circuit a fully functional model of Electric vehicle. Delfino board has many advanced capabilities which can be explored using SIMULINK. Space vector pulse width Modulation (SVPWM) can also be used to make the system efficient as it is growing configuration and readily used in many systems.

This whole control logic can also be designed using FPGA on which we can design our own control circuitry and by making ASIC we can mass manufactured towards making full electric car hardware.

5.2 Applications

Variable Frequency Drive have many wide ranges of applications and it is used in almost all the industries. The one of the most common applications is Electric Vehicle which is currently used by various Electric car manufacturers such as Tesla, BMW etc. Variable frequency drive is also used boilers, conveyer belts, air conditioners etc. It is used to control speed of blower, pump speed.

Devices are used nowadays by farmers to run their electric water pumping motor for solar energy. The mechanism is very efficient and cost effective.

5.3 Impact

The technological advancements for hardware in the past decade have been complement with an equal advancement in software that run such systems. In many cases that require small form factors we have reached a point where the hardware is way more advance than the software. Companies like TESLA and Apple have been rolling out their product in the market and their software updates follow the hardware launches. This has proven to be a successful model. Our algorithm, if implemented will be one of such leaps where a software enhancement will add a valuable feature to the products that will make a use of it. This is not only an economical solution as it requires no additional hardware, it is an efficient and effective one as well. Furthermore, it does not employ the use of fuzzy logic techniques such as Machine Learning but rather uses pure mathematical concepts to tackle a problem that has yet not been solved.

5.3 Conclusion

As we can see from the preceding explanation and findings, indigenously build variable frequency drives are the best answer for resolving inherent motor difficulties, placing in electric vehicles and solar pumps and they are also the best solution for energy savings. Other systems, such as soft starters, do not perform as well as variable frequency drive, which has a number of advantages, including the ability to manage motor starting and stopping. We believe that in a country like

Pakistan, this device would be very useful because we have a strong desire to reduce energy consumption, and that VFDs should be employed with HVAC systems in enterprises and household appliances. Similarly, EV industry also has a potential to grow in Pakistan due to its large consumer market. As we already know that local production of EVs has been started in our country, these indigenously build VFDs will be quite essential for these vehicles.

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DC–DC Converters With Coupled Inductor and Voltage Multipliers Techniques," in IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 67, no. 6, pp. 2140-2151, June 2020, doi: 10.1109/TCSI.2020.2973154.

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Appendix A – Glossary

IGBT	Insulated Gate-Bipolar Transistor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PWM	Pulse Width Modulation
SPWM	Sinusoidal Pulse Width Modulation
VFD	Variable Frequency Drive
FPGA	Field Programmable Gate Array
EV	Electric Vehicle
PI	Proportional Integral
MATLAB	Matrix Laboratory
DC	Direct Current
AC	Alternating Current
ASIC	Application Specific Integrated Circuit
PCB	Printed Circuit Board
SVPWM	Space Vector Pulse Width Modulation