

SINLGE PHASE TRANSFORMER-LESS GRID TIED INVERTER FOR PHOTOVOLTAICS APPLICATION

A Thesis Submitted
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**Summer Semester 2015-2016,
August, 2016**



American International University - Bangladesh

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A thesis submitted to the Electrical and Electronic Engineering Department of the Engineering Faculty, American International University - Bangladesh (AIUB) in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering.

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DECLARATION

This is to certify that this thesis is our original work. No part of this work has been submitted elsewhere partially or fully for the award of any other degree or diploma. Any material reproduced in this project has been properly acknowledged.

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APPROVAL

The Thesis titled “**SINLGE PHASE TRANSFORMER-LESS GRID TIED INVERTER FOR PV APPLICATION**” has been submitted to the following respected members of the Board of Examiners of the Faculty of Engineering in partial fulfillment of the requirements for the **degree of Bachelor of Electrical and Electronic Engineering** on **August, 2016** by the following students and has been accepted as satisfactory.

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TABLE OF CONTENTS

DECLARATION	I
APPROVAL.....	II
ACKNOWLEDGEMENT	III
LIST OF FIGURES	VII
LIST OF TABLES.....	IX
ABSTRACT.....	X
CHAPTER 1	1
INTRODUCTION.....	1
1.1. Introduction	1
1.2. Historical Background	2
1.2.1. Earlier Research.....	2
1.2.2. Recent Research	3
1.3. Objective of this Work	3
1.3.1. Primary Objective.....	3
1.3.2. Secondary Objectives	3
1.4. Advantage over Traditional Method.....	4
1.5. Limitation of the Study.....	4
1.5.1. PID controller limitation.....	4
1.5.2. Limitation of Inverter	4
1.6. Introduction to this Thesis	5
1.7. Summary.....	5
CHAPTER 2	6
LITERATURE REVIEW.....	6
2.1. Introduction	6
2.2. Grid connected and off grid PV system.....	6
2.2.1. Grid connected system	6
2.2.2. Off grid system	7
2.3. PV array	8
2.4. Switching.....	10
2.4.1. Switch Types	10
2.4.1.1. Vibrator Switch	11
2.4.1.2. Silicon Controlled Rectifier Switches (SCR's).....	11
2.4.1.3. Metal Oxide Semiconductor Field Effect Transistor (MOSFET's)	11
2.4.1.4. Insulated Gate Bipolar Transistor (IGBT).....	12
2.5. DC-DC Converter.....	12
2.5.1. Step-down (Buck) converter:.....	12
2.5.2. Step-up (boost) converter	14
2.5.3. Buck-boost converter.....	16
2.5.4. CUK Converter.....	17

2.6.	PULSE WIDTH MODULATION.....	18
2.6.1.	PULSE WIDTH MODULATION TECHNIQUE.....	19
2.6.2.	TYPES OF PULSE WIDTH MODULATION TECHNIQUES	19
2.7.	Gate Driver Circuit	20
2.8.	Grid tied photovoltaic Inverter	21
2.8.1.	Classification of grid-tied inverter.....	21
2.8.1.1.	Central inverter	22
2.8.1.2.	String inverter	22
2.8.1.3.	Multi-string inverter	23
2.8.1.4.	Module integrated inverter	24
2.9.	Transformer less and Transformer base inverter technology	25
2.10.	Arduino	26
2.11.	Summary.....	26
CHAPTER 3		27
DESIGN AND IMPLEMENTATION.....		27
3.1.	Introduction	27
3.2.	Boost converter Design	27
3.2.1.	Converter Specification	27
3.2.2.	Continuous conduction mode	28
3.3.	PID controller Design	30
3.4.	Gate Driver Design	32
3.5.	Inverter Design	34
3.6.	Hardware Implementation	36
3.6.1.	PWM signal	36
3.6.2.	PID controller	37
3.6.3.	Gate driver	38
3.6.4.	Total System.....	39
3.7.	Summary.....	39
CHAPTER 4		40
RESULTS AND ANALYSIS.....		40
4.1.	Introduction	40
4.2.	Simulation.....	40
4.2.1.	Simulation circuit of the Boost converter including the PID controller	40
4.2.2.	Output results.....	41
4.2.3.	Simulation circuit of the whole system	42
4.2.4.	Output Results	43
4.3.	Implementation Results	44
4.4.	Analysis	45
4.5.	Summary.....	45
CHAPTER 5		46
DISCUSSIONS AND CONCLUSIONS.....		46
5.1.	Discussions	46

5.2. Future Work.....	46
5.2.1. Suggestions for future work	46
5.3. Conclusions	47
REFERENCES	48
APPENDIX A	50

LIST OF FIGURES

FIGURE 1.1: BLOCK DIAGRAM OF PROPOSED GRID-TIED SYSTEM FOR PV APPLICATION....	2
FIGURE 2.1: GRID-TIED SYSTEM.....	7
FIGURE 2.2: OFF-GRID/ STAND-ALONE ENERGY SYSTEM	7
FIGURE 2.3: SOLAR CELL OPERATION	8
FIGURE 2.4: SOLAR CELL, MODULE, PANEL AND ARRAY	9
FIGURE 2.5: DIODE EQUIVALENT CIRCUIT OF SOLAR CELL.....	9
FIGURE 2.6: BUCK CONVERTER.....	13
FIGURE 2.7: WAVEFORM OF BUCK CONVERTER	14
FIGURE 2.8: BOOST CONVERTER.....	14
FIGURE 2.9: WAVEFORM OF BOOST CONVERTER	15
FIGURE 2.10: CIRCUIT DIAGRAM OF BUCK-BOOST CONVERTER	16
FIGURE 2.11: WAVEFORMS OF BUCK-BOOST CONVERTER.....	17
FIGURE 2.12: CUK CONVERTER CIRCUIT DIAGRAM	17
FIGURE 2.13: WAVEFORM OF CUK CONVERTER	18
FIGURE 2.14: SYMMETRIC AND ASYMMETRIC PWM SIGNALS	19
FIGURE 2.15: FUNCTIONAL BLOCK DIAGRAM OF IR2110 IC.....	20
FIGURE 2.16: PIN CONFIGURATION OF IR2110 IC.....	21
FIGURE 2.17: FULL FORMS OF THE PIN CONFIGURATION OF IR2110	21
FIGURE 2.18: CENTRAL INVERTER SYSTEM.....	22
FIGURE 2.19: STRING INVERTER WITH BOOST CONVERTER AND PV SYSTEM.....	23

FIGURE 2.20: MULTI-STRING PV SYSTEM.....	24
FIGURE 2.21: MODULE INTEGRATED INVERTER.....	25
FIGURE 2.22: ARDUINO CIRCUIT BOARD.....	26
FIGURE 3.1: SCHEMATIC OF BOOST CONVERTER.....	28
FIGURE 3.2 (A) (B): EQUIVALENT CIRCUIT FOR BOOST CONVERTER IN CCM.....	29
FIGURE 3.3: BASIC BLOCK DIAGRAM OF PID CONTROLLER.....	30
FIGURE 3.4: CIRCUIT DIAGRAM OF THE GATE DRIVER	32
FIGURE 3.5: 3D PCB LAYOUT DESIGN	33
FIGURE 3.6: 3D VIEW OF PROTEUS DESIGN	33
FIGURE 3.7: DESIGN OF THE INVERTER.....	34
FIGURE 3.8: TIMING DIAGRAM FOR 120° CONDUCTION MODE	35
FIGURE 3.9: THE SETUP SHOWING THE GENERATION OF PWM SIGNAL	36
FIGURE 3.10: THE SETUP SHOWING THE PID CONTROLLER	37
FIGURE 3.10: 3D VIEW OF THE PROTEUS DESIGN	37
FIGURE 3.11: THE IMPLEMENTATION OF GATE DRIVER CIRCUIT	38
FIGURE 3.13: THE TOTAL SETUP OF THE INVERTER	39
FIGURE 4.1: SIMULATION OF BOOST CONVERTER WITH PV ARRAYS.....	40
FIGURE 4.2: OUTPUT VOLTAGE OF PV ARRAYS.....	41
FIGURE 4.3: OUTPUT VOLTAGE FROM THE BOOST CONVERTER	41
FIGURE 4.4: SIMULATION OF THE OVERALL SYSTEM WITH THE INVERTER.....	42
FIGURE 4.5: LINE TO NEUTRAL VOLTAGE AT THE OUTPUT OF INVERTER.	43

FIGURE 4.6: LINE TO LINE VOLTAGE AT THE OUTPUT OF INVERTER.....	43
FIGURE 4.7: OUTPUT FROM THE PID CONTROLLER	44
FIGURE 4.8: OUTPUT RESULT OF GATE DRIVER CIRCUIT	44
FIGURE 4.9: OUTPUT RESULT OF THE LINE TO NEUTRAL FROM THE INVERTER	45
FIGURE 5.1 ARDUINO SOFTWARE	50
FIGURE 5.2: ARDUINO UNO PIN DIAGRAM [22].....	51

LIST OF TABLES

TABLE 2.1: COMPARISON OF TRANSFORMER-LESS AND TRANSFORMER BASE INVERTER FOR GRID TIED PV SYSTEM.....	29
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ABSTRACT

Transformer-less grid tied inverter for photo voltaic (PV) is a relatively new concept that may be used in many applications. The goal of this work is to design an efficient method for the conversion of solar energy to electrical energy and supply it to the grid. The proposed topology utilizes a PV array, a boost converter, a gate driver circuit and a multilevel inverter. For gate drive circuit of inverter, a PWM technique under grid synchronization form is used. Simulation and coding has been conducted in “MATLAB/SIMULINK” and “Arduino 1.6.9” platform respectively where both simulated and implemented circuit showed desired satisfactory results.

Chapter 1

Introduction

1.1. Introduction

Fossil fuels such as oil or natural gas along with some non-commercial fuels are considered as the main resources around the world. According to the U.S. Energy Information Administration in the International Energy Outlook 2009 it is predicted that the global electricity generation will increase from 18 trillion kWh in 2006 to 23.2 trillion kWh in 2016 and will further increase to 31.8 trillion kWh for the next 5 years [1]. With its increasing demand, the search for energy resources other than fossil fuels has become momentous. Solar, wind and hydro are renewable energy sources that are seen as reliable alternatives to this conventional energy sources. This alternatives also eliminates the emission of harmful carbon dioxide and other greenhouse gases, unfavorable to the environment. Thus, few countries around the world aims to achieve 20% of total generated electricity from renewable energy sources by the year 2020. This is believed to be accomplished through grid-connected wind farms and solar photo-voltaic (PV) systems [2].

The utmost fact about the installation of PV panel for large scale application is the significant cost of battery. Several studies found that battery costs almost 50% budget of a PV project. Moreover battery needs frequent maintenance. Our project aims to eliminate the use of battery and also transformer for step up-down operation which will ultimately save a significant cost.

Our project explores the use of several components:

- A PV array for the conversion of solar energy to electrical.
- A Boost Converter to boost up the voltage from the PV arrays to a fixed voltage.
- A PID controller the fix the output voltage of the Boost converter.
- A multi-level DC-AC inverter to obtain AC voltage.
- A PWM signal control to provide gate pulse to the inverter

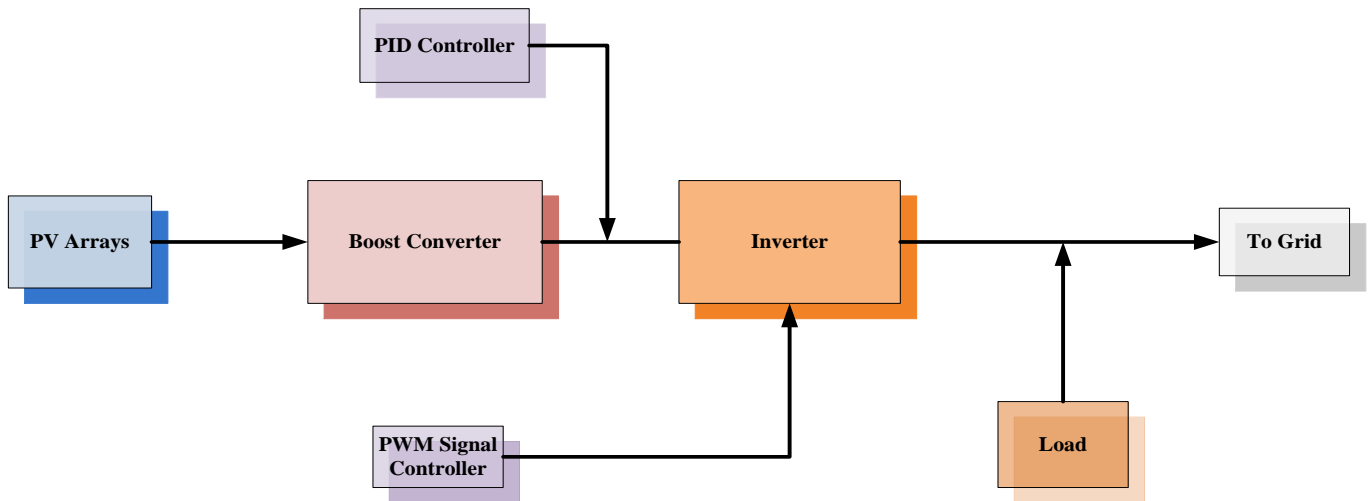


Figure1.1: Block diagram of proposed grid-tied system for PV application

1.2. Historical Background

We are in the midst of prompt evolution in electrification strategies within developing market around the world. Grid-tied inverters are the key components of distributed generation system because of their several functions as an effective consolidate between renewable energy sources and utility. Assimilation of PV power generation scheme in the grid plays an important role in securing the electric power supply in an environment friendly manner. Grid connected PV-inverters are needed to extract the energy from the PV modules and supply it into the utility grid while making sure that the power quality follows certain grid interconnection standards [3].

1.2.1. Earlier Research

With the rapid growth of worldwide economic, the demand of the electricity increase tremendously. As a result, generations after generations, people are looking for new methods-simple and efficient-to meet this hunger for electricity. Grid-connected PV generation have gained popularity due to the advert of green energy or renewable energy sources [4-5]. Conventional grid connected PV inverter systems typically use transformers to step up or down voltages extracted from the converters; this make the schemes indubitably expensive. Research has been carried out earlier to exclude this transformer from the system [6]. Instead, it made the use of buck-boost type chopper circuits but it had its own limitations. This system proposed could

only be used for home appliances. This problem was resolved in further studies where grid-connectivity came into light.

1.2.2. Recent Research

As per history, low-power PV applications have limited range [5], and most past topologies of single-stage grid connected PV inverter systems have no voltage boost stage. To achieve high DC input voltage, a large number of PV module are typically connected in series. This configuration meets the target input voltage but can be subject to partial shading which in turns affect the power output level of the PV module [7]. Meanwhile, recent approaches introduced a new family of high step-up converters with switched cell circuits [8]. The converters has the ability to provide high efficiency dc-dc conversion without a transformer.

1.3. Objective of this Work

The aim of this work is to design and develop a system for rooftop PV application which will eliminate the use of battery.

1.3.1. Primary Objective

- To design a strategy for boost converter and inverter application, which is simple, reliable, low cost and high efficiency.

1.3.2. Secondary Objectives

- To simulate the whole project connecting with the grid.
- To implement the PID controller.
- To implement the gate driver circuit for gate pulse of the inverter.
- To implement the inverter.

1.4. Advantage over Traditional Method

The proposed system has many advantages over the traditional systems. Few of them are mentioned below:

- Can be installed over every house because of its simplicity and less space required.
- As the system excludes the use of battery, the maintenance cost will be less as less space will be required.
- The system is also transformer-less and thus will reduce the cost further.
- A huge amount of electricity could be provided to the grid as the output from the inverter will always be synchronized with the system.

1.5. Limitation of the Study

The objection of this thesis was to design a small scale prototype and thus the equipment ratings selected were for small scale. The goal was to implement the PID controller and the inverter circuit and hence there were few limitations corresponding with their implementations.

1.5.1. PID controller limitation

The PID controller algorithm have been developed using an Arduino Uno microcontroller board. The three tuning parameters P I D which accounted for past present and future error have been set up in such a way that when the voltage feedback from the PV array is fed into the system, the voltage sensor would sense this and adjust the voltage. Our system did not have a voltage sensor and a variable pot have been used instead and thus the tuning performance efficiency and response time have been degraded.

1.5.2. Limitation of Inverter

The inverter that has been implemented accounts only for few hundred Watts power application and thus cannot be connected to the grid. The implemented inverter only made use of a single stage level where the simulated circuit has cascaded stage.

1.6. Introduction to this Thesis

A brief overview of the principle behind the project has been discussed in this chapter. Different research works in this field has also been discussed. Objectives along with advantages of this project were discussed in details. This paper consists of 7 chapters.

Chapter 2 contains the literature review and the descriptions of different hardware components used to complete this project.

Chapter 3 contains the design and implementation of the proposed model.

Chapter 4 contains the results and analysis of the models.

Chapter 5 covers the discussion, future work and the conclusion of this project along with the summary of the whole project.

Finally reference and appendix are included at the very end.

1.7. Summary

This chapter introduces the main principles behind this project. The chapter gives the objective of the project and the motivation behind choosing this work. This chapter includes a brief description of the project overview and the block diagram of project concept. After that, different recent works were discussed. Following that, the organization of different chapters of this book was added.

Chapter 2

LITERATURE REVIEW

2.1. Introduction

As stated earlier, the basic components of grid connected photovoltaic system are PV array, boost converter, inverter and the grid. Besides, switching method is another important issue in this system as switching has significant effect on overall efficiency of the system. This chapter deals with the whole grid connected photovoltaic system. Different components, their working principle and topologies are explained. All basic PWM switching techniques are discussed. Transformer-less and transformer base systems are compared.

2.2. Grid connected and off grid PV system

In developing countries like Bangladesh, more than 50% of the total population lives in rural areas. Providing electricity from centralized energy system in rural areas is very expensive as centralized energy systems operate on fossil fuels and need huge investment. Thus, decentralized systems is the most effective solution in this regard. Moreover, a decentralized system can be operated in the presence of grid and also as an isolated or independent system.

The decentralized energy system is called grid connected or grid-tied system when operated with the grid and when operated independently it is known as a stand-alone or off grid system [9].

2.2.1. Grid connected system

Grid connected systems are ideal when locations are near the grid. Figure 2.1 shows a grid connected system where DC generated in PV array is converted into AC by power converter and then fed into the distribution panel. When the system produces more energy than demand of the site, excess energy is supplied to the grid and when site need more energy than energy produced, power grid fulfills the demand [10].

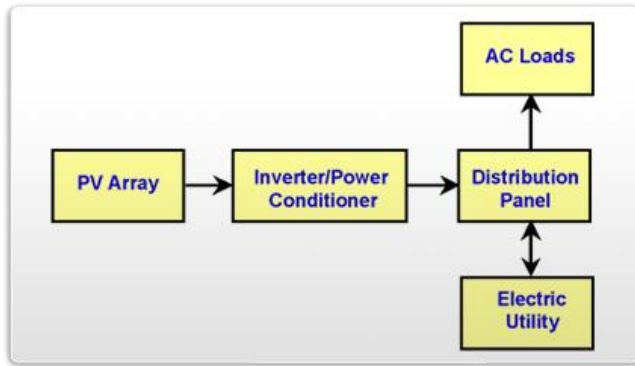


Figure 2.1: Grid-tied system

2.2.2. Off grid system

Off grid systems are suitable for the remotest areas where grid cannot penetrate. Figure 2.2 shows off grid system. In off grid or stand-alone systems battery storage is needed to supply electricity when renewable energy sources are not available. This system should contain large amount of PV arrays to fulfill the energy demand of the site as well as recharge the batteries at the same time [11].

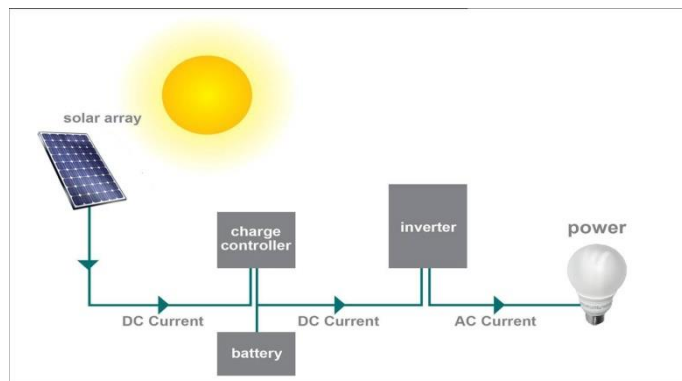


Figure 2.2: Off-grid/ Stand-alone energy system

Grid connected system takes care of seasonal load variations as there's not limit to storage capacity in this system. So, the overall efficiency of grid connected system is higher than Off-grid or stand-alone system [9].

2.3. PV array

Some materials exhibit a property called Photoelectric effect that allows them to absorb photons of light and release electrons. These electrons can be captured to produce electricity. Figure 3 describes the basic operation of photovoltaic cell which is also known as solar cell.

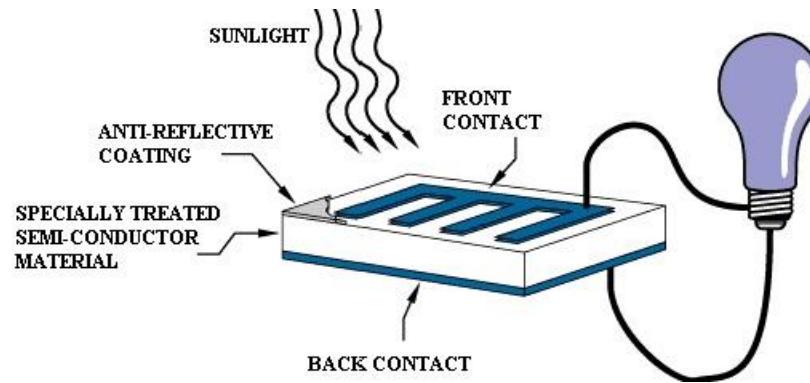


Figure 2.3: Solar cell operation

Semiconductor materials such as Silicon are used to make solar cells. Specially treated semiconductor wafer is used to make an electric field which forms positive and negative end in two ends. When the sun rays strike PV cell, electrons get detached from the atoms in the semiconductor material and these electrons can be captured in the form of electrical current by electrical conductors attached to the positive and negative ends [12].

Solar cells are integrated into series and/or parallel to form photovoltaic modules to produce higher voltages or current levels. Photovoltaic panels consist of one more PV modules and a Photovoltaic array is a complete power producing unit which consists of PV modules and panels [13].

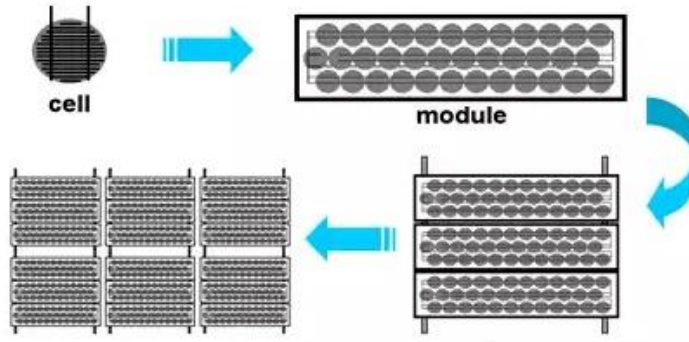


Figure 2.4: Solar cell, module, panel and array

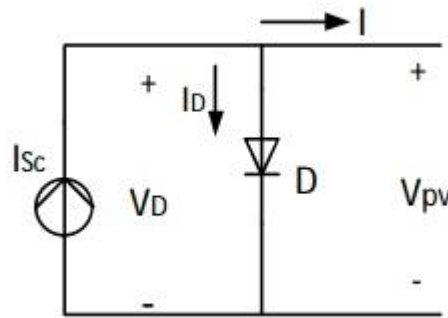


Figure 2.5: Diode equivalent circuit of solar cell

PV cell I-V characteristics are shown by the following equations: [14]

Module Photo current (I_{ph}):

$$I_{ph} = [I_{scr} + K_i(T - 298)]G \div 1000 \quad (2.1)$$

Module reverse saturation current I_{rs} :

$$I_{rs} = \frac{I_{scr}}{e^{\left(\frac{qV_{oc}KAT}{N_s}\right)} - 1} \quad (2.2)$$

Module saturation current I_o :

$$I_o = I_{rs} = \left[\frac{T}{T_r}\right] e^{\frac{qE_{gv}}{BK\left(\frac{1}{T_r} - \frac{1}{T}\right)}} \quad (2.3)$$

Output current of PV module I_c :

$$I_c = N_p I_{ph} - N I_o \left[e^{\frac{q(V_c + I_{ph})}{NAKT}} - 1 \right] \quad (2.4)$$

Where,

V_c is output voltage of PV module (V)

T_r is the reference temperature = 289K

T is the module operating temperature

A is an ideality factor = 1.6

K is Boltzmann constant = $1.3805 * 10^{-23}$ J/K

q is the electron charge

R_s is the series resistor of PV module

I_{scr} the PV module short circuit current = 1.1A

K is the short circuit current temperature coefficient=0.0017A/C

G is the PV module illumination = 1000W/m²

E_{go} is the band gap for silicon = 1.1eV

V_o is the open circuit voltage = 18V

2.4.Switching

Semiconductor-switching network can be regarded as heart of the power electronic circuit. The reason behind using semiconductor as switching device is their ability to control and manipulate large amount of power from input to load with very small power dissipation in switching device which results in increase of overall efficiency of power electronic system [15].

2.4.1. Switch Types

In recent years, the performance of switches has been improved significantly thus the efficiency of the inverter has also increased and power levels are also on the rise. Switches are used to break up the direct current (DC) into pulses to produce higher voltage alternating current (AC). Several types of switches are available and they have different features. In this section, several different switch types are explained with their notable features.

2.4.1.1. Vibrator Switch

Very first inverter technologies are made of vibrator switches for switching.

Advantages:

- 1: Able to conduct high currents
- 2: Low resistive losses

Disadvantages:

- 1: poor reliability
- 2: contacts suffered from arcing

2.4.1.2. Silicon Controlled Rectifier Switches (SCR's)

SCR's replaced the vibrator switches. To turn on the SCR, a minimum current level is needed which is applied to the gate of the SCR.

Advantages:

- 1: Capable of handling high current.
- 2: Operate well with high voltages.

Disadvantages:

- 1: High on state voltage drop.
- 2: Slow switching speed.

2.4.1.3. Metal Oxide Semiconductor Field Effect Transistor (MOSFET's)

MOSFET or FET is the latest switching technology and it has solved many problems regarding inverter design.

Advantages:

- 1: Low "on" resistance
- 2: Cheap
- 3: High current handle capability

Disadvantages:

- 1: High voltage performance is not up to the mark.
- 2: Cannot handle high voltage compared with SCR's

2.4.1.4. Insulated Gate Bipolar Transistor (IGBT)

With a FET type control gate, IGBT's are similar to a bipolar transistor.

Advantages:

- 1: Excellent high voltage performance.
- 2: Operate well with high current.
- 3: Suitable for high-frequency operation

Disadvantages:

- 1: Switching speed is low
- 2: Expensive
- 3: Increase the complexity of the circuit.

2.5. DC-DC Converter

The main function of a DC-DC converter is to change the DC voltage level to higher or lower voltage as needed. Another important function of DC-DC converter is to provide isolation between input source and load when required. It is also used to protect supplied system and the input source from electromagnetic interference (EMI). In this section, [15] four basic DC-DC converters are described with their waveforms.

2.5.1. Step-down (Buck) converter:

A basic step-down converter is shown in figure 2.6. It consists of dc input voltage source V_s , Switch S , diode D , inductor L , filter capacitor C and load resistance R .

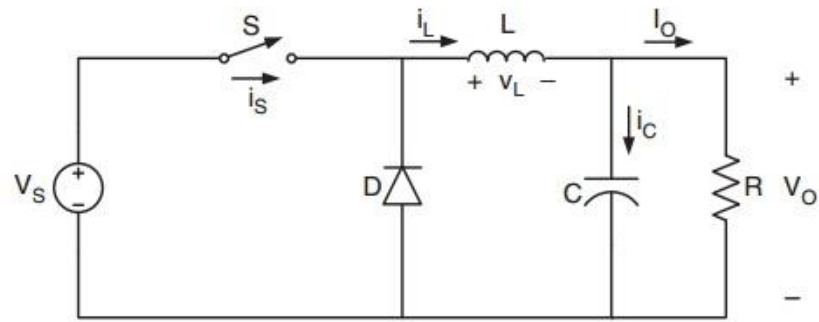


Figure 2.6: Buck converter

Operation:

When the switch is on, the diode is reversed biased and energy is stored in the inductor. So, during the “on” state, the current through the load and charge on the capacitor increases gradually. When the switch is off, the back e.m.f of the inductor causes current to flow through the load and through the diode which is now forward biased. The capacitor is now acting like main source of current and it keeps flowing current until next “on” period begins. The output voltage equation of buck converter can be written as follows,

$$V_{out} = V_s \times \frac{t_{on}}{T} \quad (2.5)$$

Where,

t_{on} = on time of the switch

T = period of switching

This equation proves that the output voltage of a buck converter is smaller than input voltage [16]. The waveforms of buck converter are shown in figure 2.7.

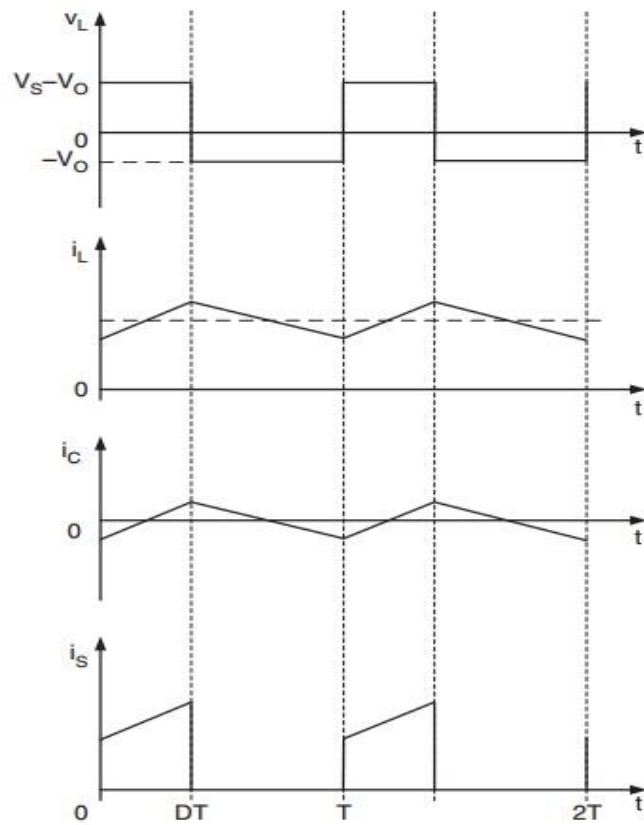


Figure 2.7: Waveform of buck converter

2.5.2. Step-up (boost) converter

A basic boost converter circuit is shown in figure 2.8. It consists of dc input voltage source V_s , boost inductor L , switch S , diode D , capacitor C and the resistance R .

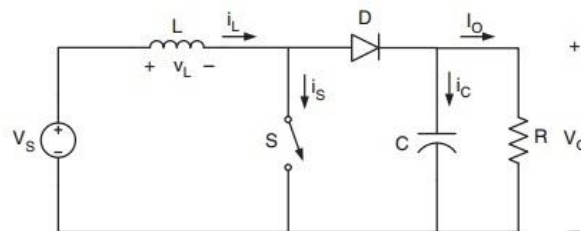


Figure 2.8: Boost Converter

Operation:

When the switch is on, two poles of the inductor are directly connected with the positive and negative terminal of the supply voltage. So during this on period, inductor stores energy in the form of magnetic field until the switch is turned off and no current flows through the other part of the circuit.

When the switch is turned off, a back e.m.f is produced in the inductor and the diode is forward biased. So, there are two voltages ($V_{in}+V_L$) acting now on the capacitor. As a result, the capacitor charges up to $V_{in}+V_L$ minus forward voltage drop across the diode.

The theoretical output equation of a dc-dc boost converter can be written as,

$$V_o = \frac{V_s}{1-D} \quad (2.6)$$

Where, D stands for duty cycle of switching. Equation 2 states that, the output voltage of a DC-DC boost converter is greater than the input voltage [17].

The waveforms of DC-DC boost converter are shown in figure 2.9.

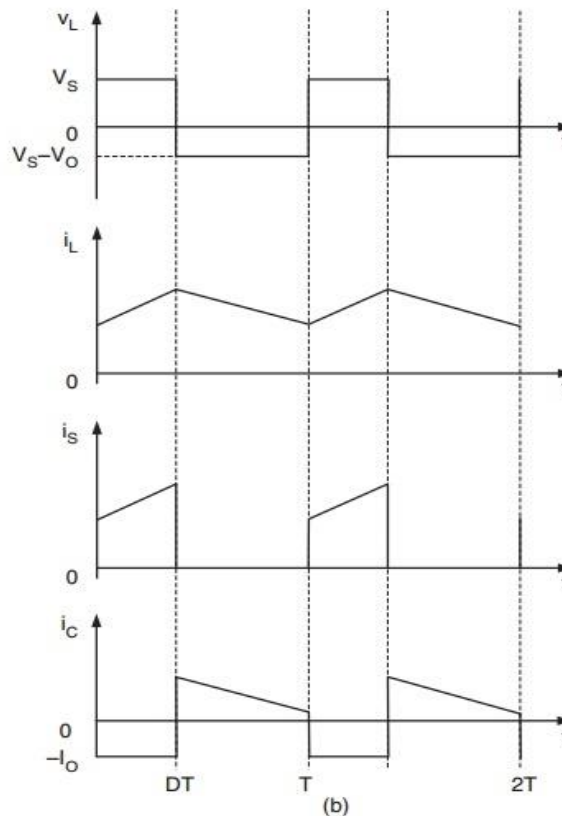


Figure 2.9: Waveform of Boost converter

2.5.3. Buck-boost converter

A basic circuit configuration of a buck-boost converter is shown in the figure 2.10. A buck-boost converter provides an output voltage which is negative and either smaller or greater the input voltage [15].

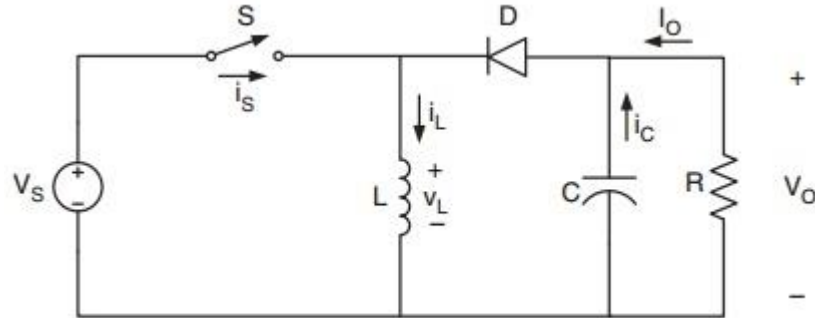


Figure 2.10: Circuit diagram of Buck-boost converter

Operation:

When the switch is on, current through the inductor increases gradually and being reversed biased the diode is at blocking state. When the switch is off, diode provides a path for inductor current and energy in the inductor is transferred from the inductor to capacitor and a voltage with opposite polarity compared to V_{in} appears in the resistor.

During steady state, the circuit is said to be operated in discontinuous conduction mode (DCM) if the current in the inductor is zero and if the current never reaches zero the circuit operates in continuous conduction mode (CCM). The output equation in continuous conduction mode of a buck-boost converter is,

$$V_{out} = -\frac{D}{1-D}V_{in} \quad (2.7)$$

The waveforms of basic buck-boost converter are shown in figure 2.11

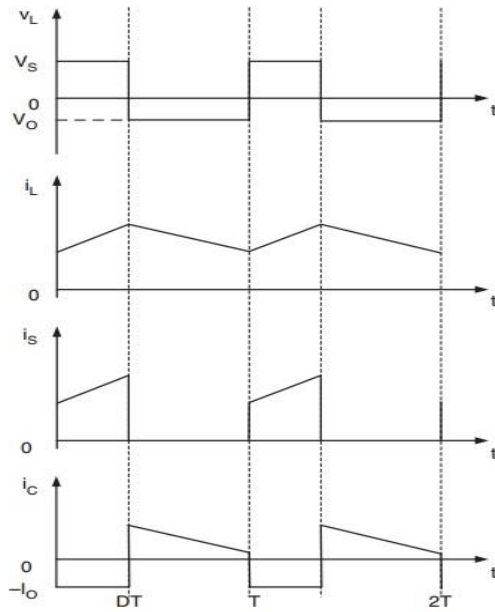


Figure 2.11: Waveforms of buck-boost converter

2.5.4. CUK Converter

Basic circuit diagram of a CUK converter is shown in figure 2.12. It consists of dc input voltage source V_s , inductor L_1 , switch S , capacitor C_1 , diode D , filter inductor L_2 , filter Capacitor C and resistance R as a load [15].

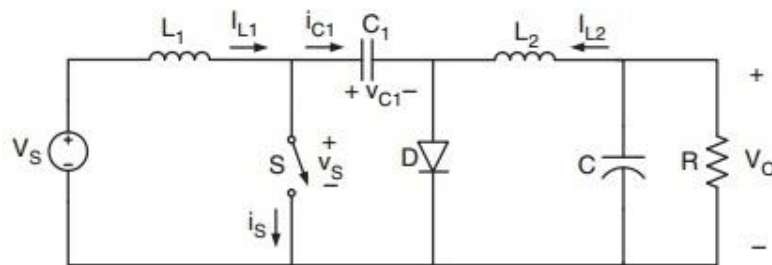


Figure 2.12: CUK converter circuit diagram

Operation:

When Switch S is on, current through the inductor L_1 starts increasing gradually. When switch S is turned off, inductor L_1 tries to keep the current flowing through the circuit thus it starts dissipating energy to the capacitor C_1 . When the switch turns on again, current in the inductor increases and diode D is at blocking

state and capacitor C1 discharges through RL load. Voltage induced in the R is opposite polarity of input voltage. Output voltage equation of CUK converter in continuous conduction mode is:

$$V_{out} = -\frac{D}{1-D}V_{in} \quad (2.8)$$

Waveforms of CUK converter are shown in figure 2.13.

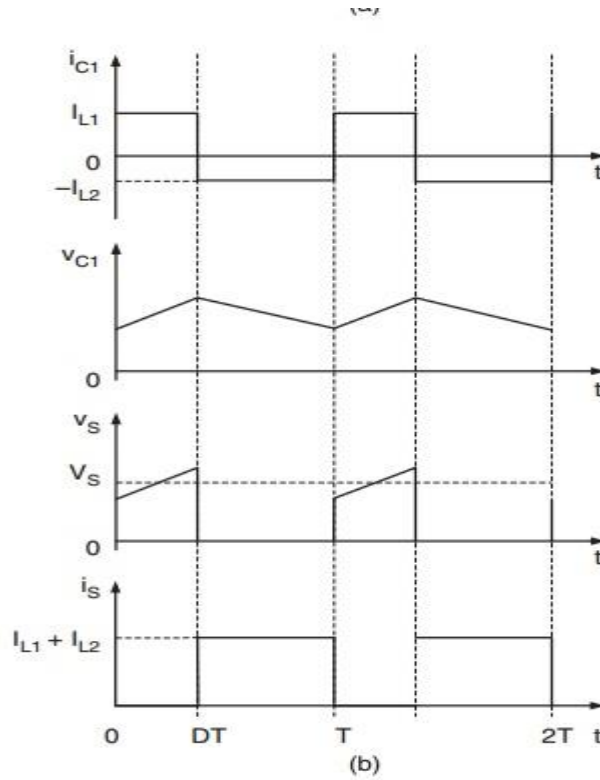


Figure 2.13: Waveform of CUK converter

2.6. PULSE WIDTH MODULATION

We can manage the output of Inverter by PWM control. For this we need to provide a DC input to the Inverter and by managing the on-off period of the inverter we can get an AC output voltage. Pulse Width Modulation speed drivers are now new concern of many industrial applications. Development in power electronics have improved that made circuit like PWM more popular to researchers. Sinusoidal PWM is commonly used for voltage source inverter [18].

2.6.1. PULSE WIDTH MODULATION TECHNIQUE

As there are advanced power devices and microprocessors we need switching power converters to provide the energy to the motor or the load. PWM signals have the fixed frequency, variable pulse width and fixed magnitude. There must have one pulse of fixed magnitude in for every PWM period. Width will change according to modulating signals and it will change pulse to pulse. When we provide PWM pulse to the gate of an Inverter it controls the on-off period of the inverter according to the modulating signals.

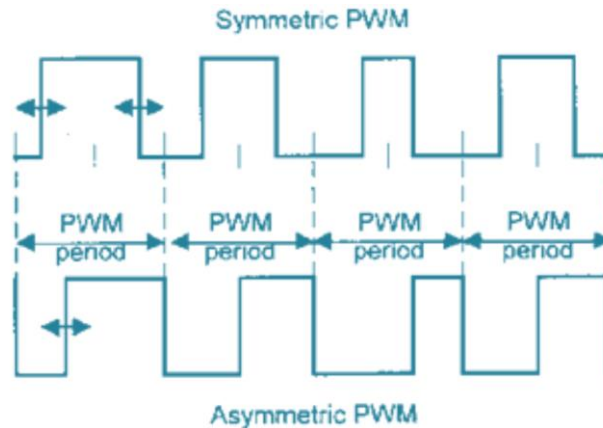


Figure 2.14: Symmetric and Asymmetric PWM Signals

There are two types of PWM signals, symmetric and asymmetric. The pulse of a symmetric PWM is generally symmetric and the asymmetric pulse must have the same side batched for end of the PWM period. The symmetric PWM signals generally produce fewer harmonics for output. The PWM control is getting popular day by day. The advantages of this type of control are significant. PWM control is very much easy to implement, it has now power waste, and there are no temperature variations. Most importantly this technique is suitable for digital microprocessors. This technique itself controls the output no need of further components.

2.6.2. TYPES OF PULSE WIDTH MODULATION TECHNIQUES

There are different PWM techniques classified by their constant amplitude pulses. They are multiple pulse modulation and Sinusoidal pulse width modulation, Single-pulse modulation, modified sinusoidal pulse with modulation.

2.7.Gate Driver Circuit

Power semiconductor devices have three operating states which are commonly known as the cut-off, the active and the saturation mode. The aim of converters in power electronics which utilize switch mode operation is to operate these converters in either the saturation or the cut-off region, whilst making the transient through the active or linear region as short as possible in order to ease maximum power conversion efficiency. Thus in order to achieve this fast transient times, a gate driver circuit is required [15].

A gate driver is a power amplifier that accepts a lower power input from a controller IC and produces the appropriate high-current gate drive for power MOSFET. A gate driver is thus used when a pulse-width-modulation (PWM) controller cannot provide the output current required to drive the gate capacitance of the associated MOSFET. Driver circuits offers additional functions which includes isolating the control circuit and the power circuit, detecting malfunctions, storing and reporting failures to the control system, serving a precaution against failure. The most common driver is IR2110.

The IR2110 are high voltage, high speed power MOSFET and IGBT drivers with high and low side referenced output channels [15]. The figures below show the functional block diagram and functionality of the driver IC.

Functional Block Diagram

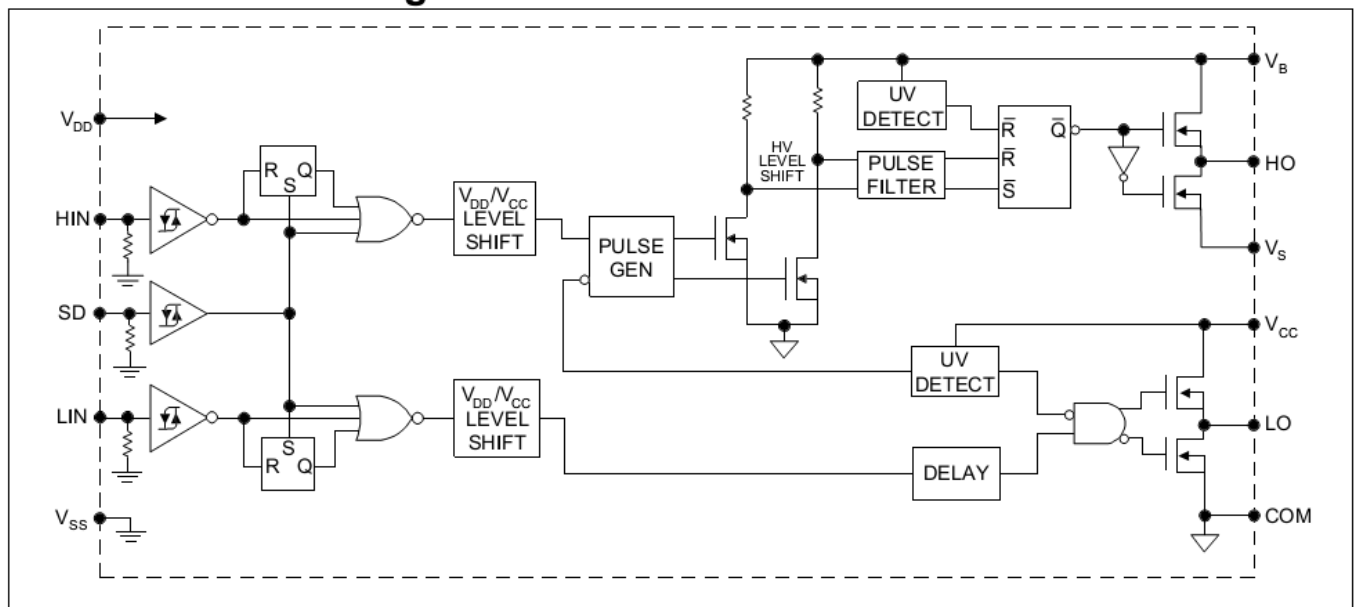


Figure 2.15: Functional block diagram of IR2110 IC

Lead Assignments

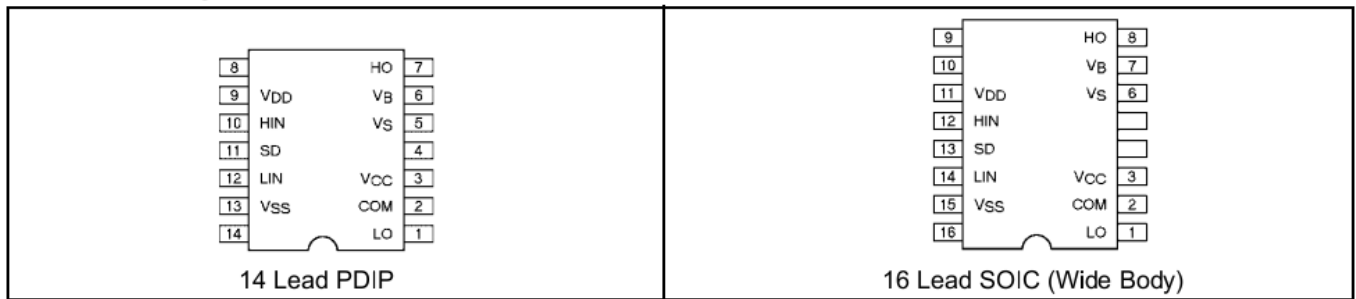


Figure 2.16: Pin configuration of IR2110 IC

Lead Definitions

Symbol	Description
V _{DD}	Logic supply
HIN	Logic input for high side gate driver output (HO), in phase
SD	Logic input for shutdown
LIN	Logic input for low side gate driver output (LO), in phase
V _{SS}	Logic ground
V _B	High side floating supply
HO	High side gate drive output
V _S	High side floating supply return
VCC	Low side supply
LO	Low side gate drive output
COM	Low side return

Figure 2.17: Full forms of the pin configuration of IR2110

2.8. Grid tied photovoltaic Inverter

Inverter takes the DC as input and converts it to the AC output. The grid-tied photovoltaic inverter is one of the fundamental components of distributed generation system. It works as the interface between renewable energy sources and the grid [19].

2.8.1. Classification of grid-tied inverter

The grid tied inverter can be classified as follows [19]:

- Central inverter
- String inverter
- Multi-string inverter

- Module integrated inverter

2.8.1.1. Central inverter

The Central inverter is also known as single stage photovoltaic. In central inverter system, the solar panels are connected in series/parallel combination to form a string and the output of this string is fed into MPPT then to a single inverter which is connected to the grid. So, there is no use of boost converter in this system. However, this system has several disadvantages like high power losses, expensive and design is not flexible [19] [20]. A basic diagram of central inverter is shown in figure 2.22.

2.8.1.2. String inverter

A basic diagram of string inverter is shown in figure 2.23. In this system, photovoltaic modules are connected in series and a dc-dc converter is used for maximum power point tracking (MPPT) of the solar cells and also amplifies the voltage to a required level. Then dc-ac inverter converter dc power into ac. The design of this inverter topology is simple however it is not cost effective and less reliable. [20]

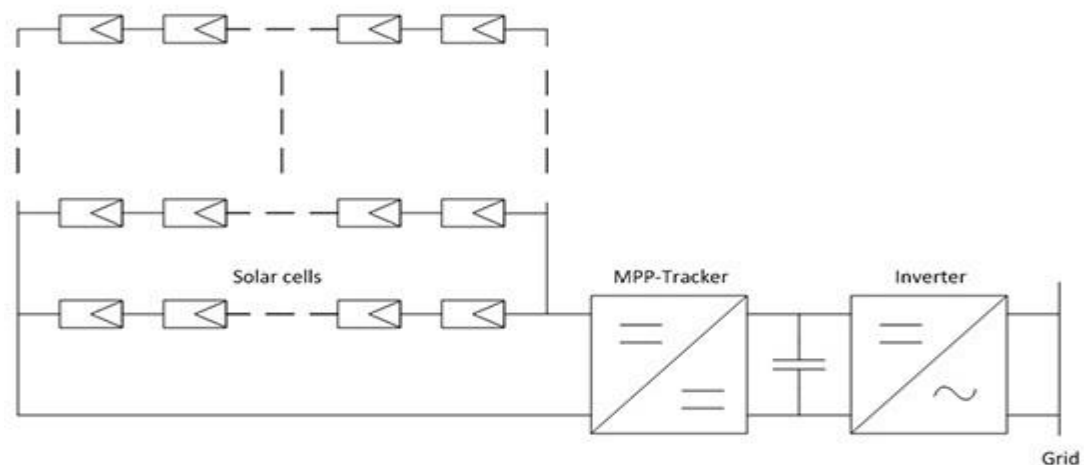


Figure 2.18: Central Inverter system

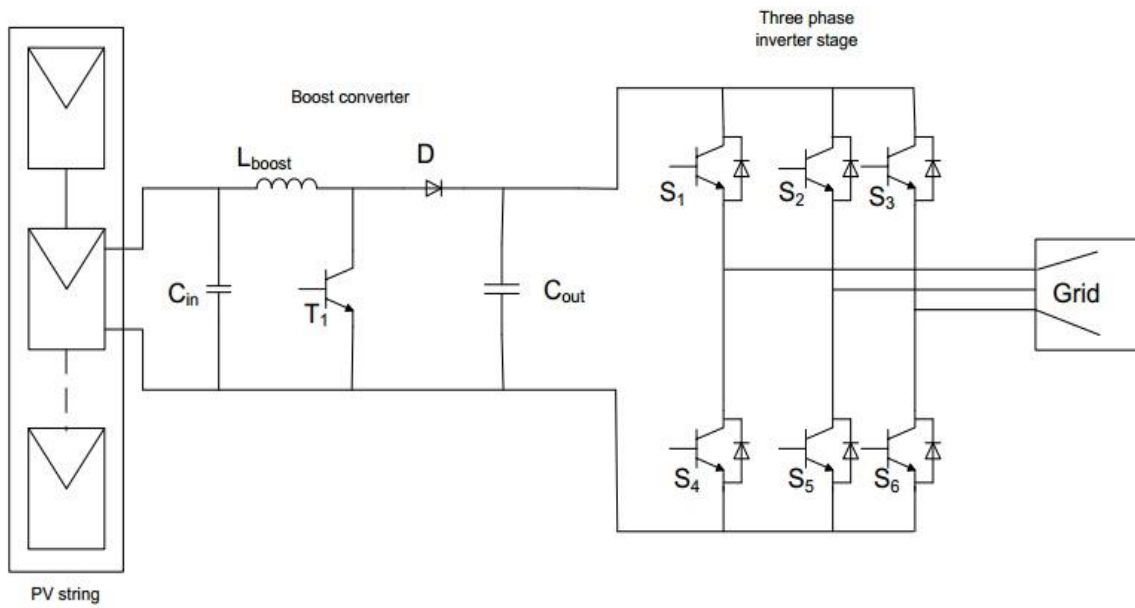


Figure 2.19: String inverter with boost converter and PV system

2.8.1.3. Multi-string inverter

A basic diagram of multi string inverter is shown in figure 2.24 where several PV string are connected to a dc bus. The output of the dc bus is fed into a common dc-ac inverter which is connected with the grid. The main advantage of this system is its capability to produce high power by integrating more PV modules. If any one of the PV goes down, it does not affect the operation of the system. This system is cost effective, efficient enough and flexible [19] [20].

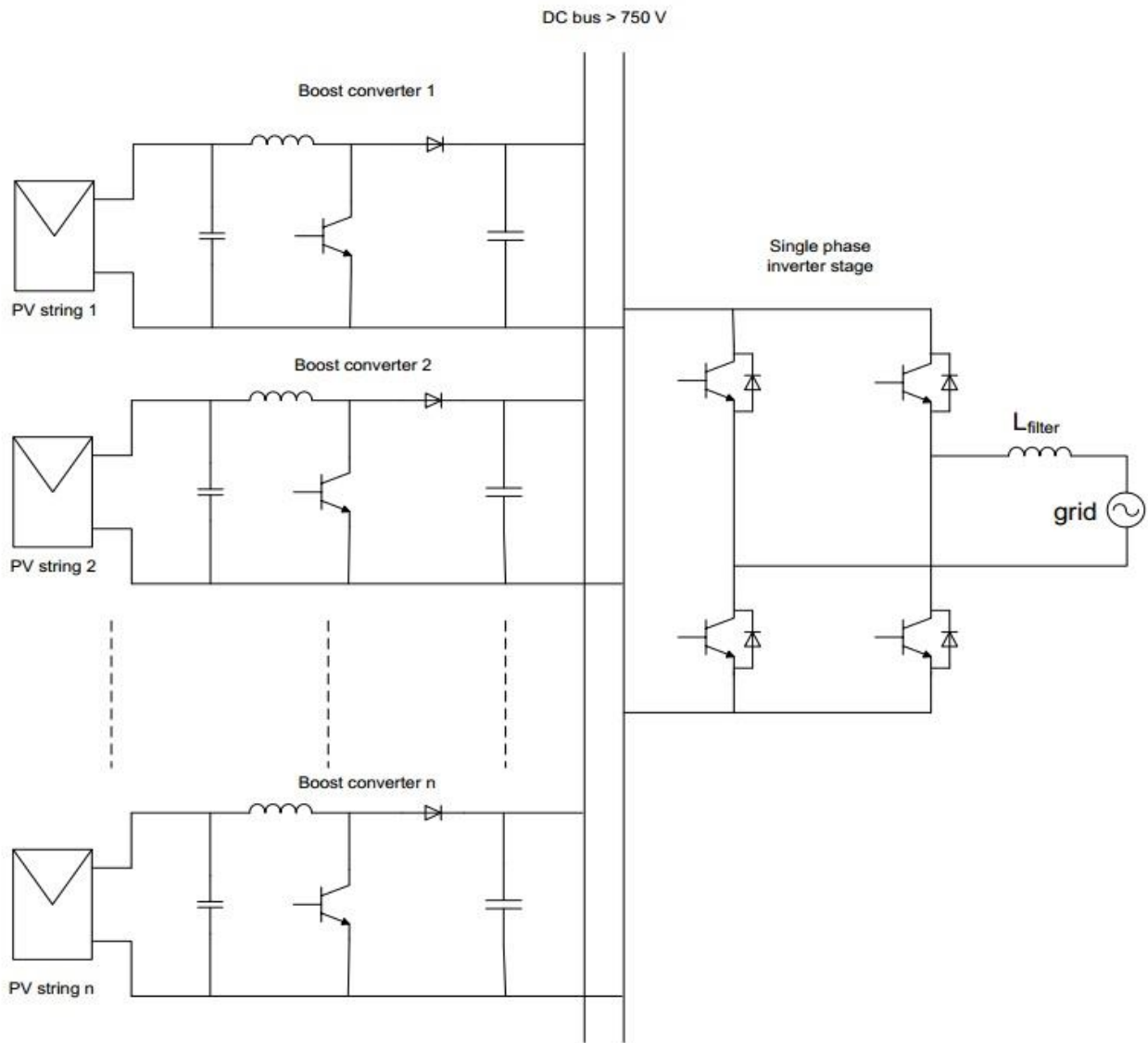


Figure 2.20: Multi-string PV system

2.8.1.4. Module integrated inverter

Module integrated inverter is shown in figure 2.25. In this system, no mismatch occurs between the PV modules so that the overall system loss gets reduced. Module integrated inverter system able to extract maximum power from the PV modules. The system can also be expanded to produce more power. The major disadvantages are high installation cost and reduced overall efficiency [19].

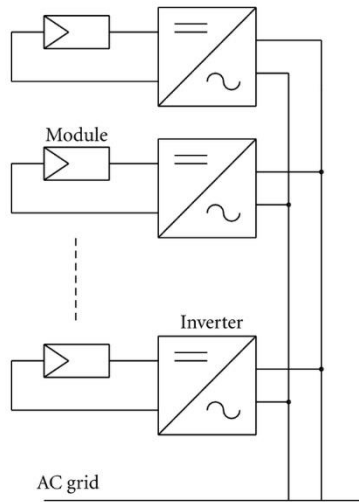


Figure 2.21: Module integrated inverter

2.9. Transformer less and Transformer base inverter technology

Transformer-less inverter technology has several advantages over conventional transformer base inverter. Eliminating the transformer brings several advantages like it makes the inverter much lighter, compact, more affordable also reduces the cost of the inverter [14]. A recent survey in Europe shows that transformer-less inverter technology is much better than transformer-base inverter. 30 different inverters were compared by Ranjita [14] of which seven were transformer-less and rest of them are transformer-base inverter. The result of this comparison is shown in table 2.1.

Inverter Type	MAX. EFFICIENCY (%)	WEIGHT kg/KW	PRICE AS\$/W
With Transformer	93.1	16.1	1.95
Transformer-less	95.9	12.3	1.47

Table 2.1: Comparison of transformer-less and transformer base inverter for grid tied PV system

So, it is clear from above comparison that transformer-less inverter is nearly cheaper than conventional transformer base inverter. However, having several advantages safety issue is the major concern for transformer-less inverter. Transformer-less inverter lacks electrical isolation between DC and AC part of

the system. Transformer-less inverter may also develop quite stronger electromagnetic field than transformer base inverter [21].

2.10. Arduino

Arduino is one of the most popular electronic projects building platform. It consists of a microcontroller and a software or IDE ((Integrated Development Environment). The microcontroller is a physical programmable circuit board. Computer code is written in the software and the code is uploaded on the circuit board by using a USB cable. Arduino uses the simplified version of C++ language. [22]



Figure 2.22: Arduino circuit board

2.11. Summary

In this chapter, different components of grid connected PV system have been discussed along with Different topologies of grid tied inverter and dc-dc converter have been discussed. Types of switches and different PWM techniques are also explained. With the help this study the reason behind choosing transformer-less inverter is clearly understood.

Chapter 3

Design and Implementation

3.1. Introduction

The design of the system along with the implementation have been discussed in this chapter. To accomplish this work, resistors, power MOSFET, Driver IC, op-amp, LEDs, capacitor and a laptop was used. In this chapter, the completion of objective using different software and hardware are discussed.

3.2. Boost converter Design

There are different types of DC-DC converter to change the DC voltage level to higher or lower voltage level as need. This different types was discussed in previous section 2.5.2. In this section only the Boost converter design have been discussed which is present in our system.

3.2.1. Converter Specification

The purpose of using the DC to DC boost converter is to regulate switching mode DC power supplies. The input of the converter is an uncontrolled DC voltage which is obtained from the PV array and thus will be fluctuated owing to different physical conditions. In these type of converters, PID controlled technique is always used to obtain the desired value although the input voltage is changing. The PID controller controls the time durations of the absorption and injection intervals. Boost converters design and development mainly concerns with its efficiency, output power and comfort of design. Renewable energy source uses boost converter as a medium of power transmission to transact energy absorption and injection to loads. The means of energy absorption and injection is performed by a combination of four components which are electronic switch, diode, inductor and output capacitance. The connections of boost converter is shown in the figure 3.1.

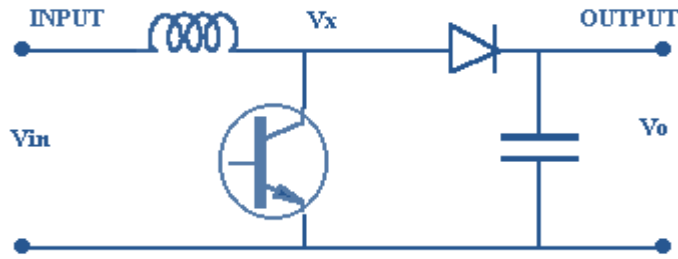


Figure 3.1: Schematic of boost converter

The process of energy absorption and injection will establish a switching cycle. This means, the average output voltage is controlled by a switch on and of duration.

$$V_o = V_s / (1-D) \quad (3.1)$$

To obtain a constant frequency, the on-off duration of the switch is adjusted; the switching duty cycle **D** is defined as the ratio of the duration to the switching time period. Depending on its energy storage capacity and the relative length of switching period the converter can operate in two different modes: continuous conduction mode and discontinuous conduction mode. Our scheme used the continuous conduction mode technique [23].

3.2.2. Continuous conduction mode

Continuous conduction mode is again subdivided into two modes: mode 1 and mode 2 [24].

Mode 1 ($0 < t \leq t_{on}$)

Mode 1 initiates when power MOSFET is switched on at $t=0$ and stops at $t= t_{on}$. The equivalent circuit for the mode 1 is shown in fig 3.2. The inductor current $I_L(t)$ greater than zero and increases linearly. The inductor voltage is V_i .

Mode 2 ($t_{on} < t \leq T_s$)

Mode 2 initiates when MOSFET is switched off at $t=t_{on}$ and stops at $t=T_s$. The equivalent circuit for the mode 2 is shown in Fig. 3.2. The inductor current ramp down until the MOSFET is turned on again during the later cycle. The voltage across the inductor in this period is $V_{in}-V_{out}$.

$$V_{int_{on}} + (V_{in}-V_{out})t_{off} = 0 \quad (3.2)$$

Where;

V_{in} : The input voltage, V.

V_{out} : The average output voltage, V.

t_{on} : The switching on of the IGBT's.

t_{off} : The switching off of the IGBT's.

Dividing both sides by T_s and rearranging items yield

$$\frac{V_{out}}{V_{in}} = \frac{T_s}{t_{off}} = \frac{1}{1 - D} \quad (3.3)$$

Where;

T_s : The switching period, s.

D : The duty cycle.

Thus, V_o is inversely proportional to $(1-D)$ it is obvious that the duty cycle, D , cannot be equal to 1 otherwise there would be no energy transfer to the output assuming a lossless circuit, $P_i=P_o$, then

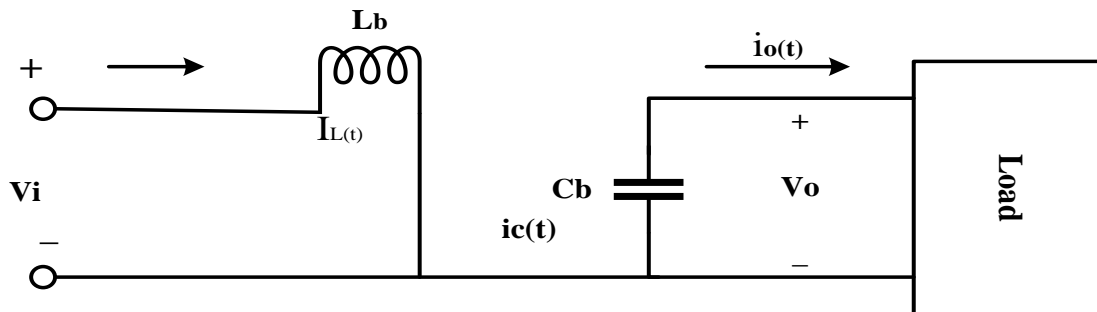
$$I_{in}V_{in}=I_{out}V_{out}$$

$$\frac{T_s}{t_{off}} = \frac{1}{1 - D} \quad (3.4)$$

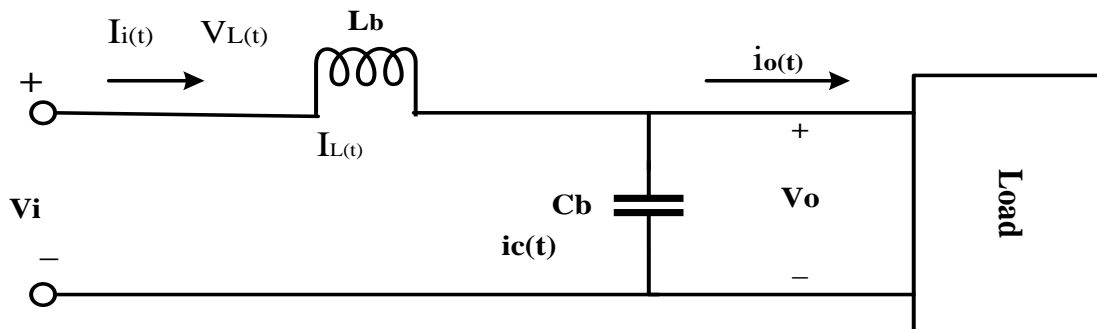
Where;

I_{out} : The average output current, Amp.

I_{in} : The average input current, Amp.



(a) Mode 1 ($0 < t \leq t_{on}$)



(b) Mode 2 ($t_{on} < t \leq T_s$)

Figure 3.2 (a) (b): Equivalent Circuit for boost Converter in CCM

3.3. PID controller Design

Nowadays most of the industrial controllers are based on PID controllers as it provides the best way to solve many complicated real world control problems more efficiently than other techniques [25]. As the name suggests, PID stands for Proportional-integral-derivative. PID controller measures the difference between a set point and a measured variable which is termed as error value and assists the system to improve its performance by reducing this error value [26].

PID controller is known as “three-term” controller and its transfer function can be written as,

$$G(s) = K_p + K_I(1/S) + K_Ds$$

$$= K_p [1 + (1/ T_I s) + T_D s] \quad (3.5)$$

Where,

K_p = Proportional gain

K_I = Integral gain

K_D = derivative gain

T_I = Integral time constant

T_D = Derivative time constant

A basic block diagram of PID controller is shown in figure 1

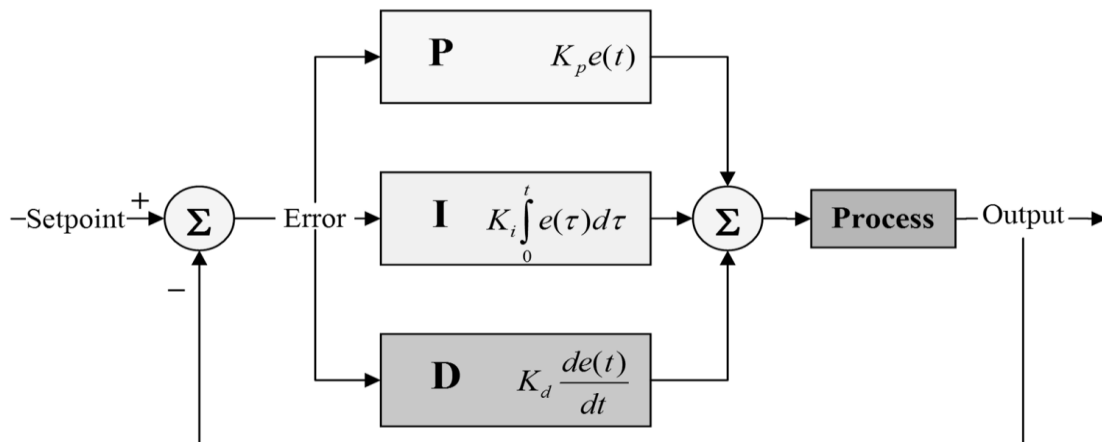


Figure 3.3: Basic block diagram of PID controller

The proportional term of the controller formed by multiplying the gain factor with the error signal and hence it yields an overall action proportional to the error signal. Mathematically the output of this controller is given by the equation,

$$\begin{aligned} A(t) &\propto e(t) \\ A(t) &= Kp \times e(t) \end{aligned} \tag{3.6}$$

The proportional term intends to reduce the overall error with time but it's not able to reduce the error level to zero and there are always some steady state errors in the system.

The integral term contributes to eliminate the steady state errors by providing an output which is directly proportional to the integration of error signal [25]. Mathematically, the output of integral term can be written as,

$$\begin{aligned} A(t) &\propto \int_0^t e(t) d(t) \\ A(t) &= Ki \int_0^t e(t) d(t) \end{aligned} \tag{3.7}$$

The derivative term assists to improve the transient response through high-frequency compensation by a differentiator [25]. The output of derivative controller can be written as,

$$\begin{aligned} A(t) &\propto \frac{de(t)}{d(t)} \\ A(t) &= Kd \times \frac{de(t)}{d(t)} \end{aligned} \tag{3.8}$$

3.4. Gate Driver Design

The figure below shows the circuit diagram of the gate driver circuit used in our system. Details of gate driver ICs and types have been discussed in the previous section 2.7.

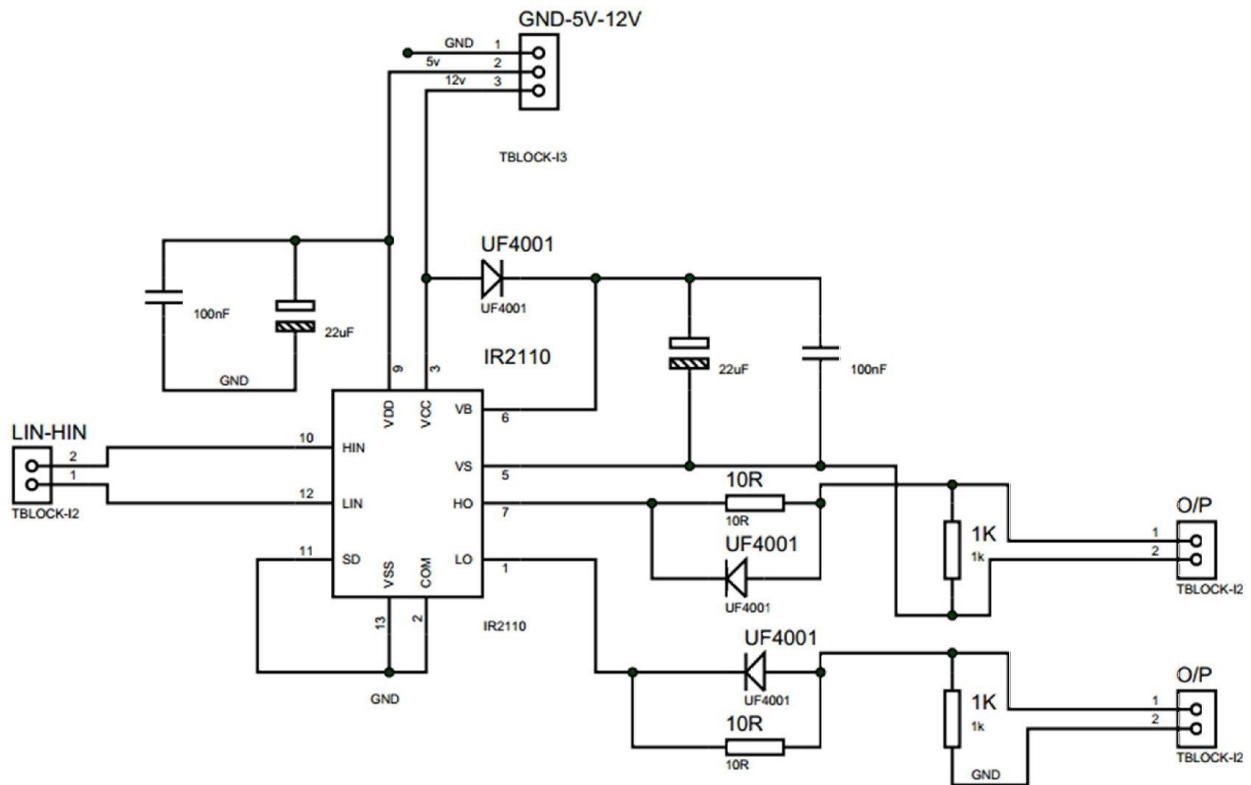


Figure 3.4: Circuit diagram of the gate driver

D1, C1 and C2 along with the IR2110 form the gate driver circuitry. When LIN = 1 and Q2 is on C1 and C2 get charged to the level on VB, which is one diode drop below +VCC. When LIN = 0 and HIN = 1, this charge on the C1 and C2 is used to add the extra voltage – VB in this case – above the source level of Q1 to drive the Q1 in high-side configuration. To keep Q1 on for all the time a large enough capacitance must be chosen for C1 so that it can supply required the charge. C1 must also not be too large that charging is too slow and the voltage level does not rise sufficiently to keep the MOSFET on. The higher on time requires the higher capacitance. Thus, the lower frequency requires the higher capacitance for C1. For the higher duty cycle, higher capacitance is required for C1. There is formulas available for calculating the capacitance. For that we just estimate the required capacitance. For low frequencies such as 50Hz, we used between 22 μ F and 100 μ F capacitance. For high frequencies like 30 kHz to 50 kHz, I use between 4.7 μ F and 22 μ F. D2 and D3 discharge the gate capacitances of the MOSFET quickly, bypassing the gate resistors, reducing the turn off time. R1 and R2 are used as gate current-limiting resistors [27] [28].

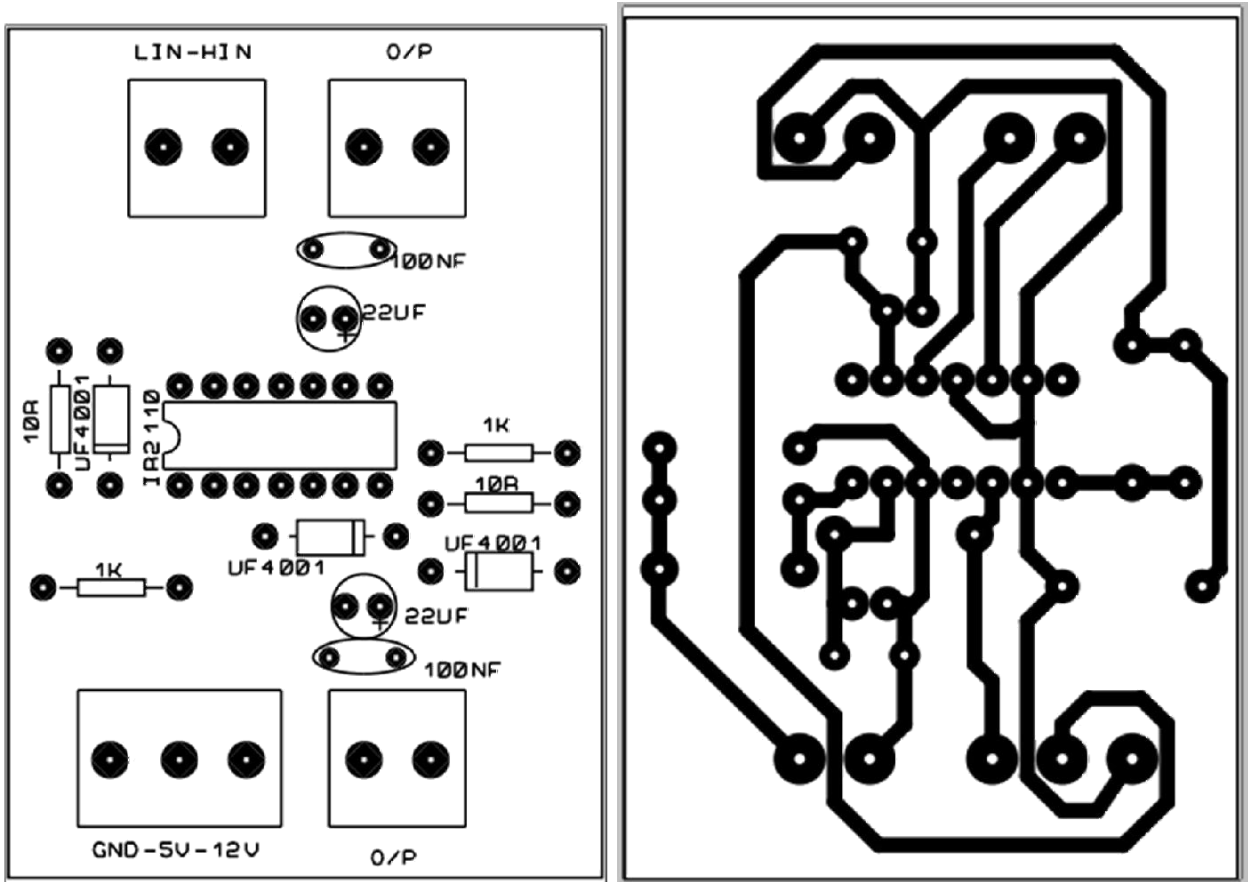


Figure 3.5: 3D PCB layout design

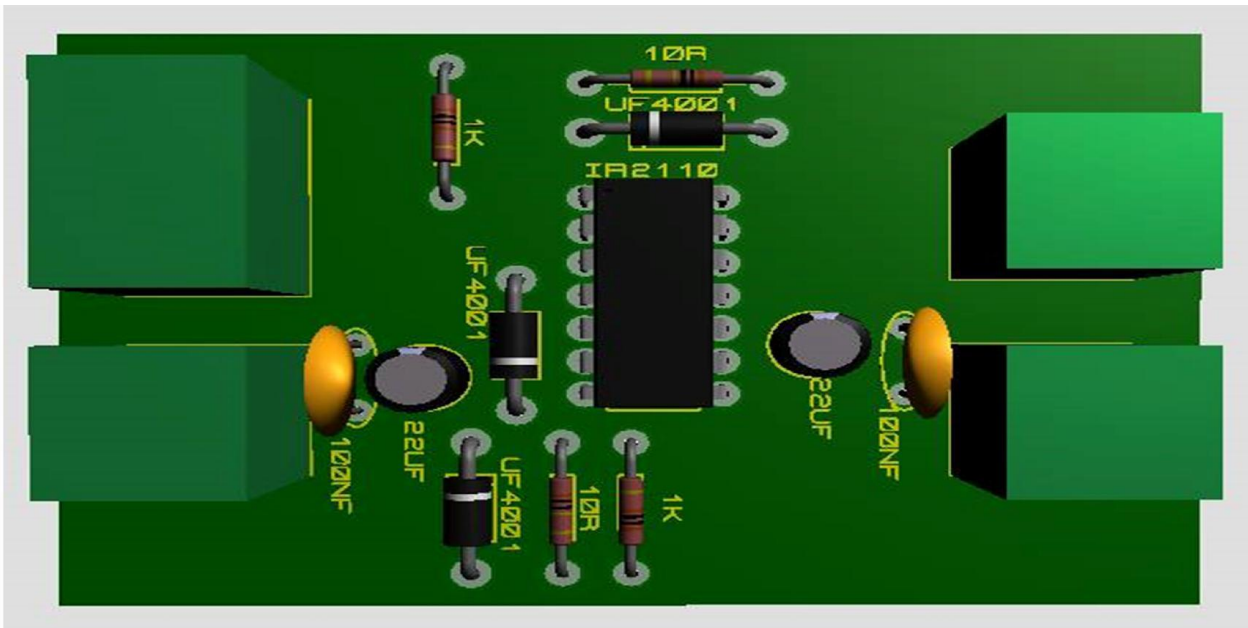


Figure 3.6: 3D view of Proteus design

3.5. Inverter Design

The inverter have been designed using the multilevel inverter topology. Multilevel inverters can provide high output power from a moderate voltage source. For moderate and high power industrial applications multilevel inverter has become the best choice nowadays. It is also possible to interface renewable energy resources with the multilevel inverter to obtain high power [27].

Multilevel inverter takes multiple low level dc voltages as input and provides desired ac output. Capacitors, batteries and renewable energy sources can be used to generate multiple low level dc voltages. Multilevel inverter is better than conventional full bridge inverter in the sense that the output sinusoid produced by multilevel inverter is more accurate than full bridge inverter. Multilevel inverter needs less filter components which results in reduced cost, light in weight and makes it more compact [14]. The circuit diagram that have been used in this thesis have been shown below.

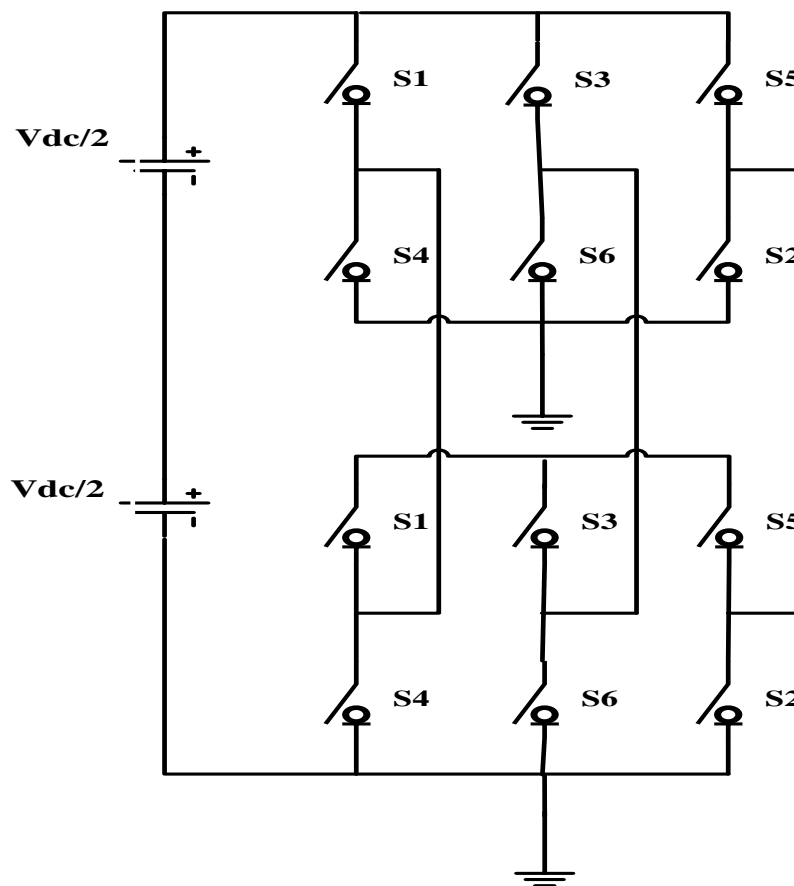


Figure 3.7: Design of the inverter

120 degree conduction modes have been used here as shown in the figure below:

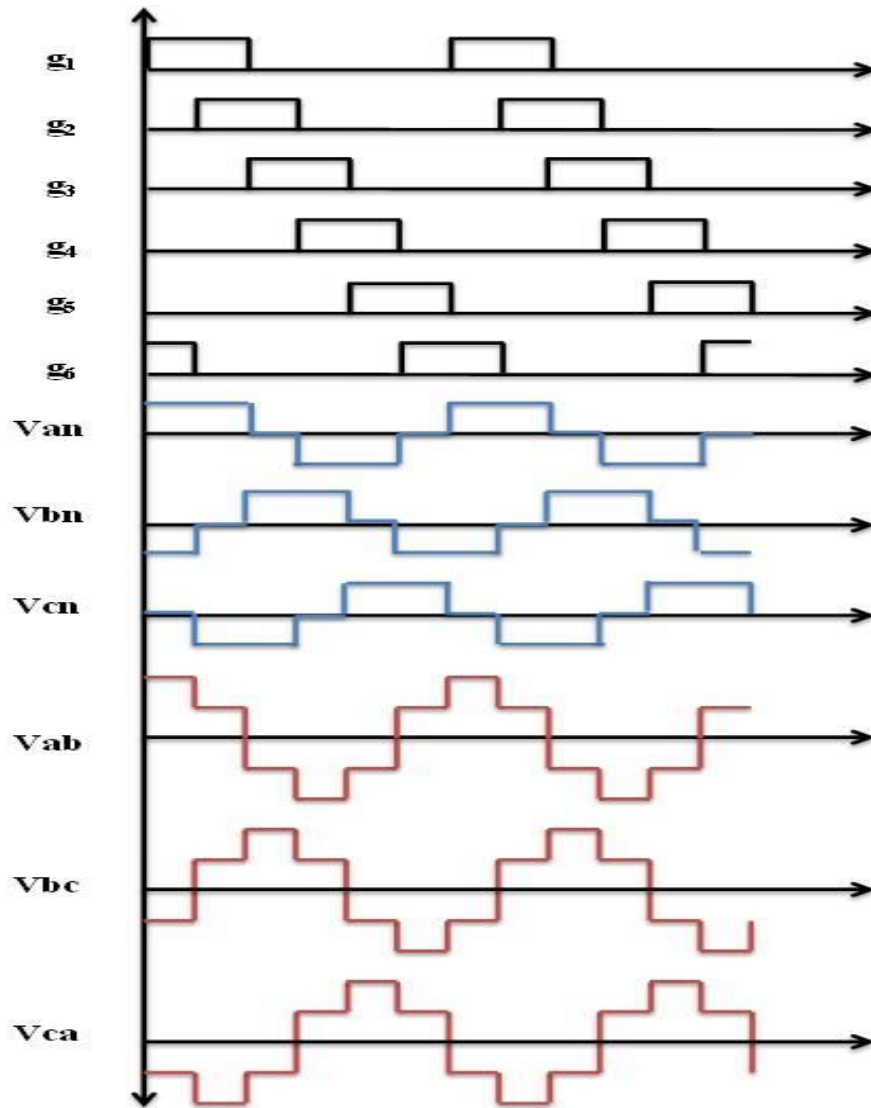


Figure 3.8: Timing diagram for 120° conduction mode

During the first 120 degree, S1 conducts with S6 for 60 degree, and then conducts with S2 for another 60 degree. The S3 will conduct for 120 degree (from 120 to 240) for 60 (from 120 to 180) with S2 and then S2 conduct another 60 (from 180 to 240) with S4. The S5 will conducts 120 (from 240 to 360) with S4 for 60 (from 240 to 300) and then conducts for another 60 (from 300 to 360) with S6. The conduction sequence can be written as follows: S6S1, S1S2, S2S3, S3S4, S4S5, S5S6, and S6S1 and the sequence is repeated. This algorithm have been developed using “ARDUINO SOFTWARE 1.6.9”, where the frequency have been fixed for 50Hz.

3.6. Hardware Implementation

A prototype have been implemented for small scale voltage which includes the PID controller part and the inverter part. In this section, part to part hardware implementation have been discussed.

3.6.1. PWM signal

The PWM signal for gate pulse have been generated using the Arduino Board and the output have been shown in a digital oscilloscope. The frequency 50Hz have been maintained using an algorithm in the Arduino software.

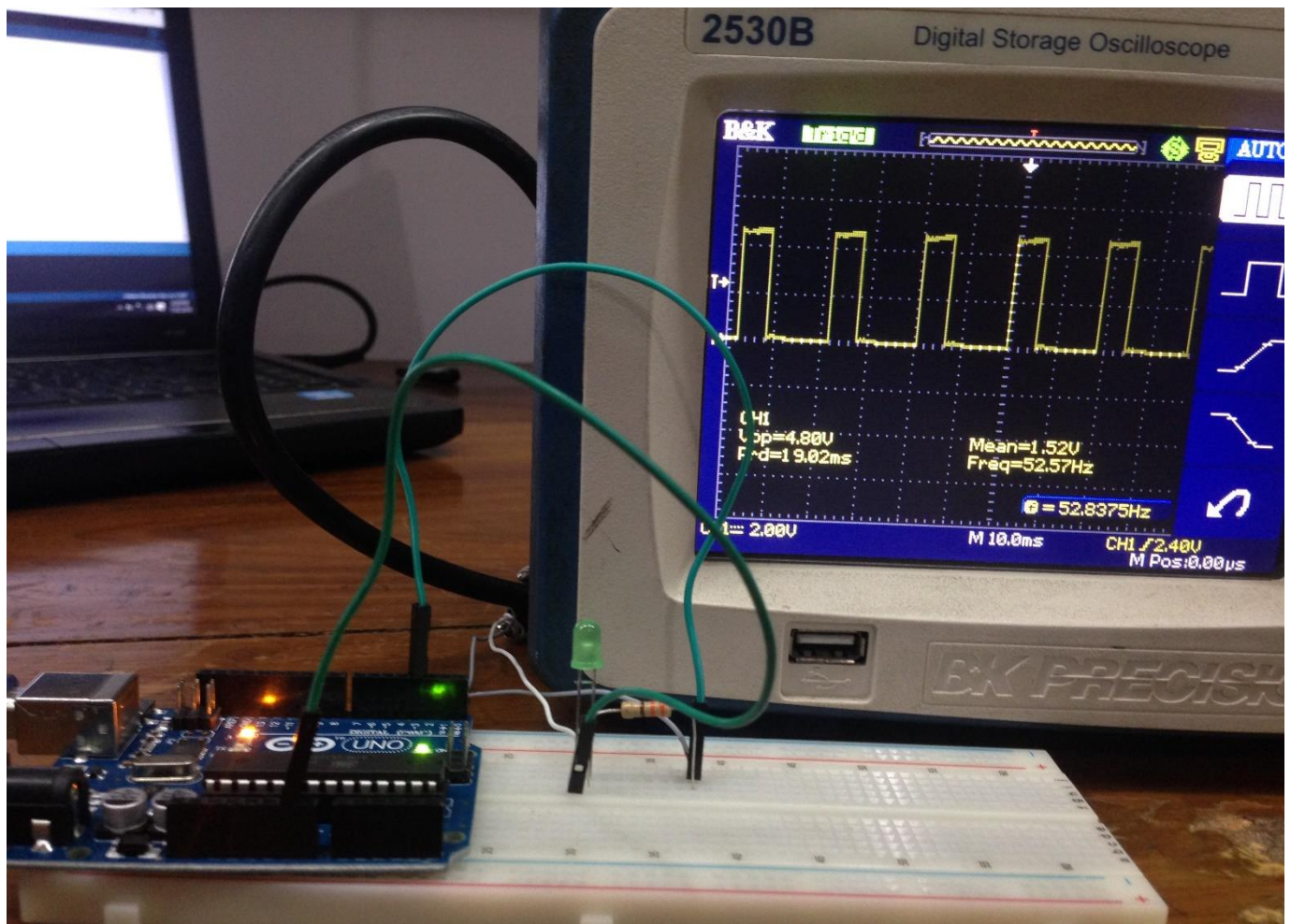


Figure 3.9: The setup showing the generation of PWM signal

3.6.2. PID controller

The PID controller have been implemented in a PCB using a variable pot for the tuning which acts as a voltage sensor. The PID algorithm have been developed using an Arduino. The figure below shows the implementation.

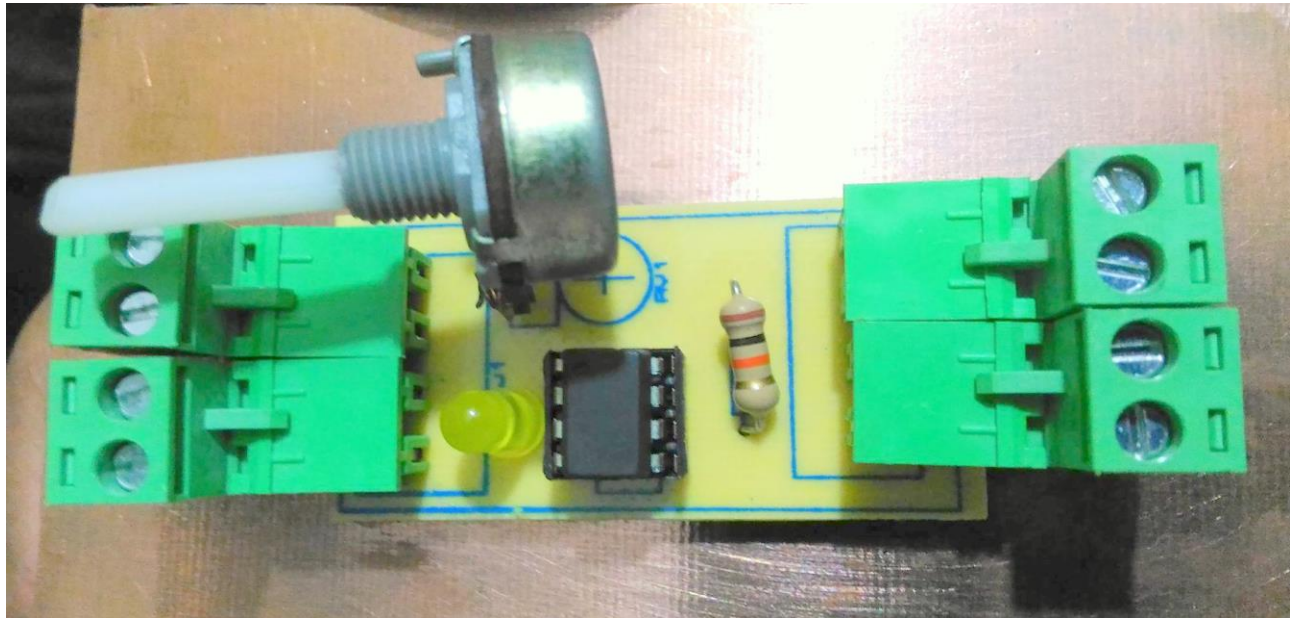


Figure 3.10: The setup showing the PID controller

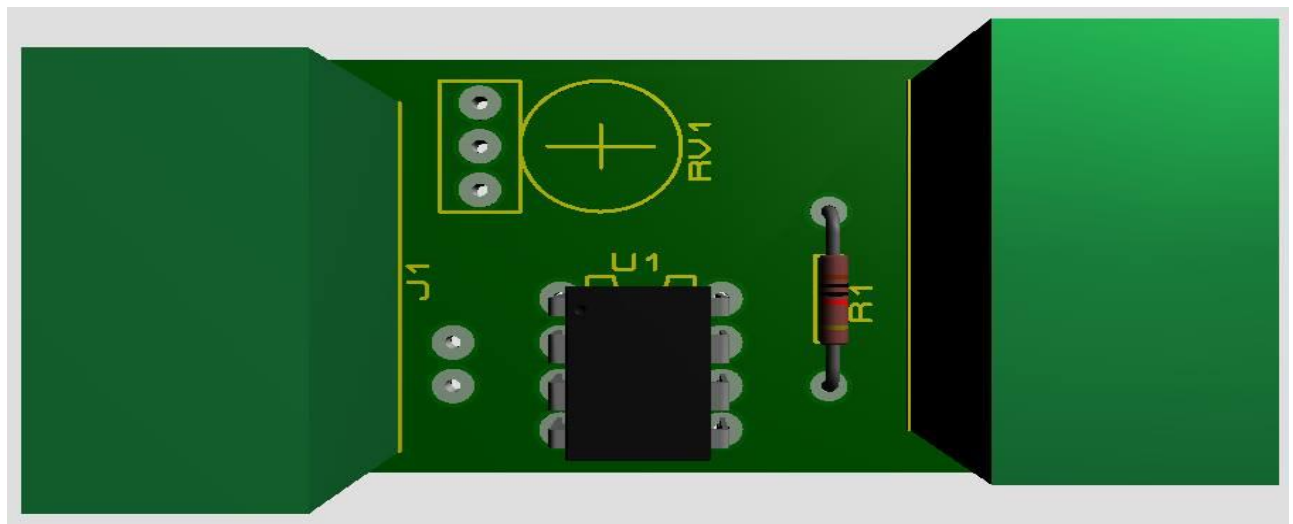


Figure 3.10: 3D view of the Proteus design

3.6.3. Gate driver

The gate driver have been implemented in a PCB board as shown in the figure below.

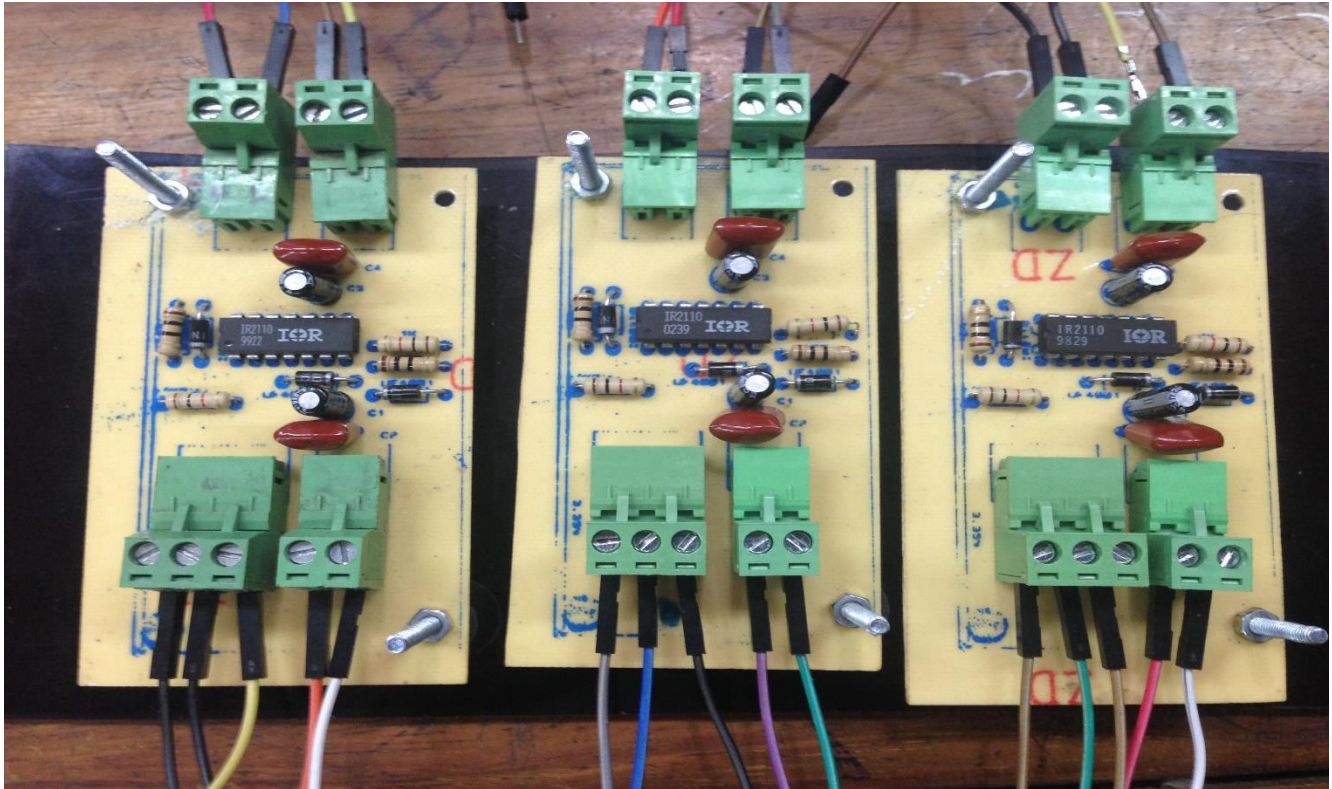


Figure 3.11: The implementation of gate driver circuit

Here three gate drivers have been implemented which generated 6 sets of output. Each of this outputs has been used as gating pulse in the six set of IGBT's in the inverter circuit. The gate driver here is used to turn on the IGBT's as inverter never work without a driver circuit. This driver circuit also acts as an isolation for the inverter.

3.6.4. Total System

The overall circuit diagram connecting the gate driver and the inverter circuit.

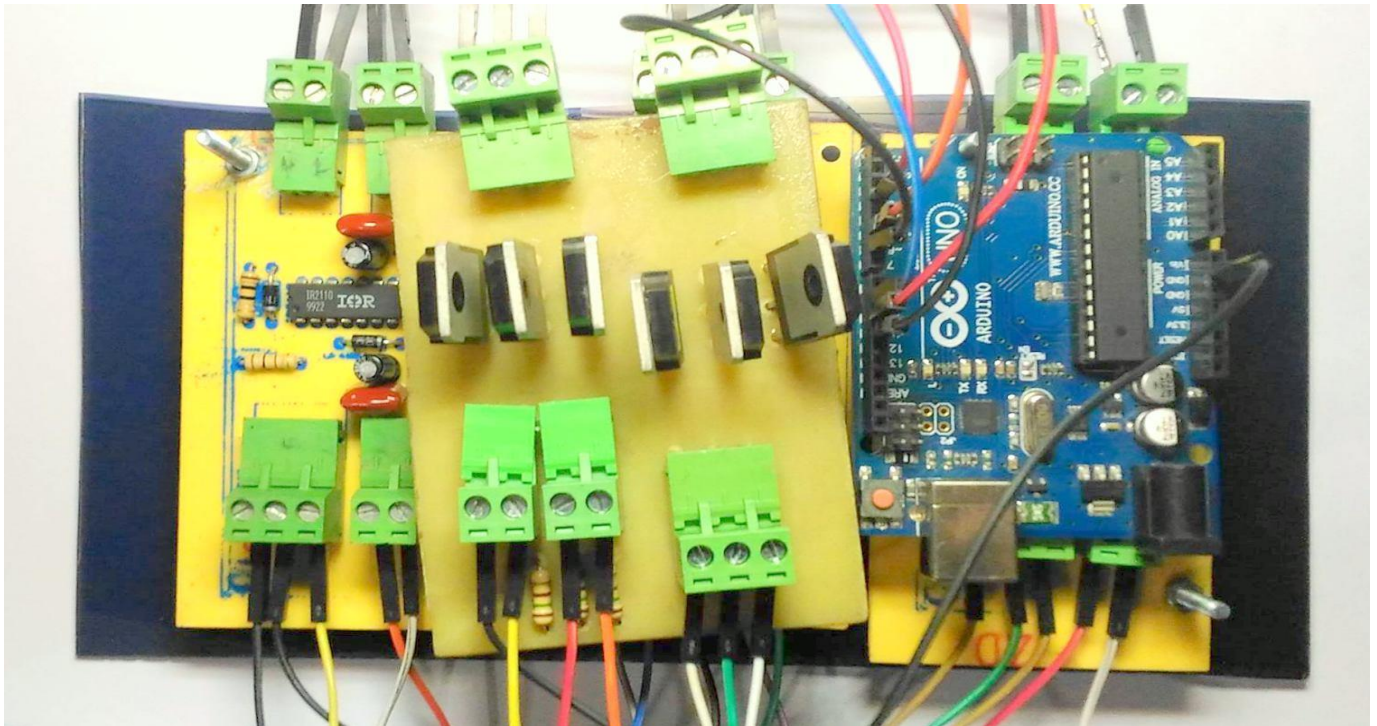


Figure 3.13: The total setup of the inverter

3.7. Summary

Outputs from different components have been collected in this chapter. Hardware outputs were obtained from the circuit connected to Arduino Uno. These outputs have been used to manipulate drivers and circuits.

Chapter 4

RESULTS AND ANALYSIS

4.1. Introduction

Firstly, this chapter covered the simulation parts. Secondly, results have been shown and finally analysis have been made among the results. This chapter also includes the limitations of the design that have been implemented.

4.2. Simulation

The proposed models have been simulated via MATLAB/Simulink software. Simulations are divided into two parts. The model of dc-dc boost converter has been simulated in the first part. The input of dc-dc boost converter is provided by the PV array. In the second part of the simulation, the dc-dc boost converter works as the input of the inverter which is then connected to the grid. In figure 4.1, simulation of boost converter is shown. The output of PV array is shown in figure 4.2. The output of PV array varies with time as depicted in figure 4.2 but the dc-dc boost always provides a fixed dc output of 350V as demonstrated in figure 4.3.

4.2.1. Simulation circuit of the Boost converter including the PID controller

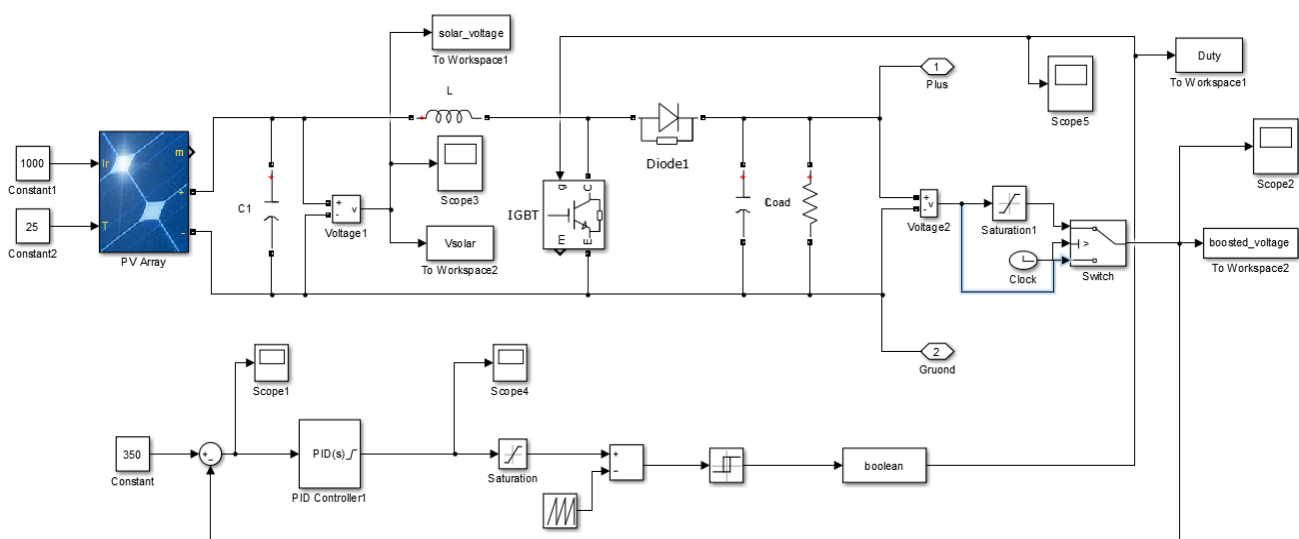


Figure 4.1: Simulation of boost converter with PV arrays.

4.2.2. Output results

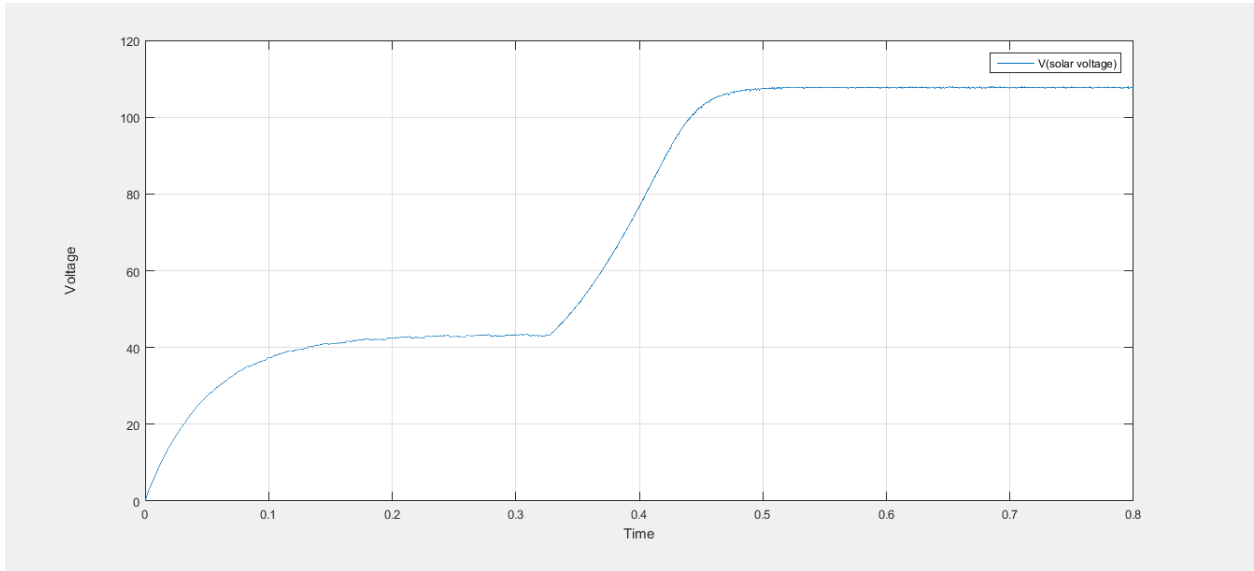


Figure 4.2: Output voltage of PV arrays.

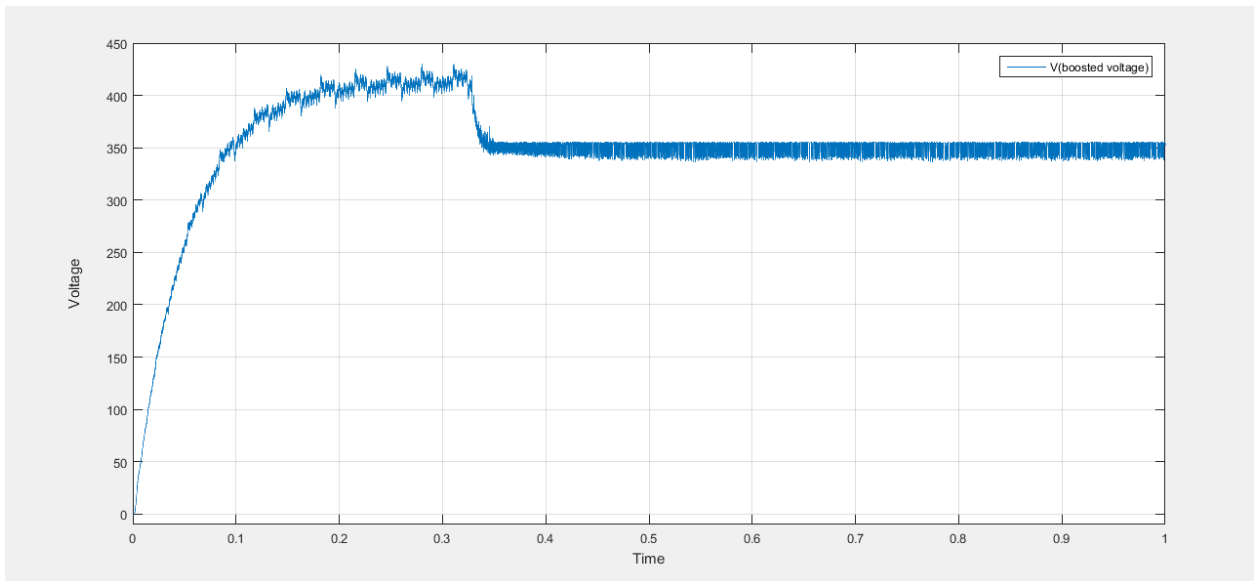


Figure 4.3: Output voltage from the boost converter

4.2.3. Simulation circuit of the whole system

The simulation of whole system is shown in figure 4.4 where the output of dc-dc boost converter is fed into the input of multilevel inverter. The inverter provides 400V line to line voltage and 220V line to neutral voltage to the grid as shown in figure 4.5 and 4.6.

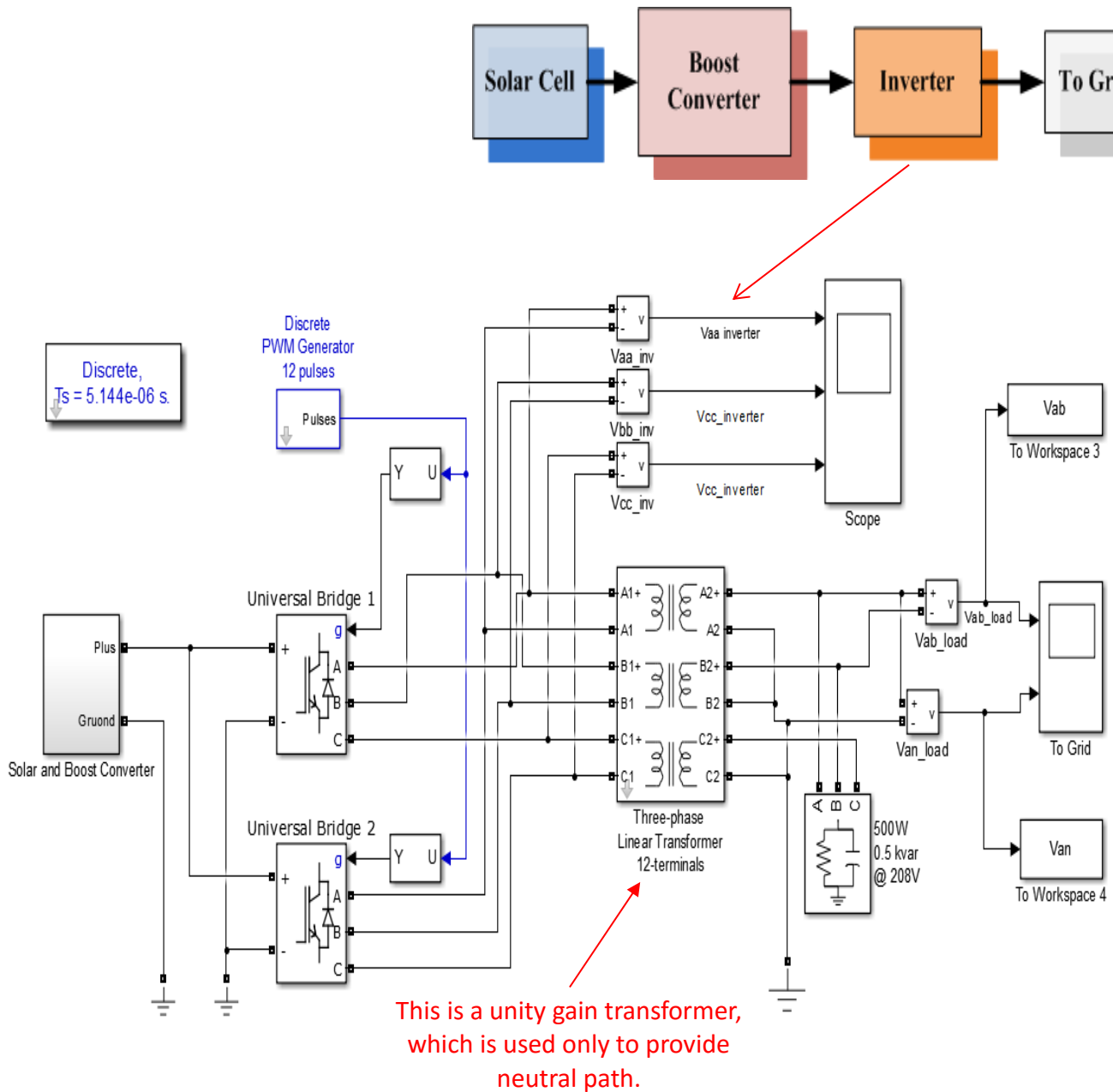


Figure 4.4: Simulation of the overall system with the inverter.

4.2.4. Output Results

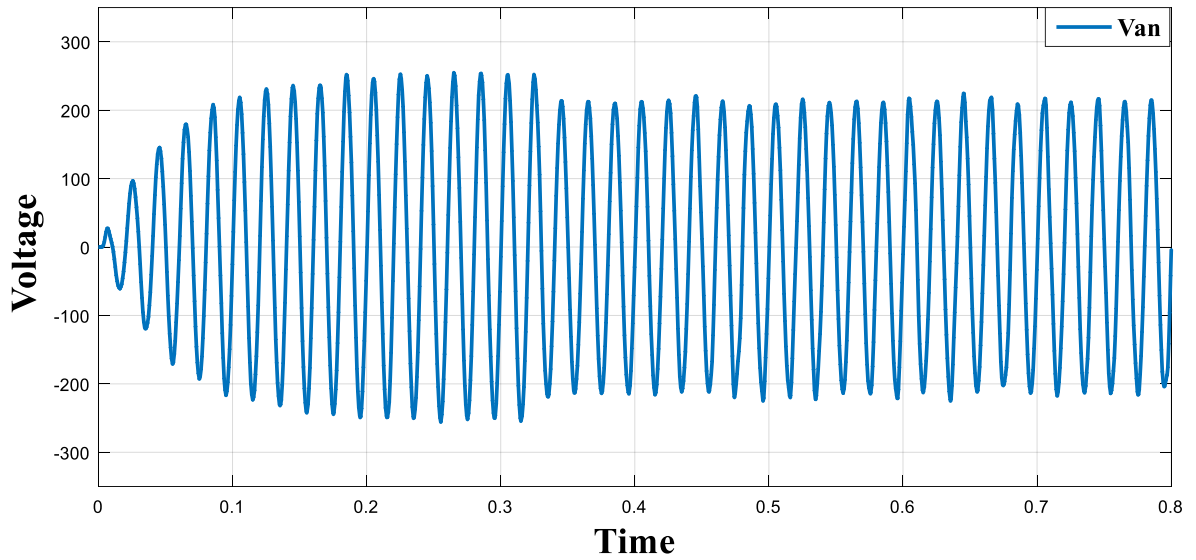


Figure 4.5: line to neutral voltage at the output of inverter.

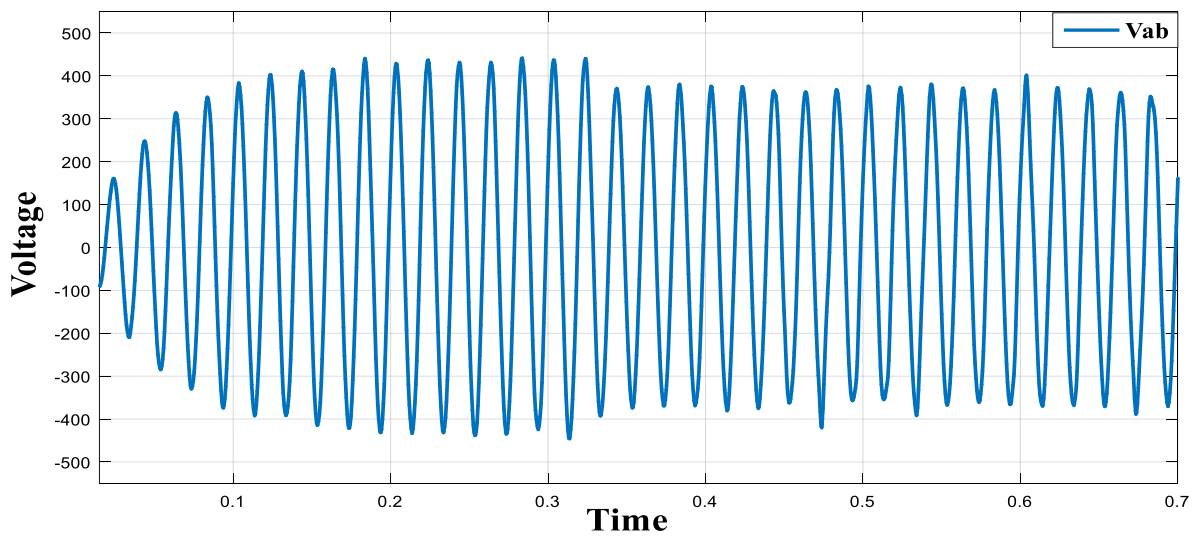


Figure 4.6: line to line voltage at the output of inverter.

4.3. Implementation Results

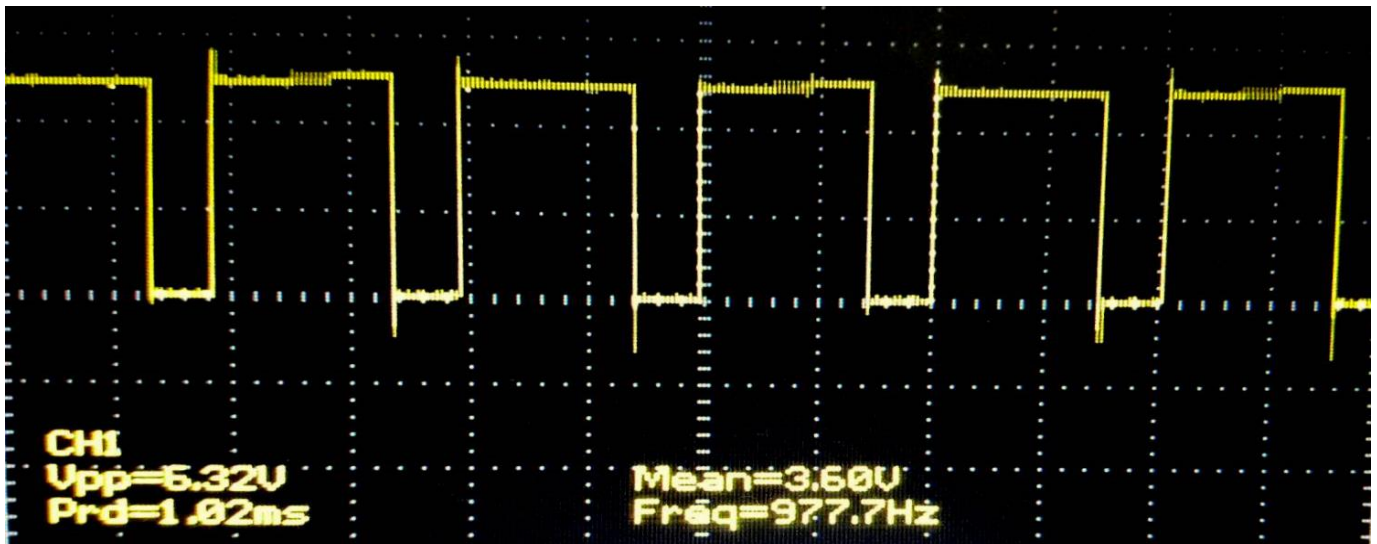


Figure 4.7: Output from the PID controller

The output of the PID controller varies with its need to fix the voltage output of the boost converter to a certain level. It does this by varying its duty cycle in accordance to the output obtained from the PV arrays. Here, its switching frequency is 1 kHz.

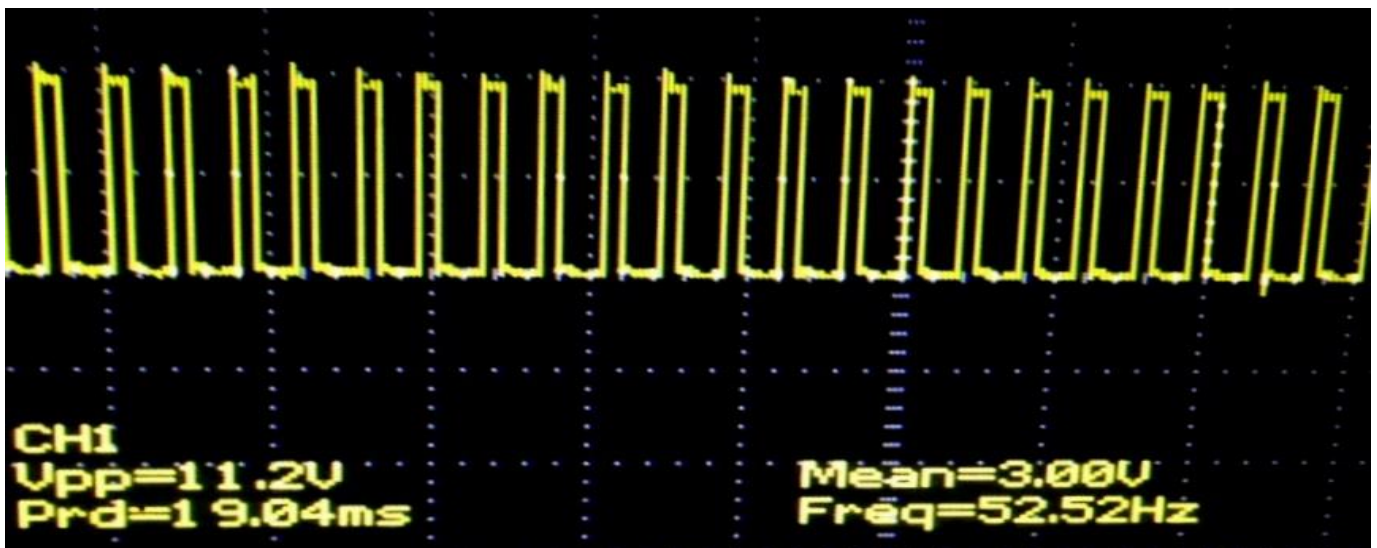


Figure 4.8: Output result of gate driver circuit

The output from the gate driver is required to be such that when a 5 volt amplitude pulse is fed into the circuit, a 12 volt amplitude pulse is obtained in return which is then fed to the gates of the IGBTs.

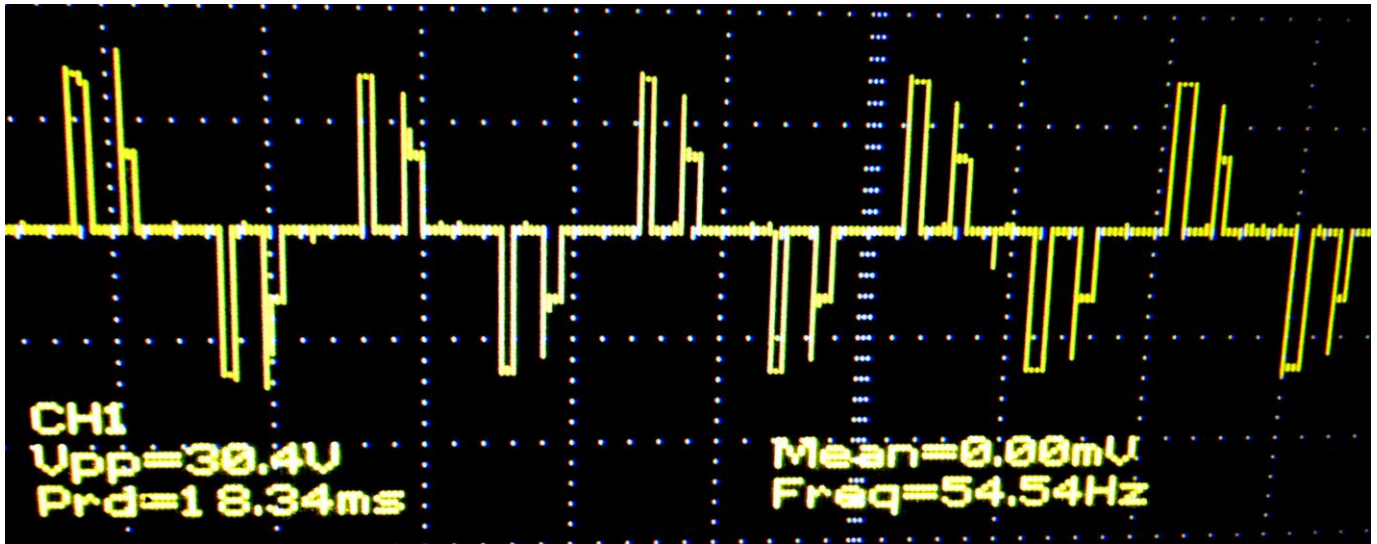


Figure 4.9: Output result of the line to neutral from the inverter

Here the output waveform from the inverter was obtained not totally sinusoidal because in the implemented prototype two inverters has not been cascaded. Increasing the number of levels will smoothen up the wave shape.

4.4. Analysis

The output from the PID controller is limited to ± 5 volt as pulse was generated by the means of Arduino Uno. A Saw-tooth wave was generated using a function generator and the output was fed to a comparator circuit along with the output from the Arduino. The output from the comparator circuit was varied using a potentiometer as shown in the above figure 4.7.

The output shown in figure 4.8 was the output obtained from the implemented gate driver circuit. Usually when a pulse of an amplitude of 5 volt is fed into a gate driver circuit, a 12 volt amplitude pulse is expected in return. Figure 4.8 shows a successful result of the implemented gate driver circuit.

4.5. Summary

In this chapter, a model of single phase transformer-less grid connected system has been simulated part by part and the output of different components has been obtained. Finally, the outputs of hardware implemented circuits are attained and analyzed.

Chapter 5

Discussions and Conclusions

5.1. Discussions

The strategy that we have proposed eliminated the use of transformer which reduced the total cost of the overall system. Our prototype of the proposed model made use of the Arduino Uno microcontroller for the design of PWM signal and PID controller circuit. This led to the advantage where the PWM offered the inverter to obtain sinusoidal waveform effectively and rapidly; the PID controller on the other hand, benefited the dc-dc boost converter to provide a fixed dc output. Multilevel inverter used in our scheme provided better sinusoidal waveform compared to conventional full-bridge inverter.

5.2. Future Work

The future work of this research can extend to the implementation of the whole system for the analysis of inverters response when it is connected to a power source that is generated from the PV array instead of a constant DC source that is used in the lab. This research furthermore opens up the topic to the study of reactive power exchange with the utility grid in large scale.

5.2.1. Suggestions for future work

Increasing the number of level of inverter will lead to better and smooth output that can directly be connected to the grid. For implementation, the use of voltage sensor is highly recommended as it increases the efficiency and response of the total system. It is suggested to increase the equipment ratings for large voltage application and is advised to use Arduino Due to generate sawtooth wave instead of function generator to reduce complication of the circuit.

5.3. Conclusions

Keeping cost, space and other conditions in mind, our scheme turned out to be a good and effective one for grid-tied photovoltaic application. Although our implementation was for small scale voltage only, the hypothesis behind our work matches with our simulated work. This scheme if used in rural area of Bangladesh, the people of this areas will be highly benefitted. The large scale production of this system will lead to the load shading problem in Bangladesh if installed in the rooftop of our home. There is also no high maintenance cost as the system eliminates the use of battery.

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Appendix A

Arduino Software:

<http://arduino.cc/> is Arduino website address. It is full of latest information of model, files and other sources and problem solution discussion related Arduino Uno, Arduino Mega and etc.

Arduino Software can be used in Windows, Mac OS X and Linux. It's easy to write code and upload it to the i/o board.

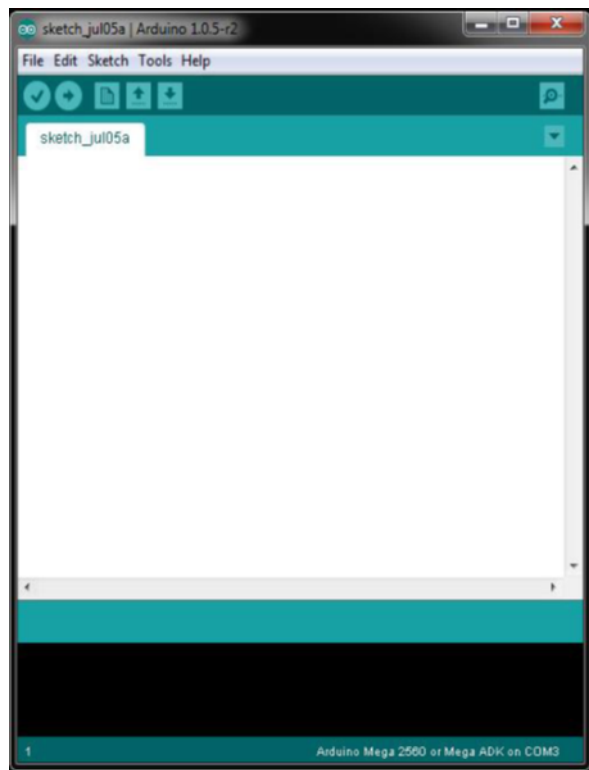


Figure 5.1 Arduino Software

Arduino Uno:

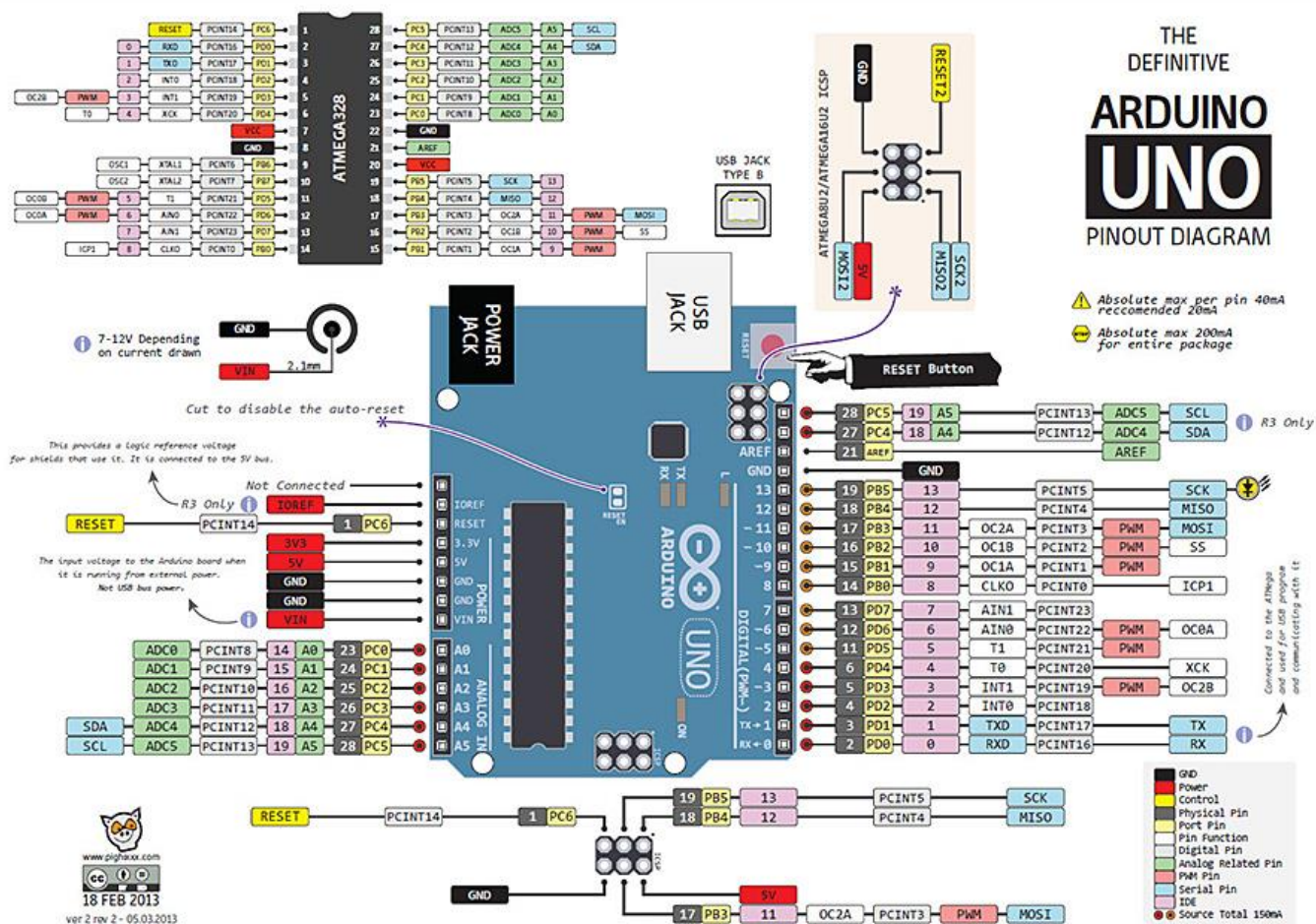


Figure 5.2: Arduino Uno Pin diagram [22]

Code for Arduino (for PID controller):

```
#include <PID_v1.h>

const int ledvoltage = 9; // LED pin for output of PID voltage loop

double Setpoint_voltage, Input_voltage, Output_voltage,lightlevelvoltage;
PID myPID1(&Input_voltage, &Output_voltage, &Setpoint_voltage, .65, 5, 0.0000027, DIRECT);

void setup(){

Serial.begin(9600);
Input_voltage = analogRead(A0);
Setpoint_voltage = 150;
myPID1.SetMode(AUTOMATIC);
}

void loop(){

lightlevelvoltage = analogRead(A0);
Input_voltage = map(lightlevelvoltage, 0, 1023, 0, 255);

Serial.print(" Input voltage = ");
Serial.println(Input_voltage);
delay(1000);

myPID1.Compute();.
analogWrite(ledvoltage, Output_voltage);
delay(30);

Serial.print(" PID output voltage = ");
```



```
Serial.println(Output_voltage);  
delay(1000);  
  
}
```

Code for Arduino (for PWM signal for the gate pulse of inverter):

```
int pin1=3;  
int pin4=9;  
int pin3=5;  
int pin6=10;  
int pin5=6;  
int pin2=11;  
  
float pin61on=6.67; float pin61off=13.33;  
float pin12on=6.67; float pin12off=13.33;  
float pin23on=6.67; float pin23off=13.33;  
float pin34on=6.67; float pin34off=13.33;  
float pin45on=6.67; float pin45off=13.33;  
float pin56on=6.67; float pin56off=13.33;  
  
void setup() {  
  
pinMode(pin1,OUTPUT);  
pinMode(pin2,OUTPUT);  
pinMode(pin3,OUTPUT);  
pinMode(pin4,OUTPUT);  
pinMode(pin5,OUTPUT);  
pinMode(pin6,OUTPUT);  
}  
void loop() {
```

```
{ digitalWrite(pin1,HIGH);  
digitalWrite(pin6,HIGH);  
delay(pin61on);
```

```
digitalWrite(pin1,LOW);  
digitalWrite(pin6,LOW);  
delay(pin61off);}
```

```
{ digitalWrite(pin1,HIGH);  
digitalWrite(pin2,HIGH);  
delay(pin12on);
```

```
digitalWrite(pin1,LOW);  
digitalWrite(pin2,LOW);  
delay(pin12off);}
```

```
{ digitalWrite(pin2,HIGH);  
digitalWrite(pin3,HIGH);  
delay(pin23on);
```

```
digitalWrite(pin2,LOW);  
digitalWrite(pin3,LOW);  
delay(pin23off);}
```

```
{ digitalWrite(pin3,HIGH);  
digitalWrite(pin4,HIGH);  
delay(pin34on);
```

```
digitalWrite(pin3,LOW);  
digitalWrite(pin4,LOW);
```

```
delay(pin34off);}
```

```
{ digitalWrite(pin4,HIGH);  
digitalWrite(pin5,HIGH);  
delay(pin45on);
```

```
digitalWrite(pin4,LOW);  
digitalWrite(pin5,LOW);  
delay(pin45off);}
```

```
{ digitalWrite(pin5,HIGH);  
digitalWrite(pin6,HIGH);  
delay(pin56on);
```

```
digitalWrite(pin5,LOW);  
digitalWrite(pin6,LOW);  
delay(pin56off);}
```

```
}
```