DESIGN AND IMPLEMENTATION OF GRID CONNECTED INVERTER USING PIC 16F887 CONTROLLER

By

HEMDIPSINH S GOHIL

12MEEP07

DEPARTMENT OF ELECTRICAL ENGINEERING

AHMEDABAD-382481

MAY 2014

DESIGN AND IMPLEMENTATION OF GRID CONNECTED INVERTER USING PIC 16F887 CONTROLLER

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(Power Electronics, Machines & Drives)

By

HEMDIPSINH S GOHIL

12MEEP07

DEPARTMENT OF ELECTRICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

MAY-2014

Certificate

This is to certify that the Major Project Report (Part-II) entitled **" DESIGN AND IMPLEMENTATION OF GRID CONNECTED INVERTER USING PIC 16F887 CONTROLLER"** submitted by **Mr.HEMDIPSINH S GOHIL (Roll No: 12MEEP07)** towards the partial fulfillment of the requirements for semester-IV of Master of Technology (Electrical Engineering) in the field of Power Electronics, Machines & Drives of Nirma University is the record of work carried out by him under our supervision and guidance.The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Date:

Project Guide

Prof. MIHIR.C.SHAH

Department of Electrical Engineering

Institute of Technology

Nirma University

Ahmedabad

Head of the Department

Department of Electrical Engineering

Institute of Technology

Nirma University

Ahmedabad

Director

Institute of Technology

Nirma University

Ahmedabad

Undertaking for Originality of the Work

I **Hemdip S. Gohil**, Roll No. **12MEEP07**, give undertaking that the Major Project entitled **"DESIGN AND IMPLIMENTATION OF GRID CONNECTED INVERTER USING PIC16F887"** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Power Electronics Machines** & **Drives, Electrical Engineering**, under Institute of Technology of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

....

Signature of Student

Date:

Place:

Endorsed by:

....

(Signature of Project Guide)

Mihir C. Shah

Assistant Professor

Department of Electrical Engineering

Institute of Technology

Nirma University

Ahmedabad

Acknowledgement

I owe a great many thanks to a great many people who helped and support me during this project. My deepest thanks to Dr. P. N. Tekwani (Head of Department, Electrical Engineering, IT, NU) and Prof. Mihir. C. Shah (Assistant Professor, Electrical Engineering Department, IT, NU) the guides of the project for guiding me with great attention and care.I am very thankful to Dr. K. Kotecha (Director, IT, NU) for providing the great facilities for the work.I am also thankful to lab assistant Rakeshbhai,Bhaveshbhai,Sajidbhai,Hiteshbhai.I am also thankful to peon Ravibhai and my classmates.I am also thankful to all the member of Electrical Engineering Department who have directly or indirectly helped me during the project.

Special thanks to my parents , my family and God , without their support i can not reach at this stage.

HEMDIPSINH GOHIL
12MMEP07

Abstract

The grid connected inverters are often used to convert DC power into AC. MPPT (maximum Power Point Tracking) algorithm is used to find maximum Power Point of the Solar.MPP is the operating point of the solar panel. From the MPPT algorithm, the Voltage and Current are given to boost converter.The PIC controller is used for MPPT algorithm. The output of the boost converter is given to 3-phase inverter using SVPWM.The SVPWM is advanced method and best method among all PWM techniques. The percentage THD is less in case of SVPWM.The output of inverter is given to PLL block. According to output of the PLL block, the gate pulses are given to inverter to match the Grid Voltage and Phase.

List of Figures

Abbreviations

PV .... Photo Volaitic
VSI .... Voltage Source Inverter
THD .... Total Harmonic Distortion
IEEE .... Institute of Electrical and Electronic Engineers
PWM .... Pulse Width Modulation
IGBT .... Insulated Gate Bipolar Transistor
MOSFET .... Metal Oxide Semiconductor Field Effect Transitor
PLCs .... Programmable logic controller
LPF .... Low Pass Filters)
ADC .... Analog to Digital Converter
CAP .... Capture
VSI .... Voltage Source Inverter
WD .... Watchdog Timer

Nomenclature

P_o .... Output Power

V_{out} .... Output Voltage

I_l .... Load Current

V_{in} .... Input Voltage

f_s .... Switching Frequency

D_{max} .... Maximum Duty Cycle

D_{min} .... Minimum Duty Cycle

ϕ .... Phase

Contents

Chapter 1

Overview of grid connected system

1.1 Introduction

PV Panels generates DC power.The main function of solar inverter is to convert the direct power generated by solar panels into grid-synchronized alternating Power. Depending on the PV power plant, PV inverters can be categorized as:[1]

- Module integrated inverters, typically in the 50 to 400 W range for very small PV plants
- String inverters, typically in the 0.4 to 2 kW range for small roof-top plants with panels connected in one string.
- Multi string inverters, typically in the 1.5 to 6 kW range for medium large roof-top plants with panels connected in one to two strings.
- Mini central inverters, typically 6 kW with three-phase topology and modular design for larger roof-tops or smaller power plants in the range of 100 kW and typical unit sizes of 6, 8, 10 and 15 kW.

Central inverters, typically in the 100 to 1000 kW range with three-phase topology and modular design for large power plants ranging to tenths of a MW and typical unit sizes of 100, 150, 250, 500 and 1000 kW.

so, voltage cannot be controlled.

1.2 Scope of work

The function of the grid-connected system is to deliver energy into grid with a power factor nearly unity. The Grid connected inverters are available in different technologies in markets. Instead of converting direct current directly to 120 V or 240 V AC, high-frequency transformers employ computerized multi-step process that involves converting the power to high-frequency AC and then back to DC and then to the final AC output voltage.

1.3 Problem identification

- Photo volatic inverters have high cost, weight, size and low efficiency due to presence of transformer.
- As per the sandwich structure involving glass, silicon semiconductors capacitance to earth is appearing so it creates leakage current.
- PV inverters generally do not give high efficiency due to reduced radiation levels.

1.4 Solution of problem

- To increase efficiency,reduced size and cost of PV inverter, transformer less system is used.

Chapter 2

Literature survey

- Duy C huynh,Thu A.T nguyen**"Maximum Power Point Tracking of Solar Photovoltalic Panels using Advance P and O Algorithm"**
  in this paper the P and O algorithm is given.The example of finding MPPT algorithm is given with proper figure.This paper proposes an advanced perturbation and observation (PO) algorithm for tracking the maximum power point (MPP) of a solar PV panel. Solar PV cellshave a non-linear Voltage-Current characteristic of diffrent MPP which depends on environmental factors for examples temperature and solar irradiation. The proposed P and O algorithm can reduce the main drawbacks commonly related to the PO algorithm.

- Snehamay Dhar,PG Scholar,SRM university **"Implementation of PV Cell Based Standalone Solar Power Syatem Employing Incremental Conductance MPPT Algorithm"**
  The Incremental and Conduction algorithm is given in this paper.the PV cell with DC-DC converter is explaind with same algorithm with suitable example.The paper presented here proposes a Photovoltaic (PV) System consists of PV panel, Maximum Power Point tracker (MPPT) DC-DC boost converter targeted for DC loads of a Stand-Alone Photovoltaic application. A circuit based simulation of Photovoltaic (PV) panel is proposed in order to analyse

and estimate the electrical behaviour of the panel with respective change in environmental conditions like irradiation and temperature. The Photovoltaic (PV) panel characteristic wh ich is achieved from Shockley diode equation is non linear in nature.Thus Maximum Power Point tracker is designed with the help of a new circuit based simulation of Incremental Conductancealgorithm to extract maximum power from the panel. A DC-DC boost converter is designed to get constant DC voltage output from changing DC panel voltage and hence duty cycle of the converter is calculated accordingly.

- W Houshng,School of Electrical and electronic engineering,Shandong University,china**"Research on Maximum power point Tracker based on solar Simulator"**
  in this paper the example of cuk converter is given.it is helping to find parameter related to buck boost converter.In this paper, it uses a DC power supply and a variable resistor for simulation of the solar cells output characteristic curve, its feasibility is analyzed theoretically. The basic principle of the maximum power point tracking (MPPT) is described in detail.

- David Sanz Morales Faculty of Electronics, Communications and Automation Thesis submitted for examination for the degree of Master of Science in Technology. Espoo 14.12 **"Maximum Power Point Tracking Algorithms for Photovoltaic Applications"**
  In this thesis all information about solar cells is given.Solar panels have a nonlinear voltage-current characteristic, with a diffrent maximum power point (MPP). In the past decades many MPPT techniques have been published. The first view of this thesis is to study and analyze them. The three algorithms that where found most suitable for large and medium size photovoltaic (PV) applications are perturb and observe (P and O), incremental conductance (InCond) and fuzzy logic control (FLC). These were compared and tested dynamically according a recently issued standard.Several modifications to the PO and the

InCond algorithms are proposed, which overcome their poor performance when the irradiation changes continuously.

- **“TuDelft University of technology Bacherlor Thesis” ”Maximum Power Point Tracking: Algorithm and Software Development”**-Stefan Moring and Anton Pols
  In this thesis the comparatively study of all methods of MPPT algorithm is given. Basic overviews of the methods are given shortly.In this thesis, different options were explored to solve the problem of tracking the MPP of a solar panel. The focus of this thesis was the software part of tracking the MPP and the goal of this thesis was to implement the most efficient algorithm that works in fast changing levels of irradiation and when the solar panels are partially shaded.

- L .Umanand **“Power Electronics Essentials and Application”**
  In this book the process of finding the value of inductor and capacitor for boost converter and for buck boost converter.

Chapter 3

Model Topology

3.1 Introduction

Solar panels have a characteristic which is nonlinear .Global warming and energy policies have become a very popular topic in market in the last years. Many countries are trying to reduce their greenhouse gas emissions. photovoltaic (PV) power generation is a green source.

Most of the solar power generation comes from grid-connected installations. The efficiency of a PV plant is affected mainly by three factors: the efficiency of the PV panel (in commercial PV panels it is between 8-15%) , the efficiency of the inverter (95-98 %) and the efficiency of the maximum power point tracking (MPPT) algorithm (which is over 98%). Improving the efficiency of the PV panel and the inverter is not easy. it may require high cost of the installation.

MPPT algorithms are necessary for solar cells. PV arrays have a non linear voltage-current characteristic with a unique point where the power produced is maximum. This point depends on the temperature of the panels and on the irradiance conditions.

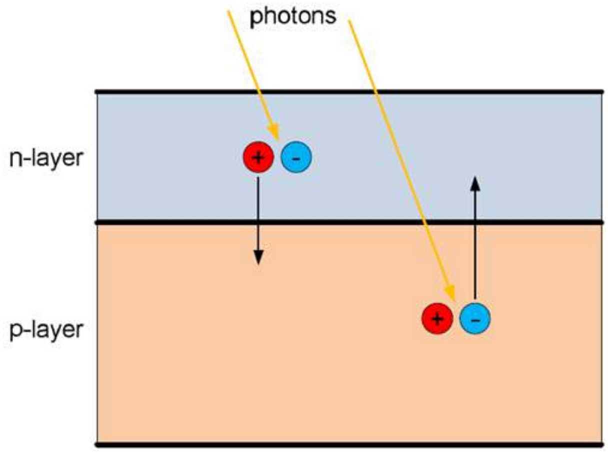

Figure 3.1: Solar cell

3.2 Solar Cell

3.2.1 Principle of Solar cell

Solar cells are basic components of photovoltaic panels. It takes advantage of the photoelectrical effect. The photoelectrical effect is to convert electromagnetic radiation directly into electrical current by semiconductors.

A solar cell is basically a p-n junction made from two different layers of silicon doped with n-layer and p-layer. When two layers are joined together, the holes from p layer and free electron from n layer interfaces each other and produce electrical energy. The diagram of solar cell is shown in figure 3.1 Metallic contacts are added at both sides to collect the electrons and holes so the current can flow. some of the photons are reflected from the top surface of the cell and metal Fingers. Only those photones with Energy level above the band gap of the silicon can create an electron-hole pair. If solar irradiation is higher, more photons will be generated. so now photons have enough energy to create pare electrons-holes pairs and consequently more current generated by solar cell.

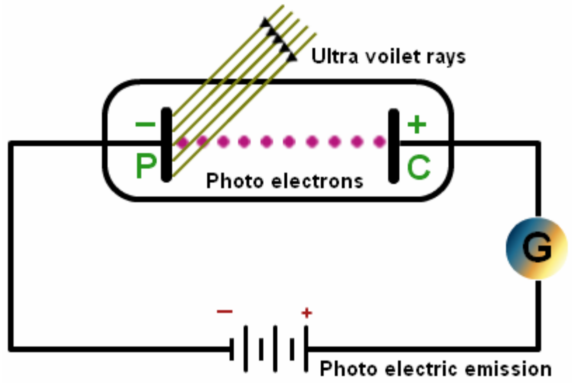

Figure 3.2: Photo electric emission

3.3 Working of solar cell (Photo Electric Emission)

Figure 3.2 shows the working of solar cell. In the figure , photosensitive plate called emitter P and collector C. Plate P is connected to the lower potential terminal and plate C is connected to the higher potential terminal of a battery through rheostat R. The potential difference between the plates P and C can be adjusted by changing the point of the rheostat. When light of suitable wavelength is incident on the plate P then electrons are emitted and reaches plate C, thus measurable current flows through the circuit.

3.4 Types of solar cells [1]

Silicon is used for manufacturing solar cell.

Types of solar cells are:

- *Monocrystalline silicon*
- *Polycrystalline silicon*
- *Amorphous and thin film silicon*

3.4.1 Monocrystalline silicon

These cells are made from pure molten silicon wafers.fig.3.3 shows the Monocrystalline silicon cell. It has crystallized structure. Size and shape of wafers are uniform. The

Figure 3.3: Monocrystalline silicon

efficiency of these cells is around 15-18% and 1 kW power in STC (standard test condition) is about 7 m^2.

3.4.2 Polycrystalline silicon

These cells are made from pure molten silicon wafers. The crystal structure is not uniform. So size and shape of cell is irregular. Fig.3.4 shows the poly crystalline silicon cell. The efficiency of these cells is 11-15%.manufacturing cost is less. The surface needed to obtain 1 kW in STC is about $8m^2$

Figure 3.4: Polycrystalline silicon

3.4.3 Amorphous and thin film silicon

It has non crystalline form of silicon.thin films are deposited onto different substrates.Fig.3.5 shows the Amorphous and thin - film silicon cell. The manufacturing process is simpler, easier and cheaper than crystalline cells. its efficiency is 6-8% in STC .its temperature coefficient is low. It has better ability to absorb the light than crystalline.

Figure 3.5: Amorphous and thin film silicon

3.5 Inverter topologies [9]

Inverters are used to convert DC to AC.DC voltage from PV model is converted by inverter. There are different inverters configurations. The different topologies of inverters are:

- *Central inverter*
- *String inverter*
- *Multi string inverter*
- *Module integrated inverter*

3.5.1 Central inverter

It is the simpler configuration of inverter.Solar strings are connected in series. number of series strings are connected in parallel so we get desired output power. Fig 3.6 shows the block diagram of Central inverter confugration.all PV strings operate at same voltage. Mismatches may occur between different PV modules. Sometimes they receive different irradiation so it is difficult to find the power losses and Maximum Power Point (MPP).

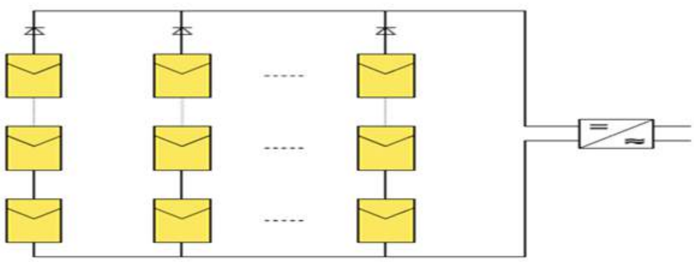

Figure 3.6: Central inverter

3.5.2 String inverter

In this configuration, every string of PV panels connected in series. All series strings are connected to different inverter. Fig 3.7 shows the block diagram of string inverter. The mismatches problem do not occur in this case because all strings operate at different MPP.As the number of components of the system increase, the installation cost increase. Number of inverters is used for each string.

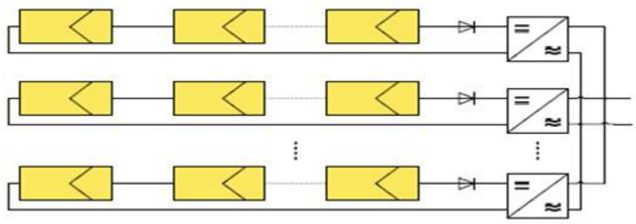

Figure 3.7: String inverter

3.5.3 Multi string inverter

In this configuration, the string of PV cell connected to different DC-DC converters. Each string has different MPP.Fig 3.8 shows the block diagram of Multi- String inverter. The price of this configuration is high as compare to string configuration.

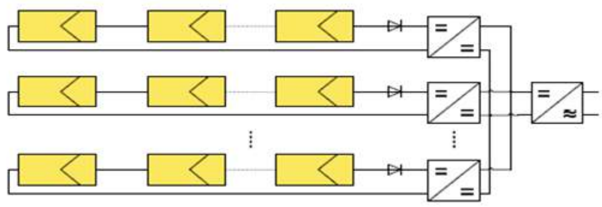

Figure 3.8: Multi string inverter

3.5.4 Module integrated inverter

In this configuration each PV cells are connected to different inverter. Fig 3.9 shows the configuration of Module integrated inverter.indivitual MPP is tracked by each inverter. When operating point of different modules have differences, this configuration is used.

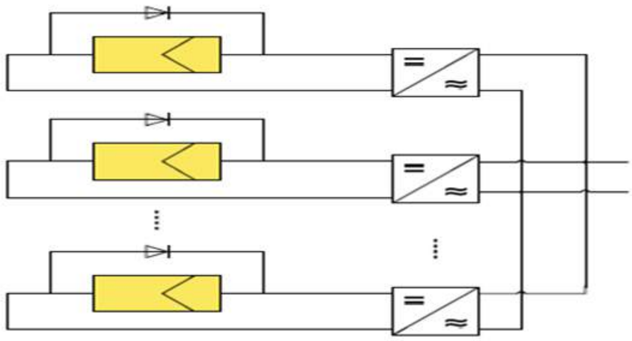

Figure 3.9: Module integrated inverter

3.6 Maximum Power Point Algorithm [2],[3]

MPPT algorithm used for buck, boost converters in continuous conduction mode. The main problem solved by the MPPT algorithms is to automatically find the panel operating voltage which gives maximum power output.

The open circuit voltage is maximum voltage of the panels. The short circuit current of the panel is the absolute maximum current. Here are some graphs related to find maximum power point.

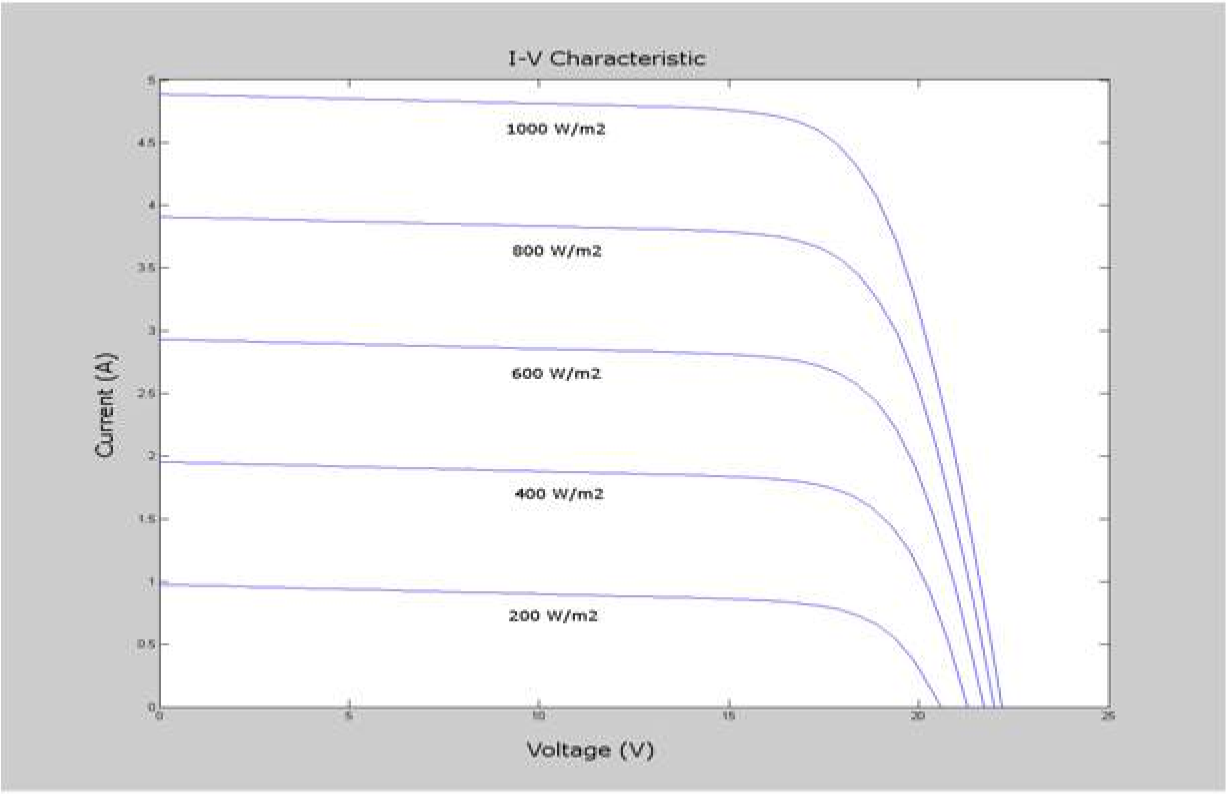

Figure 3.10: Voltage - Current Characteristic [2]

Fig 3.10 shows the V-I characteristic of PV panel.

3.6.1 Maximum Power Point Algorithm [2],[3]

The equation for open circuit voltage for different irradiance and temperature condition is:

$$V_{MPP} = k_v V_{oc} \quad (3.1)$$

The constant "k" depends on the type and configuration of the photovoltaic panel. by this equation, the open circuit voltage for MPP calculated. The load is disconnected periodely and V_{oc} can be measured.

3.6.2 Short Circuit current

The equation for open circuit voltage for different irradiance and temperature condition is:

$$I_{MPP} = k_I Isc \quad (3.2)$$

The constant k depends on the type and configuration of the photovoltaic panel. By this equation, the short circuit current for MPP is calculated. The load is disconnected periodely. For measurement of I_{sc}, an additional switch and current sensor require.

3.6.3 Types of MPPT algorithm

- **Hill-climbing techniques**[2],[3],[4]

This method is based on hill-climbing principle. In this principle, the operating point moving in the direction of power increases.This method is very easy to implement ion and also good performance so it is very popular method.

- **Perturb and observe (P and O)**[2],[3],[4]

P and O algorithm is same as Hill-climbing algorithm. The different between P and O and Hill-climbing algorithm is Hill-climbing method see small change on the duty cycle of the power converter while P and O see the operating voltage on the DC link between solar array and the power converter. In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be. Fig 3.11 show that any increment in the power,

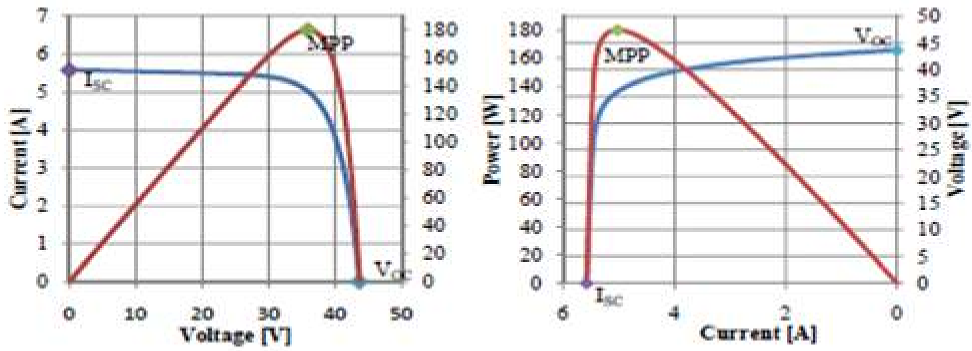

Figure 3.11: PV panel characteristic curves.

the calculation (perturb) should kept in the same direction otherwise it should be in opposite direction. Based on this the algorithm is implemented.

- **Incremental conduction** [4]

In this method, the derivation of voltage with respect to power use. If the derivation of voltage with respect to power is is zero, it gives MPP.Same curves of P and O method is used. If:

$\Delta V/ \Delta P = 0$ or $\Delta I /\Delta P = 0$ at the MPP

$\Delta V /\Delta P = 0$ or$\Delta I / \Delta P = 0$ on the left

$\Delta V /\Delta P = 0$ or$\Delta I /\Delta P = 0$ at the right

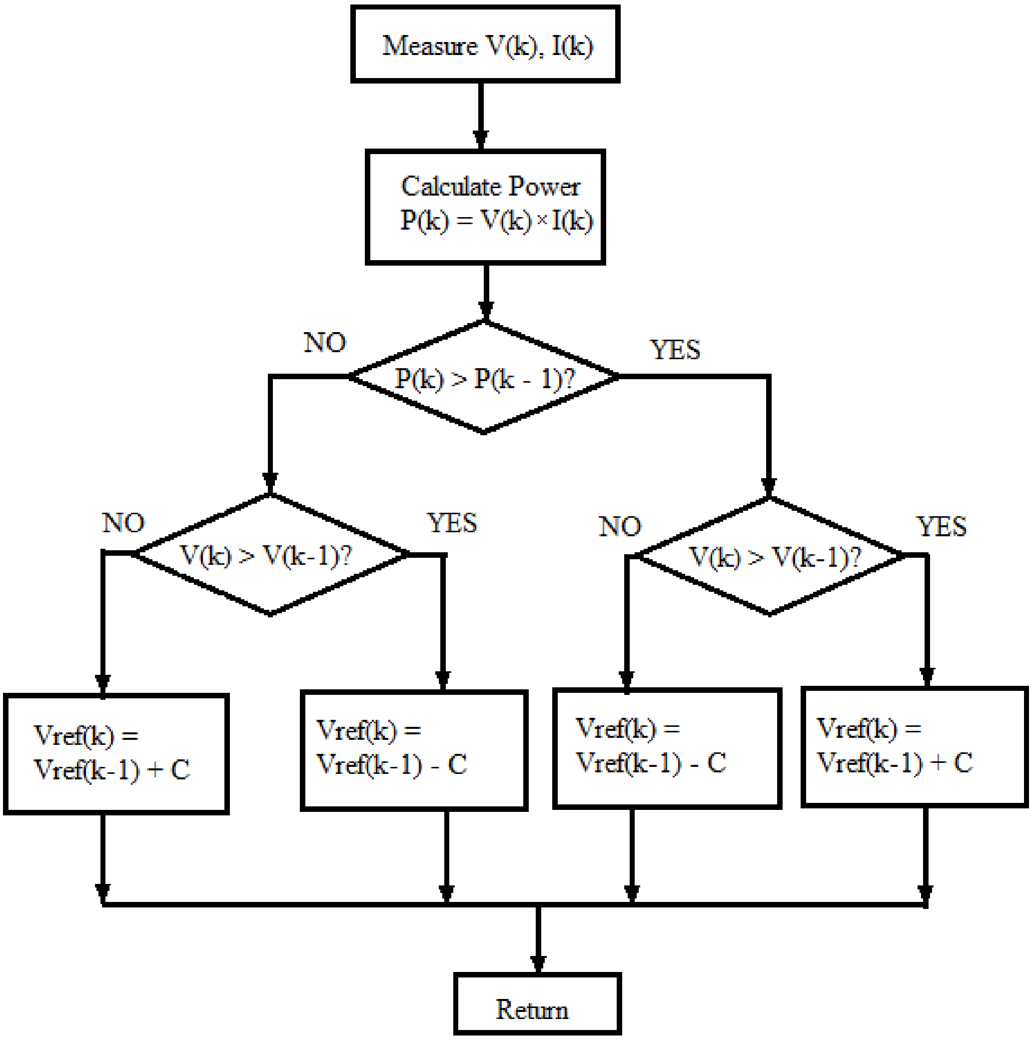

Figure 3.12: Flow chart of P and O method

3.7 Block diagram of grid connected inverter with PV cell.

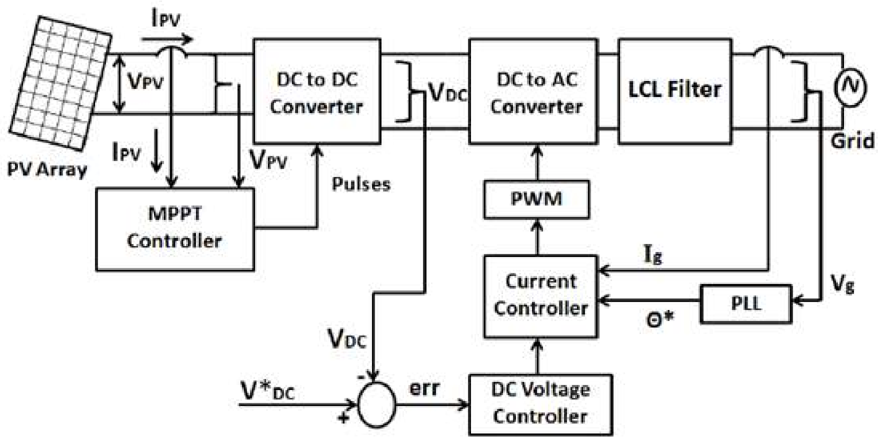

Figure 3.13: Block diagram of grid connected inverter with PV cell.

Fig 3.12 shows the overview of grid connected inverter with PV cell. In this figure the output of PV array is given to boost converter. The output of PV array is low so boost converter is needed. The duty cycle of the boost converter is controlled by MPPT controller. The output of the boost converter is given to the single phase/three phase inverter as per requirement. The output of inverter is not pure ac so it is require using filter at the end of inverter. The output of the filter is given to the grid but it is processed with Phase locked Loop for matches with grid. The actual DC voltage and reference DC voltage is compared and error processed with DC voltage controller. The output of DC voltage controller is given to current controller. The actual grid current Ig and voltage Vg given to current controller to generate desired PWM for inverter.Vg is processed in PLL.Thus; the close loop for whole system is completed.

3.8 Phase Locked Loop Circuit

In PLL block , there is VCO, phase detector, and low pass filter . Its purpose is to replicate and track the frequency and phase at the input when in lock. The PLL is a control system allowing one oscillator to track with another. $\Phi_{out}(t)$=$\Phi_{in}(t) + const$ $\omega_{out)(t)}$=$\omega_{in}(t)$

There are many applications for the PLL, but we will study: a. Clock generation b. Frequency synthesizer c. Clock recovery in a serial data link the block diagram of PLL block is shown in fig 3.14

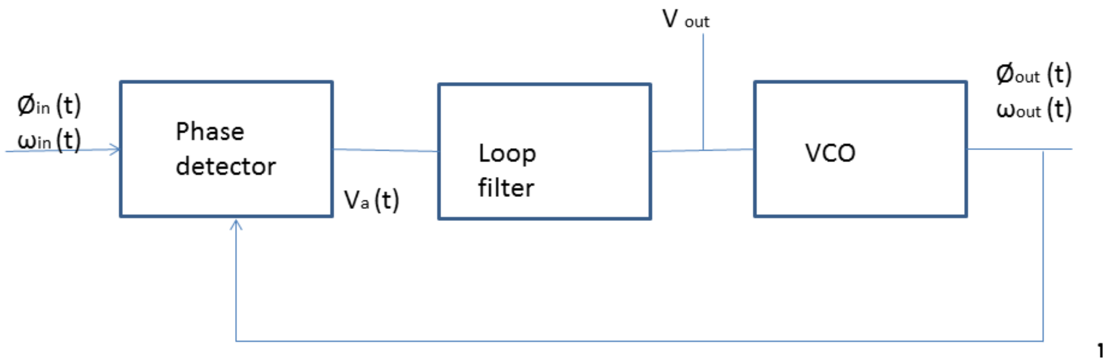

Figure 3.14: Block diagram of PLL block

Chapter 4

Simulation Results

4.1 DC-DC Boost converter

Generally, the output voltage of the PV panels is not constant. Sometimes it is low. so to make DC link voltage constant and to boost the output of the PV panels, the boost converter is used.

4.1.1 Boost inductor design

The value of inductor is finding from equation 4.1[10]

$$L = V_i D / \Delta i_L f_s \tag{4.1}$$

L= Value of inductor
V_i=input voltage
D=duty ratio
i_L=ripple current of inductor
F_s=switching frequency
To regulate V_0 (output voltage) with variation in Vi, the value of D should be varied. Thus if V_{imax} is maximum input voltage swing then D_{min} will be the corresponding

minimum duty cycle to obtain a specified V_0 . If V_{imin} is the minimum input voltage,then D_{max} will be the corresponding maximum duty cycle to obtain the specified V_0. Thus,for a regulated V_0

$$V_0 = V_{imax}/(1 - D_{min}) = V_{imin}/(1 - D_{max}) \tag{4.2}$$

From equation 4.2;

$$L = V_{imax} D_{min}/\Delta i_L f_s \tag{4.3}$$

4.1.2 Capacitor value [10]

The value of capacitor is known from question 4.4

$$C = I_0 D/\Delta V_0 f_s \tag{4.4}$$

Where,

I_0 = output current

V_i = input voltage

ΔV_0 = output ripple specification

Δi_L and F_s are the design specification.

For example, if

F_s = 50 kHz

V_0 = 15 volt

V_{imax} = 10 volt

V_{imin} = 5 volt

R_L = 15 Ω

Δi_L = 10% of inductor current

ΔV_0 = 1% of output load voltage

I_0 = 1 amp.

From equations (4.2) and (4.3) $D_{min} = 0.333$ and $D_{max} = 0.666$,

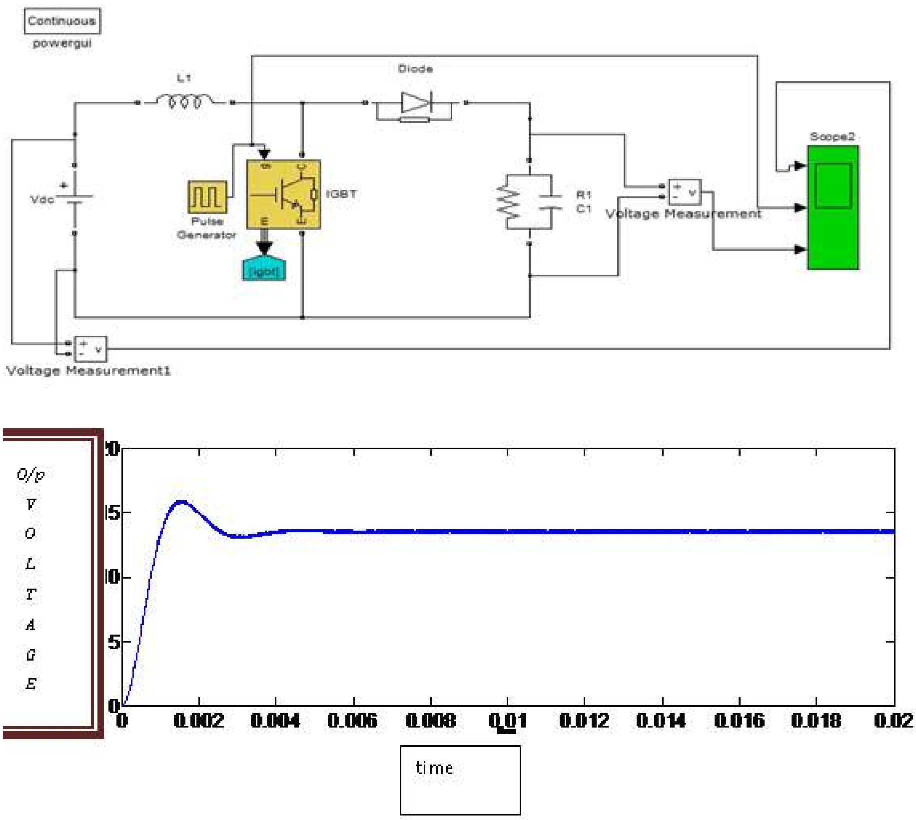

Figure 4.1: Boost Converter and waveform

L= $4.44 * 10^{-4}$ H.

from equation (4.4) C $= 8.88 * 10^{-5}$ F

With reference to above value the matlab model for boost converter and it's Waveform is shown in fig 4.1

4.2 Inverter

To convert DC to AC and giving AC supply to grid, the inverter is use, which convert DC power from DC link into AC.There are many topologies of inverter for single phase and three phases.

4.2.1 PWM Inverter

In this technique the reference signal and carrier signal are compared to generate gating signal of each switches of inverter. The output voltage waveform pattern is replica of reference signal. Its frequency is same as reference signal. The ratio between reference signal frequency and carrier signal frequency give the modulation index which determines number of pulses per half cycle. For single phase inverter bipolar inverter and unipolar inverter technique is used.

Advantage of PWM

The distortion factor is low as compare to single phase pulse width modulation.

Disadvantage of PWM

- The switching losses are high.

4.2.2 Unipolar PWM Inverter

In this technique, the spectrum of frequency is improved. The ripple current is less. The output voltage swing between 0 and V_{dc} for positive half cycle and zero to V_{dc} for negative half cycle.

Advantage of UNIPOLAR

- pesentage THD is low compared to bipolar
- EMI reduces

Disadvantage of UNIPOLAR

- High switching losses

fig 4.2 shows waveform of unipolar switching for single phase inverter.

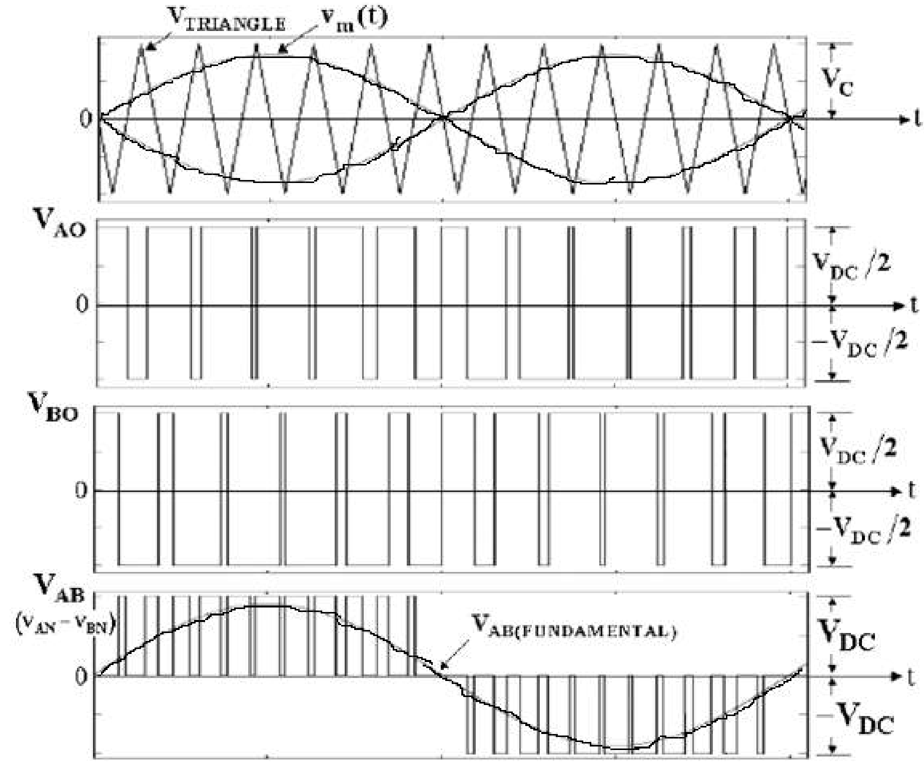

Figure 4.2: Waveform of unipolar single phase inverter

4.2.3 Bipolar PWM Inverter

In this scheme the sine triangle signals are compared. Diagonally switches are switched simultaneously. The output voltage changes between V_{dc} to V_{dc} instead of V_{dc}/ 2 to V_{dc} / 2 in case of unipolar PWM inverter.fig. 4.3 Shows the waveform of bipolar PWM inverter.

Advantage of BIPOLAR

- Implementation is simple
- Switching losses are less

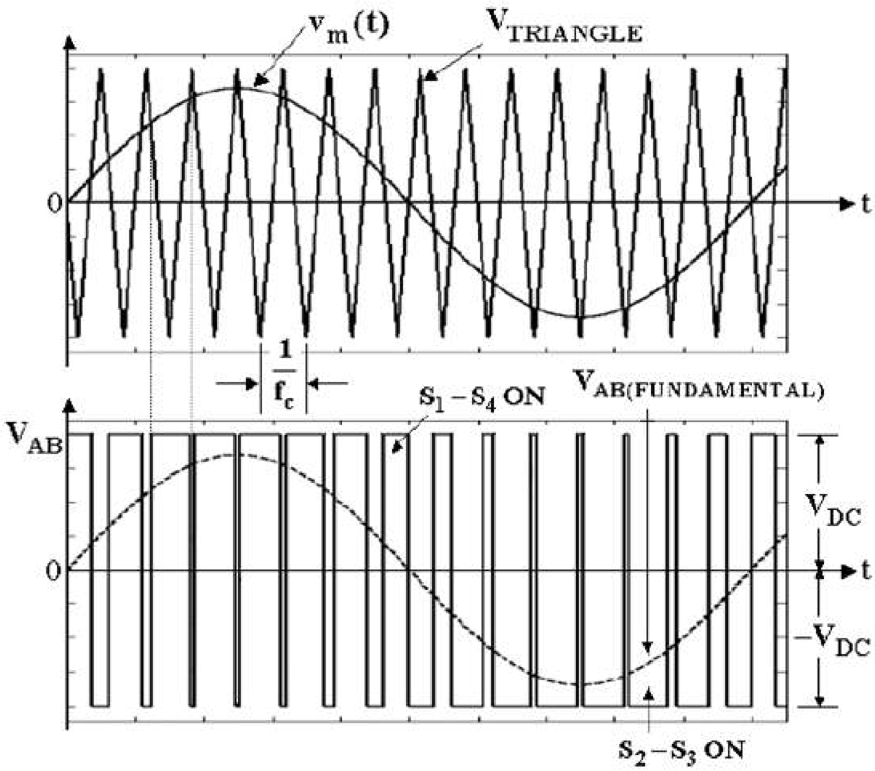

Figure 4.3: Waveform of bipolar single phase inverter

Disadvantages of BIPOLAR

- % THD high as compare to unipolar
- EMI is increased

4.3 Model of Bipolar PWM Inverter

- Reference wave frequency = 50 kHz
- Carrier wave frequency = 5 kHz
- DC link voltage = 12 volt

- Load resistance = 12 ohm

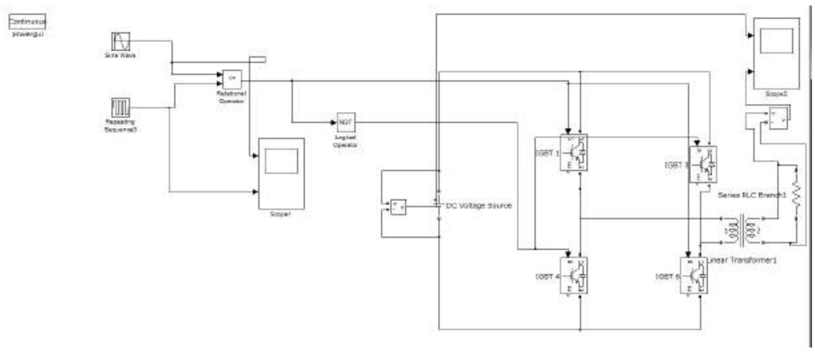

Figure 4.4: Simulation Model of bipolar inverter

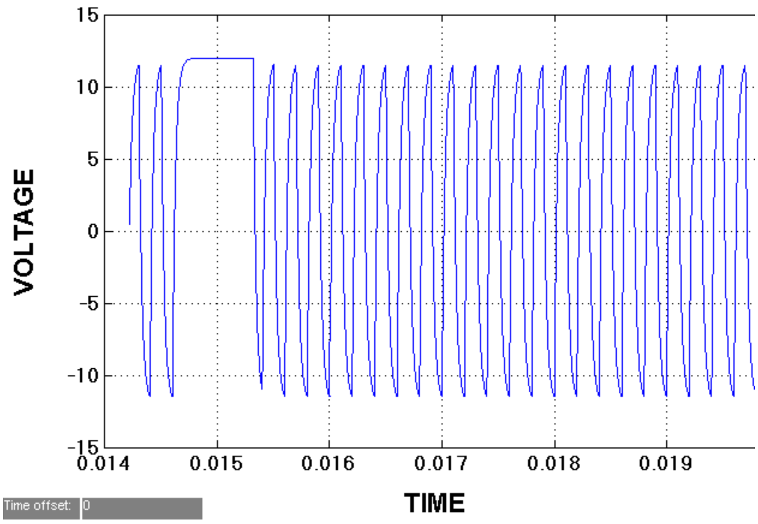

Figure 4.5: Wave form of bipolar PWM inverter: X axis = 0.001 sec/div , Y axis = 5 V/div

4.4 Model of inverter with boost converter

For boost converter

f_s = 50 kHz

V_0 = 15 volt

V_{imax} =10 volt

V_{imin} = 5 volt

R_L = 15 ohm

Δi_L = 10 % of inductor current

$\Delta V_0 = 1\% of o/p load voltage$

I_0 = 1 amp

For inverter

wave frequency = 50 kHz

Carrier wave frequency = 5 kHz

DC link voltage = 10 volt

Load resistance = 12 volt

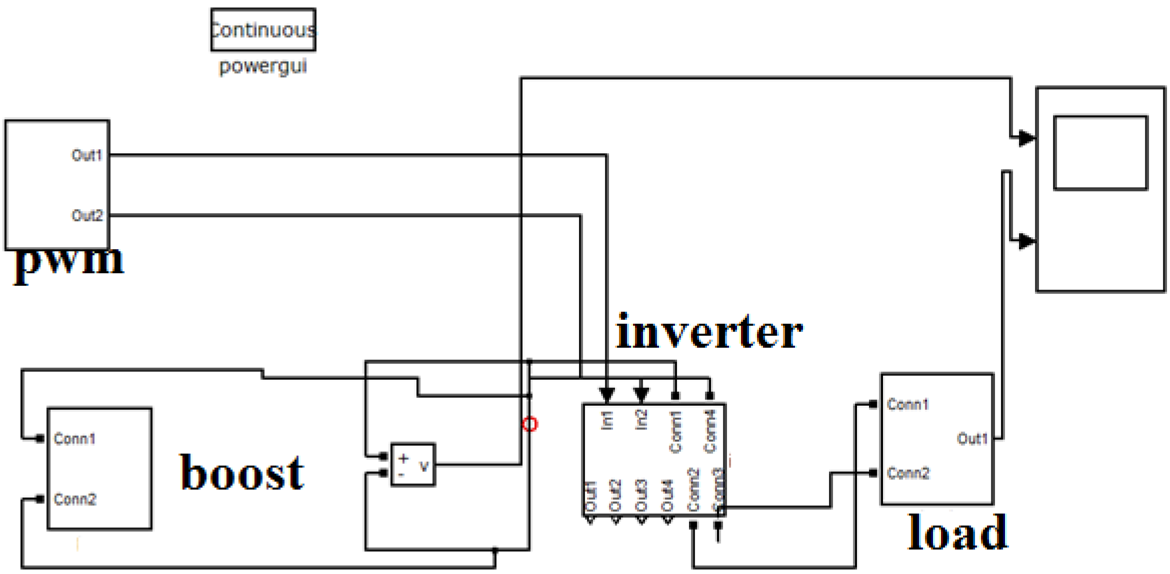

Figure 4.6: Model of single phase bipolar inverter with boost converter

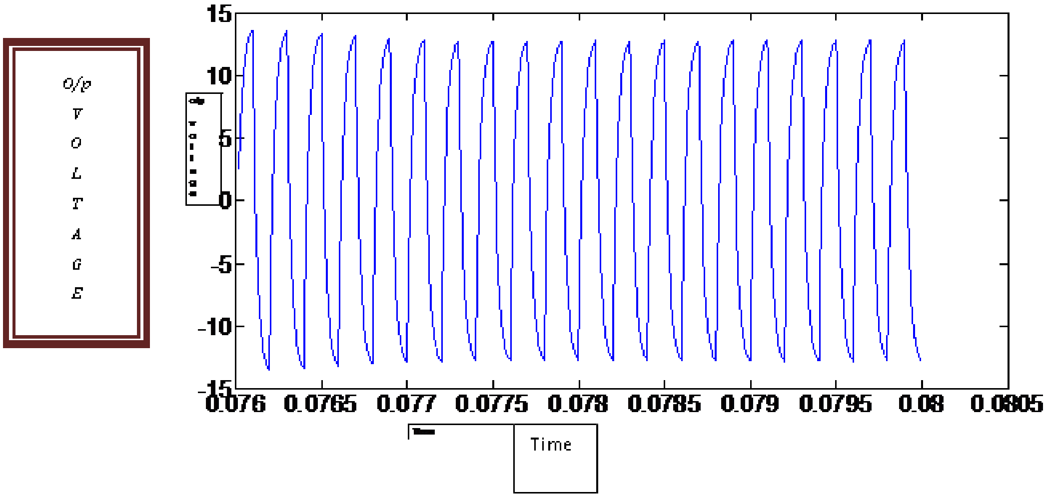

Figure 4.7: Wave form of single phase bipolar inverter with boost converter: X axis = 0.001 sec/div , Y axis = 5 V/div

4.5 Introduction of PV model [5],[6],[7]

The PV cell has electrical contacts on its top and bottom to capture the electrons, as Shown in Figure . When the PV cell delivers power to the load, the electrons flow out of the n-side into the connecting wire, through the load, and back to the p-side where they recombine with holes. The simplest model of a PV cell is shown as an equivalent circuit below.In this model there is an ideal current source.This source is parallel with an ideal diode. The current source represents the current generated by photons often denoted as I_{ph} or I_L, and its output is constant under constant temperature and constant incident radiation of light.

$$I = I_{sc} - I_d \tag{4.5}$$

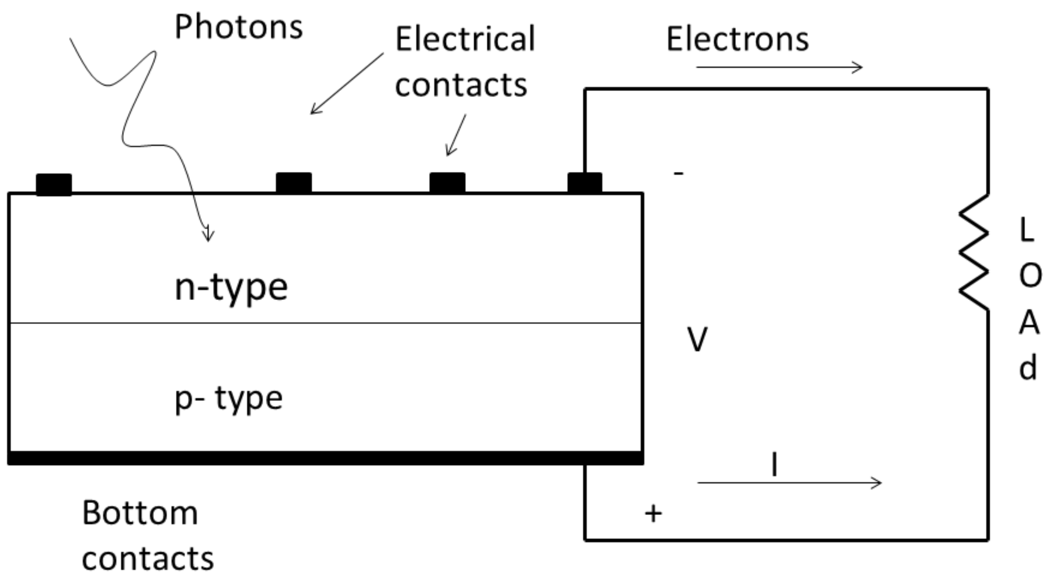

Figure 4.8: Model of solar panel[5],[6]

Where I_{sc} is the short circuit current which is equal to the photon generated current and I_d is the current shunted through the intrinsic diode.

$$I_d = I_0(e^{\frac{qv_d}{kt}} - 1) \tag{4.6}$$

Where: I_0 is the reverse saturation current of diode (A),

q is the electron charge (1.60210-19C),

V$_d$ is the voltage across the diode (V),

k is the Boltzmanns constant (1.38110^{-23} J/K),

T is the junction temperature in Kelvin (K).

From question 4.5,4.6

$$I = I_{sc} - I_0(e^{\frac{qv}{kt}} - 1) \tag{4.7}$$

Where V is the voltage across the solar cell and I is the output current from the cell. The reverse saturation current of diode (Io) is constant under the constant

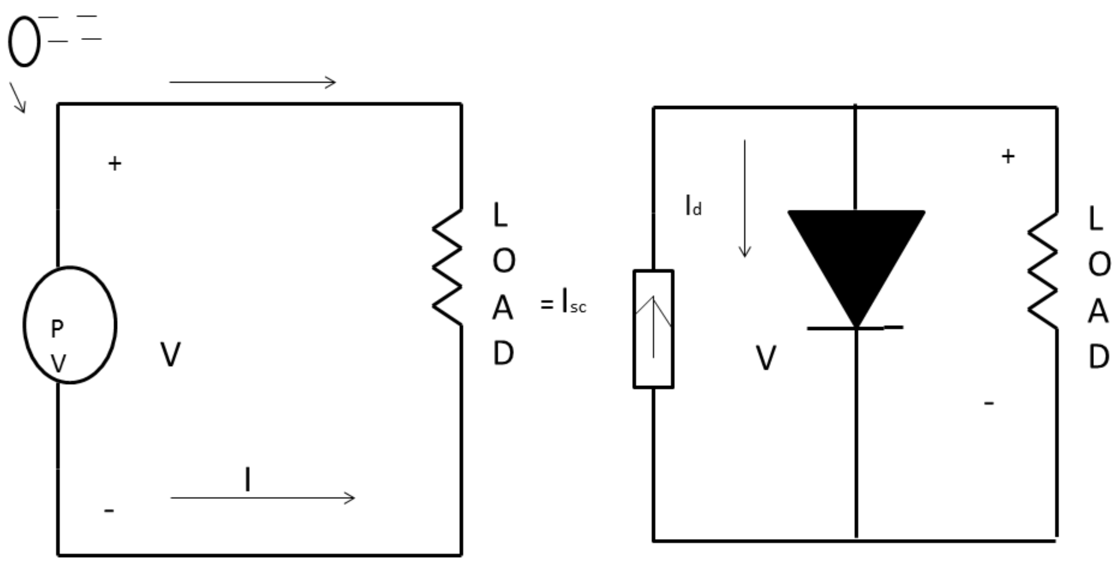

Figure 4.9: Cell with a load and its simple equivalent circuit[5],[6]

temperature and found by setting the open-circuit condition as shown in Figure 4.10 (b). Using the equation (4.7), let I = 0 (no output current) and solve for Io.

$$I_0 = \frac{I_{sc}}{(e^{\frac{qv}{kt}} - 1)} \tag{4.8}$$

The photon generated current, which is equal to I_{sc} .I_{sc}, is known from the datasheet, under the standard test condition, $G_0 = 1000W/m^2$ at the air mass (AM) = 1.5, then the photon generated current at any other irradiance, $G(W/m^2)$, is given by:

$$I_{sc}|_G = (\frac{G}{G_0})\ I_{sc}\Big|_{G_0} \tag{4.9}$$

4.6 Modeling of a PV module

Electric model is shown in Figure 4.11. The model have a current source (Isc), a diode (D), and a series resistance (Rs). The effect of parallel resistance (Rp) is very small

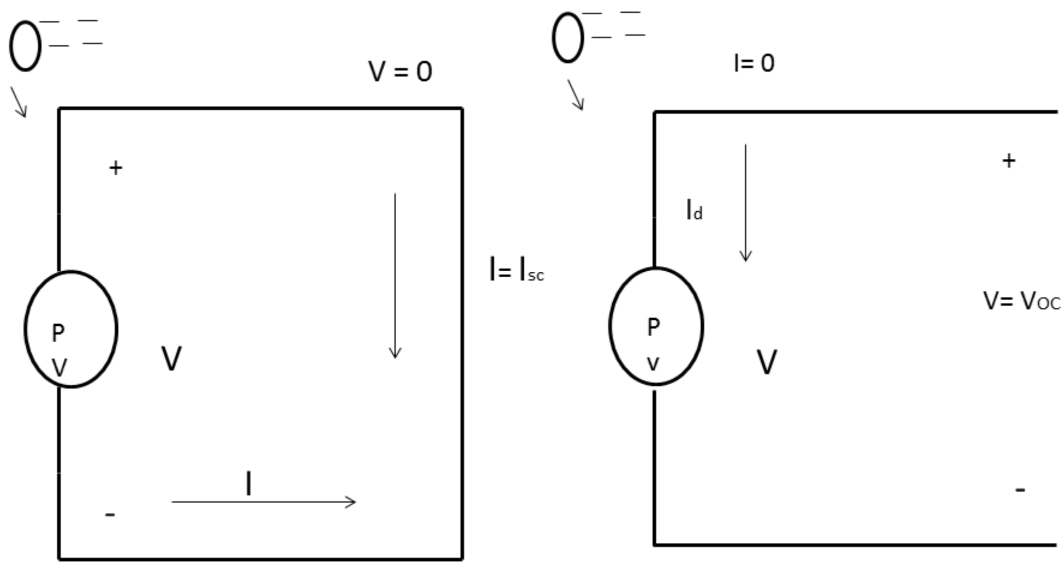

Figure 4.10: (a) Model with Short circuit current (b) Model with open circuit voltage[5],[6],[7]

in a single module. it also includes temperature effects on the short-circuit current (Isc) and the reverse saturation current of diode (Io). It uses a single diode.Diode's ideality factor is (n).This is use to set best I-V curve matching.

$$I = I_{sc} - I_0(e^{\frac{q(v+I*Rs)}{kt}} - 1) \tag{4.10}$$

Where: I is the cell current (the same as the module current), V is the cell voltage = (module voltage) ÷ (no of cells in series), T is the cell temperature in Kelvin (K). Short circuit current (Isc) at given temperature (T):

$$I_{sc}|_T = I_{sc}|_{T_{ref}}[1 + a(T - T_{ref})] \tag{4.11}$$

Where: Isc at T_{ref} is given in the datasheet (measured under irradiance of $1000W/m^2$), T_{ref} is the reference temperature of PV cell in Kelvin (K), The reverse saturation current of diode (Io) at the reference temperature (T_{ref}) is given by the equation (4.8)

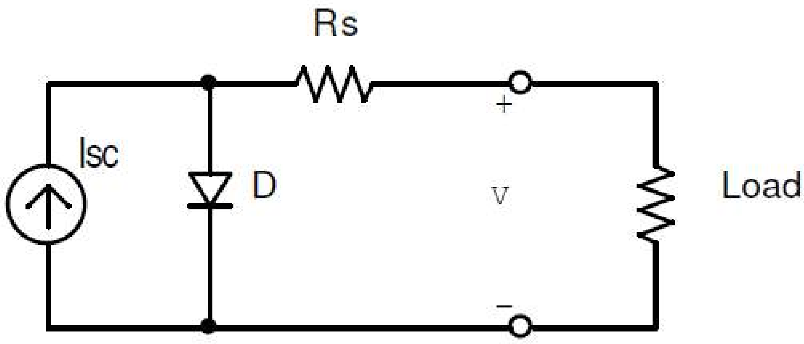

Figure 4.11: Equivalent circuit of simulation

with the diode ideality factor added:

$$I_0 = \frac{I_{sc}}{(e^{\frac{qv_{oc}}{nkt}} - 1)} \tag{4.12}$$

The reverse saturation current (Io) is temperature dependant and the Io at a given Temperature (T) is calculated by the following equation:

$$I_0|_T = I_0|_{T_{ref}} * (\frac{T}{T_{ref}})^{\frac{3}{n} * e^{\frac{-qEg}{nk}(\frac{1}{T} - \frac{1}{T_{ref}})}} \tag{4.13}$$

The value of series resistance (Rs) of the PV module is calculated by following equation:

$$a = \frac{nkT}{q} \tag{4.14}$$

$$b = I_0 e^{q(\frac{V+I*Rs}{nkT})} \tag{4.15}$$

$$Rs = -dI/dV - (a/b) \tag{4.16}$$

$$c = I_0 e^{q(\frac{V_{oc}}{nkT})} \tag{4.17}$$

Where dI/dV is the slope of the I-V curve. solve the equation (4.16) at the open circuit voltage that is $V = V_{oc}$ (also let I=0).

$$Rs = -dI/dV|_{V_{oc}} - (a/c) \tag{4.18}$$

Where dI/dVVoc is the slope of the I-V curve at the Voc (use the I-V curve in the datasheet then divide it by the number of cells in series), Voc is the open-circuit voltage of cell (found by dividing Voc in the datasheet by the Number of cells in series). it may be possible to find the answer by simple iterations method. Finally the last answer of o/p current in the form of Newtons method is:

$$d = I_0 e^{q(\frac{V+I_n*Rs}{nkT})} \tag{4.19}$$

$$g = e^{q(\frac{V+I_n*Rs}{nkT})} \tag{4.20}$$

$$f = \frac{q*Rs}{nkT} \tag{4.21}$$

$$I_{n+1} = I_n - \frac{I_{sc} - In - [d-1]}{-1 - I_0(f)*g} \tag{4.22}$$

from above equation the PV modeling is shown in figure below

parameters of simulation switching frequency of boost converter = 100 khz
inductor value = 8.13 mH
capacitor value = 10.8 μF
inverter o/p voltage(phase-ground)=220 volt
$D_{min} = 0.905$
$D_{max} = 0.944$

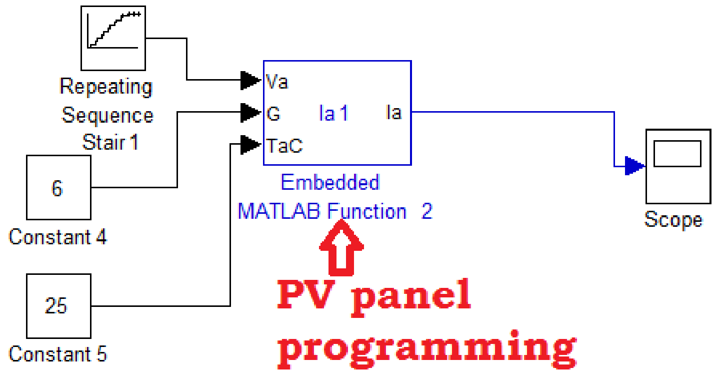

Figure 4.12: Simulation model PV panel

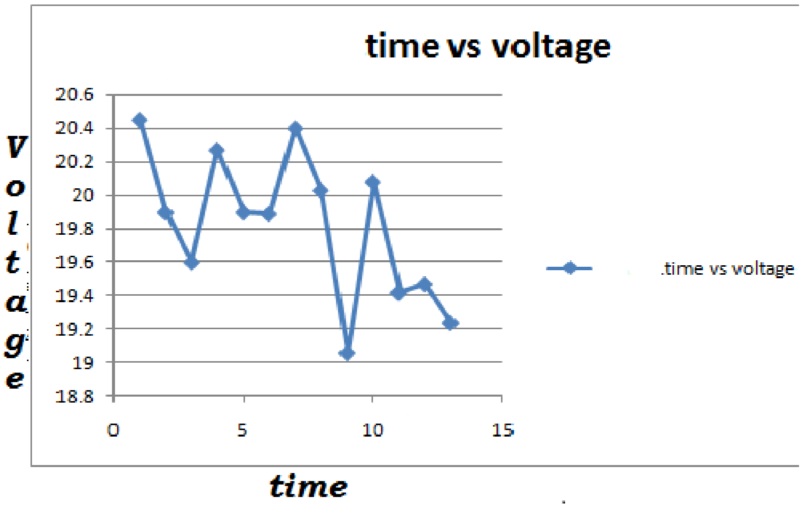

Figure 4.13: Time-voltage(open circuit) graph taken at 10/10/2013 from 10.20 AM to 5.00 PM

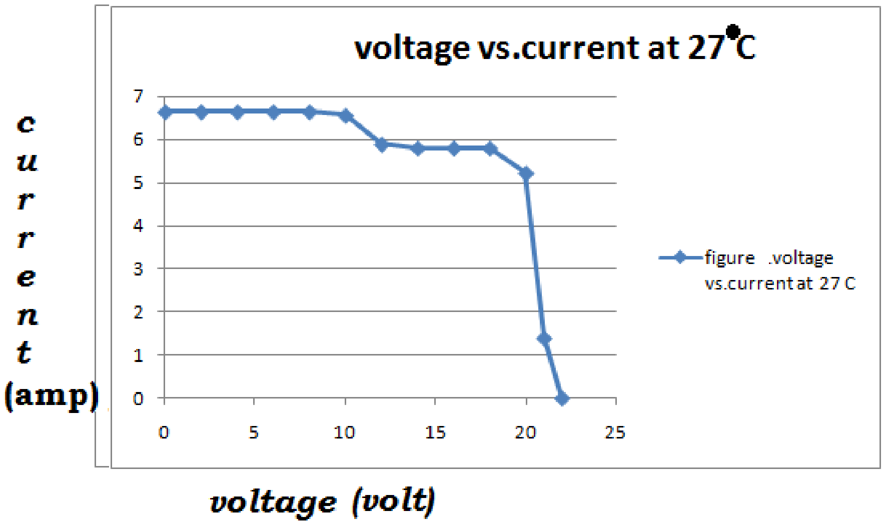

Figure 4.14: Voltage - current graph at 27° C

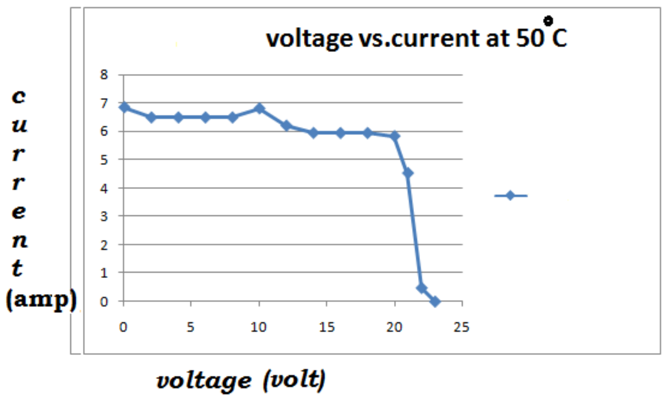

Figure 4.15: Voltage - current graph at 50° C

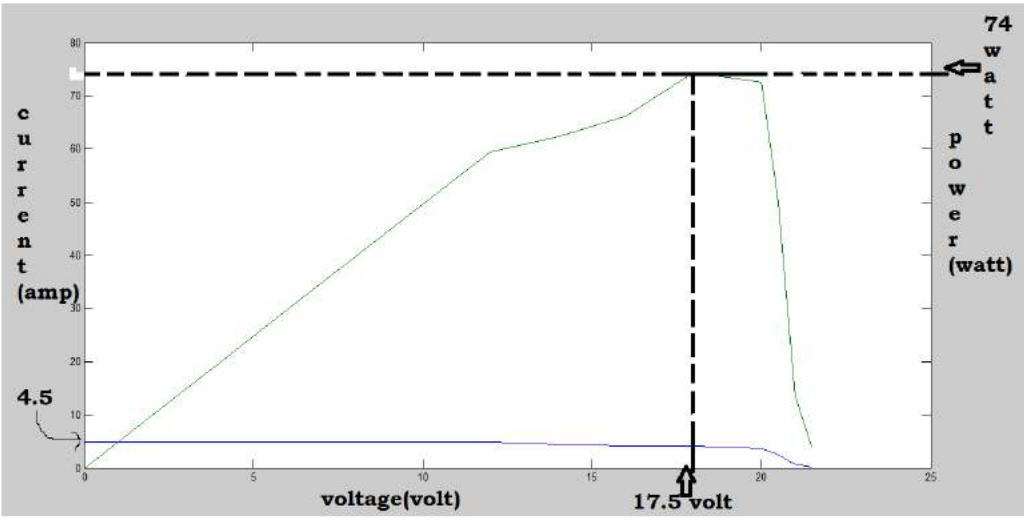

Figure 4.16: Voltage - current and voltage power - graph for MPPT

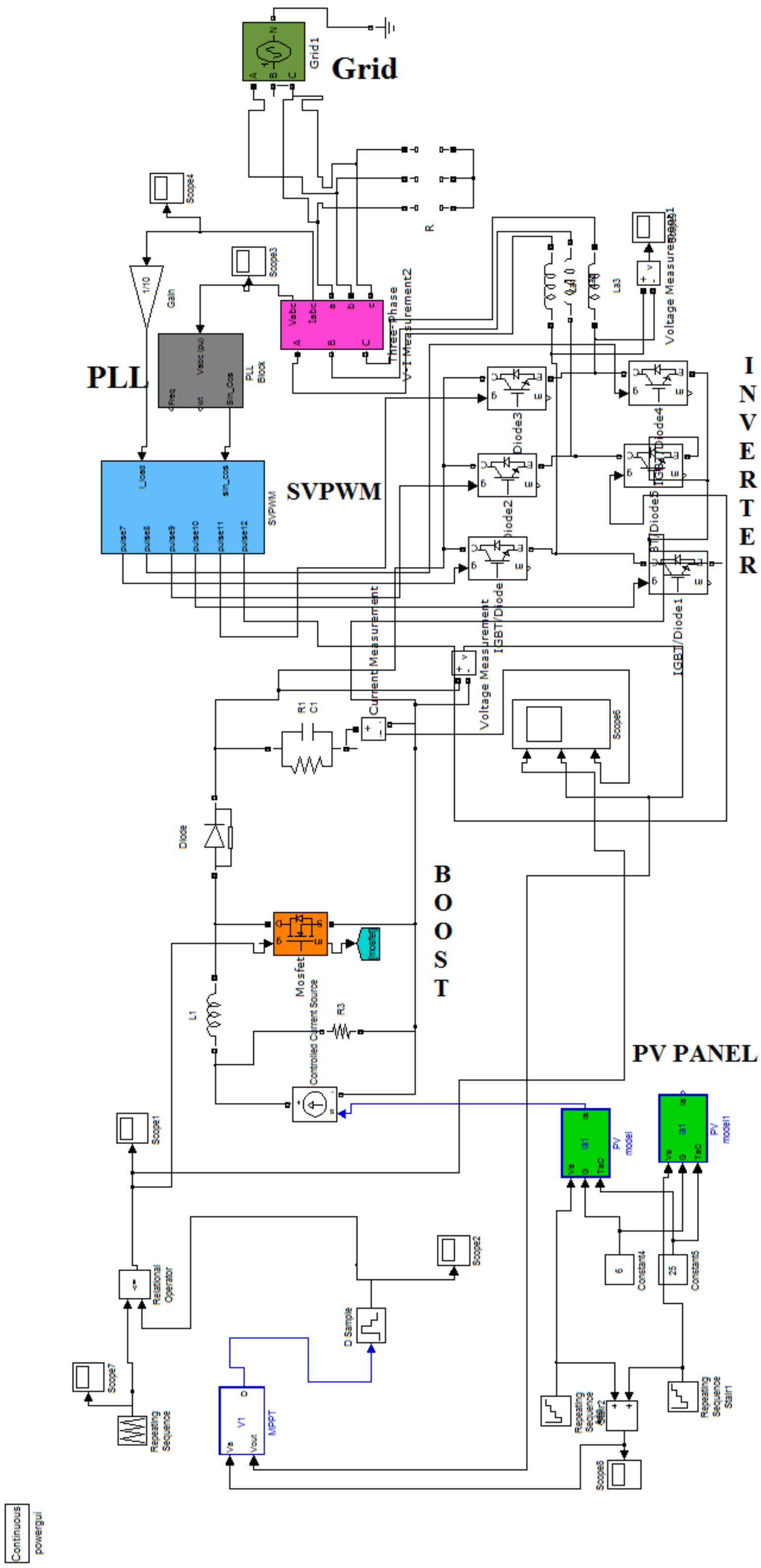

Figure 4.17: Simulation model of the system

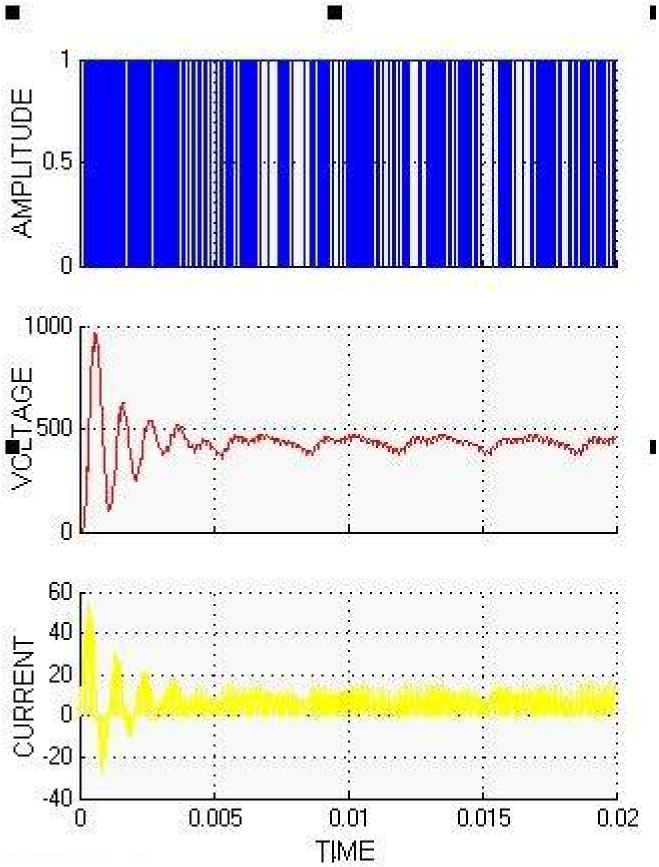

Figure 4.18: Wave form of boost converter: Trace 1 : X axis = 0.005 sec/div , Y axis = 0.5 amplitude/div , Trace 2 : X axis = 0.005 sec/div , Y axis = 500 V/div , Trace 3 : X axis = 0.005 sec/div , Y axis = 20 I/div

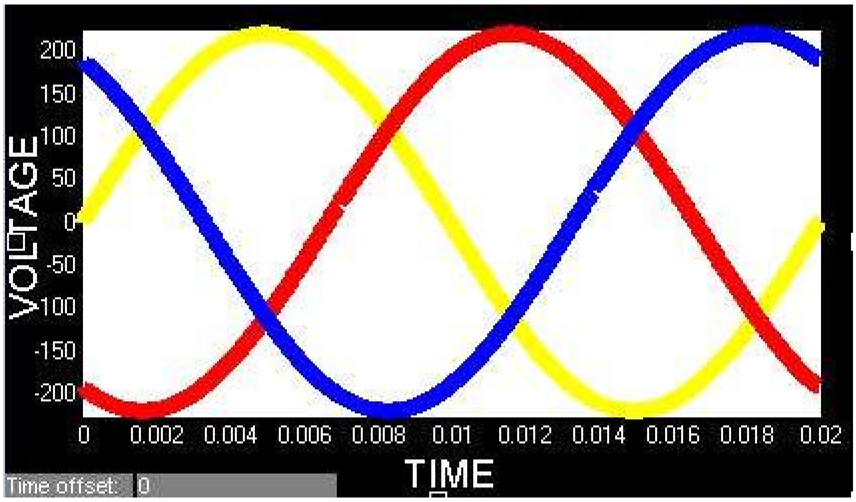

Figure 4.19: Inverter o/p voltage waveform with PLL : X axis = 0.002 sec/div , Y axis = 50 V/div

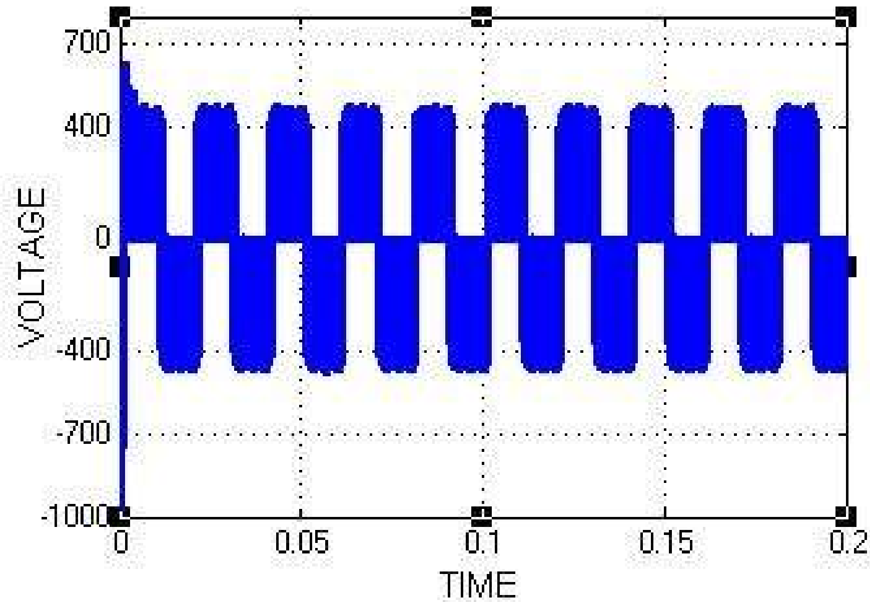

Figure 4.20: Inverter o/p voltage waveform : X axis = 0.05 sec/div , Y axis = 400 V/div

Chapter 5

Hardware Results

5.1 DC-DC Boost converter

- $V_{inMin} = 10$ V
- $V_{inMax} = 20$ V
- $V_{out} = 30$ V
- Switching Frequency = 20 KHz
- L = 1.22 mH
- C = 220 μF

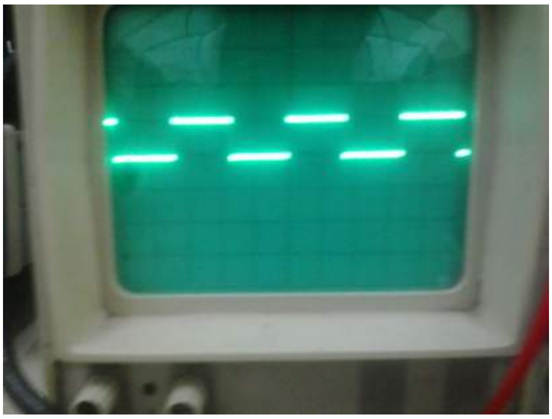

Figure 5.1: Input Pulse : X axis = 0.0005 sec/Div , Y axis = 5 V/Div

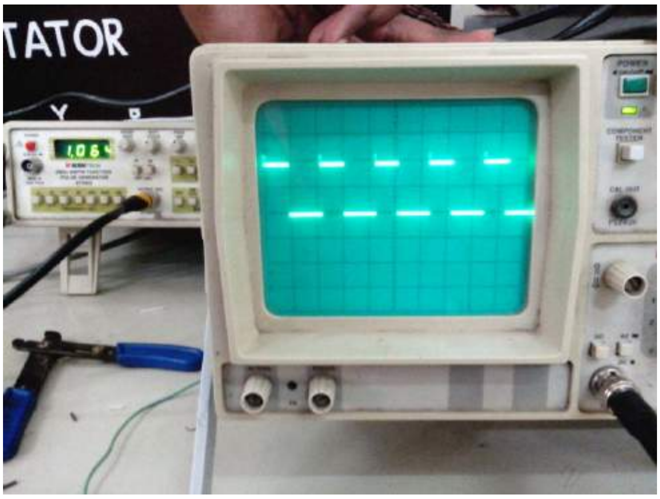

Figure 5.2: Output of TLP 250 : X axis = 0.0005 sec/Div , Y axis = 5 V/Div

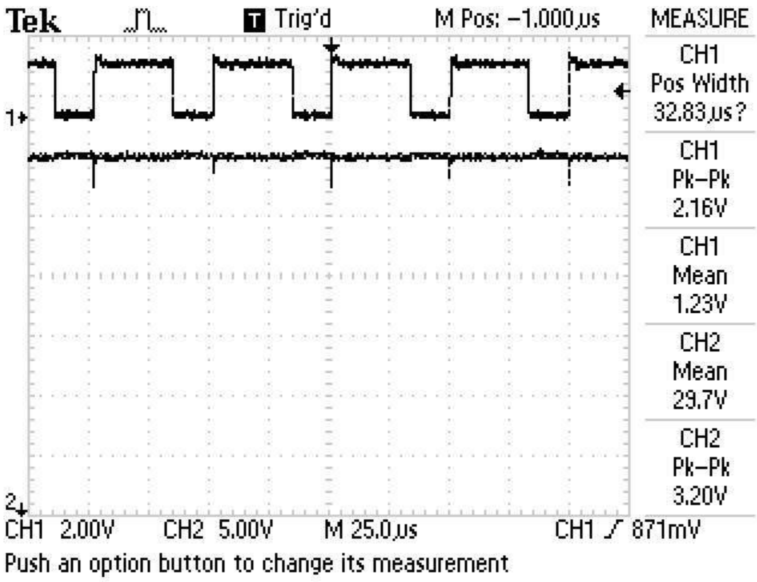

Figure 5.3: Output Waveform at 0.66 Duty Cycle of 10V input voltage : X axis = 25 μs/Div ; Y axis = for channel 1 : 2 V/Div for channel 2 : 5 V/Div

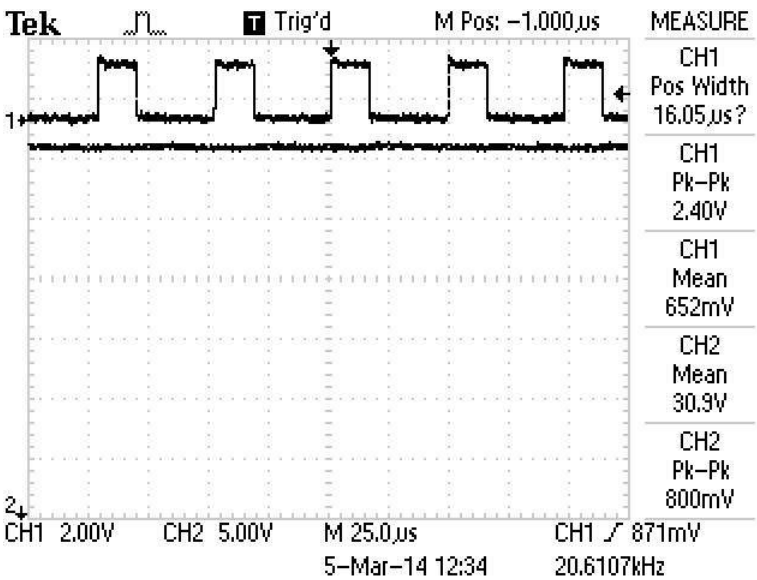

Figure 5.4: Output Waveform at 0.3 Duty Cycle of 20 V input voltage : X axis = 25 μs/Div ; Y axis = for channel 1 : 2 V/Div for channel 2 : 5 V/Div

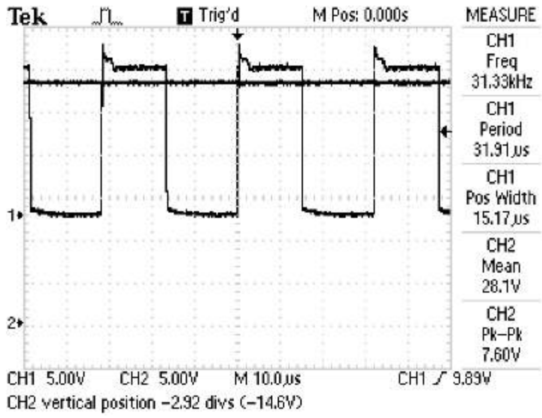

Figure 5.5: Output Waveform of boost converter : X axis = 10 μs/Div ; Y axis = for channel 1 : 5 V/Div for channel 2 : 5 V/Div

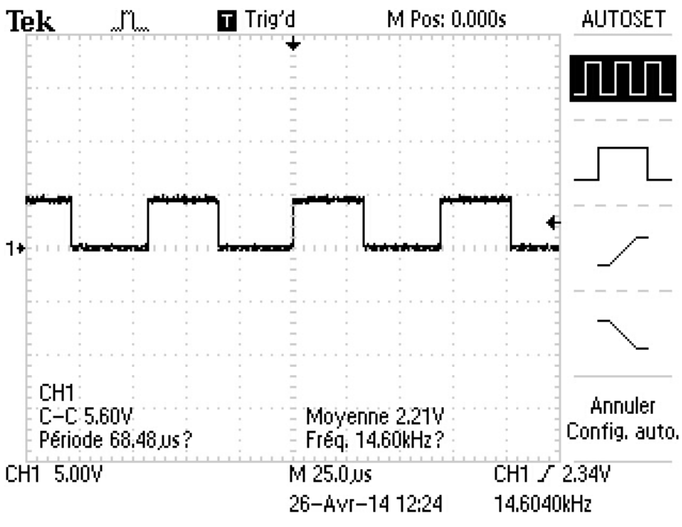

Figure 5.6: Output pulses generated by PIC controller from MPPT algorithm : X axis = 25 μs/Div ; Y axis = for channel 1 : 5 V/Div [8]

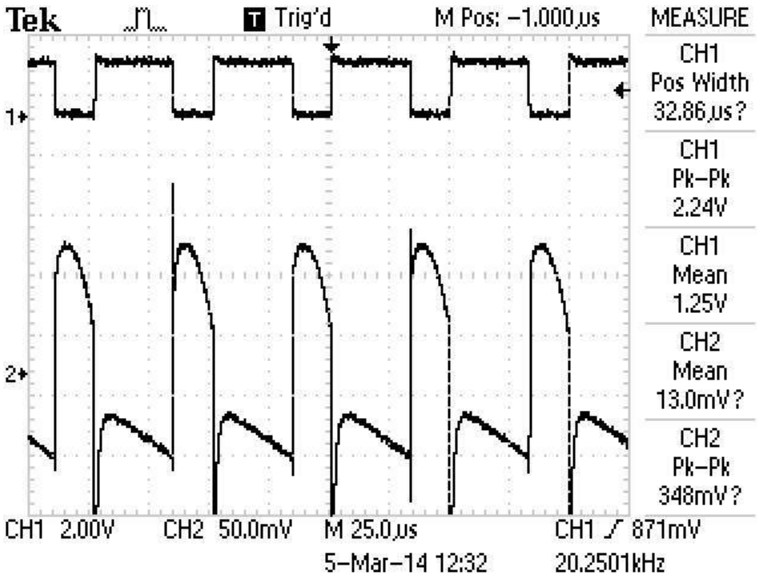

Figure 5.7: Output Voltage Ripple : X axis = 25 μs/Div ; Y axis = for channel 1 : 2 V/Div for channel 2 : 50 mV/Div

5.2 Inductor Design

Energy E_L = L * $I_m{}^2/2 = 3.32 * 10^-3J$

Areaproduct, A_P = A_W A_C = 2 * E_L / K_C * K_W *J * B_m = 12830.9 mm^4

Pot core is chosen.

Core type : P 36/22

A_P = 20301 mm^2

Mean length , l_m = 53.2 mm

A_C = 201 mm^2

A_W = 101 mm^2

Air gap , l_g = 0.5 mm

$\lambda = \mu_0 * \mu_r * A_C / l_m + \mu_r * l_g = 469.21 * 10^{-8}$ H/turn^2

Number of Turns = $\sqrt{L}/\lambda = 18.80 = 19$

Wire guage

Cross section area of wire,a = I_{rms} / J = 0.766 mm^2

SWG = 19.

5.3 Inverter

5.3.1 Dead Band

In Dead Band R = 220Ω

C= 0.01μ F

Dead Band = 45 μ Sec

if C = 0.001 μ F ,

Dead Band = 8 μ Sec

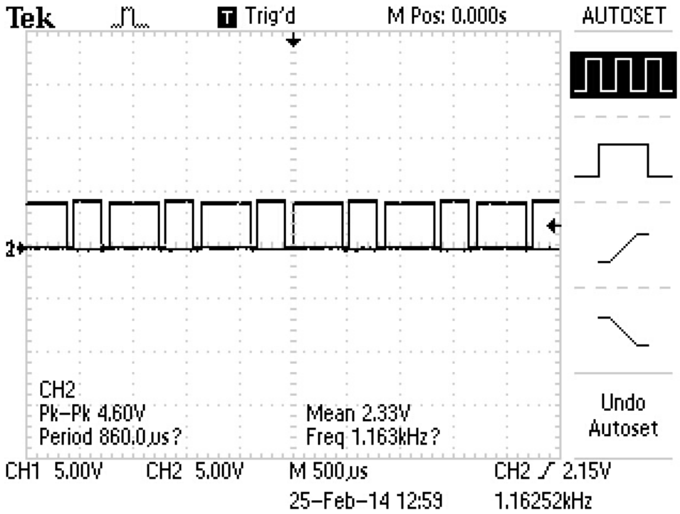

Figure 5.8: Waveform of Dead Band at 45 μ sec : X axis = 500 μs/Div ; Y axis = for channel 1 : 5 V/Div for channel 2 : 5 V/Div

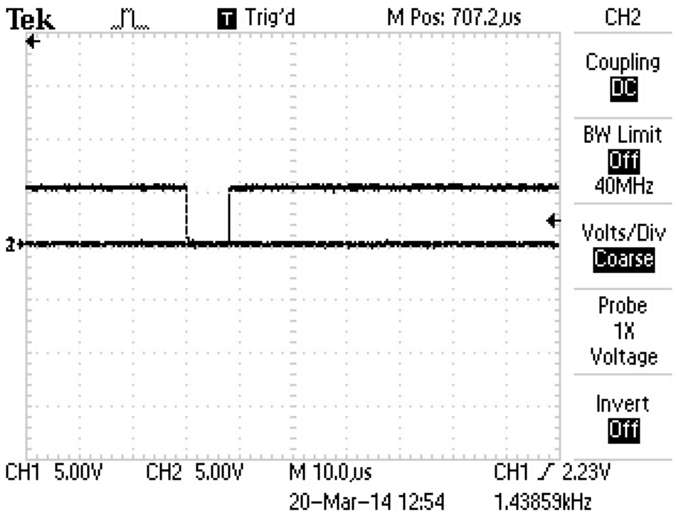

Figure 5.9: Waveform of Dead Band at 8 μ sec : X axis = 10 μs/Div ; Y axis = for channel 1 : 5 V/Div for channel 2 : 5 V/Div

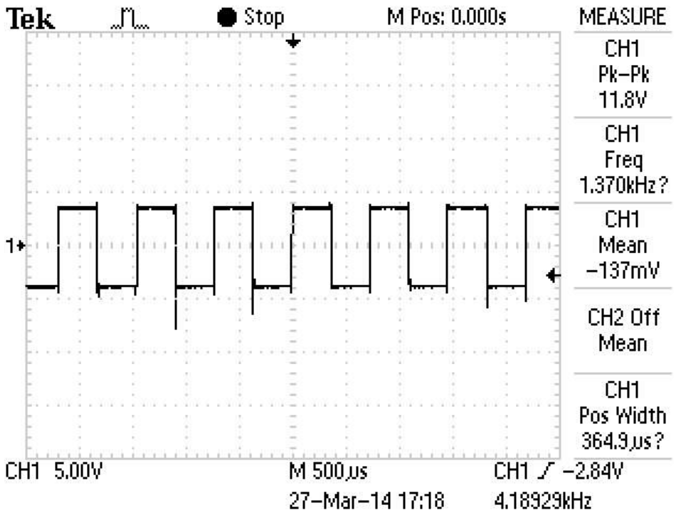

Figure 5.10: Waveform of inverter : X axis = 500 μs/Div ; Y axis = for channel 1 : 5 V/Div

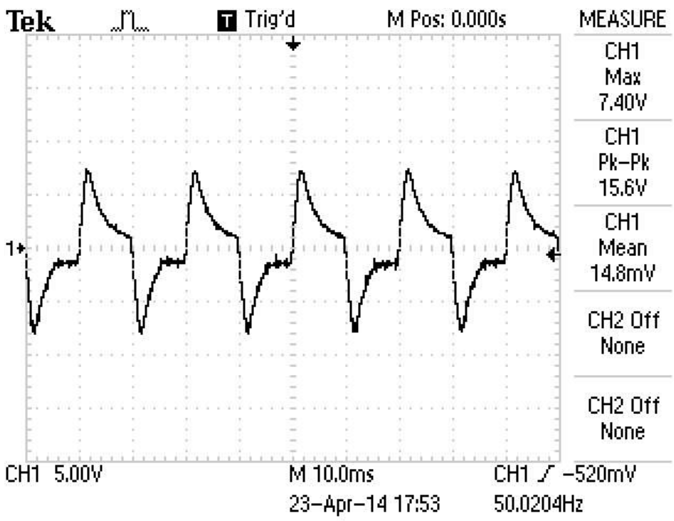

Figure 5.11: Waveform of inverter(integrated with boost) : X axis = 10 μs/Div ; Y axis = for channel 1 : 5 V/Div

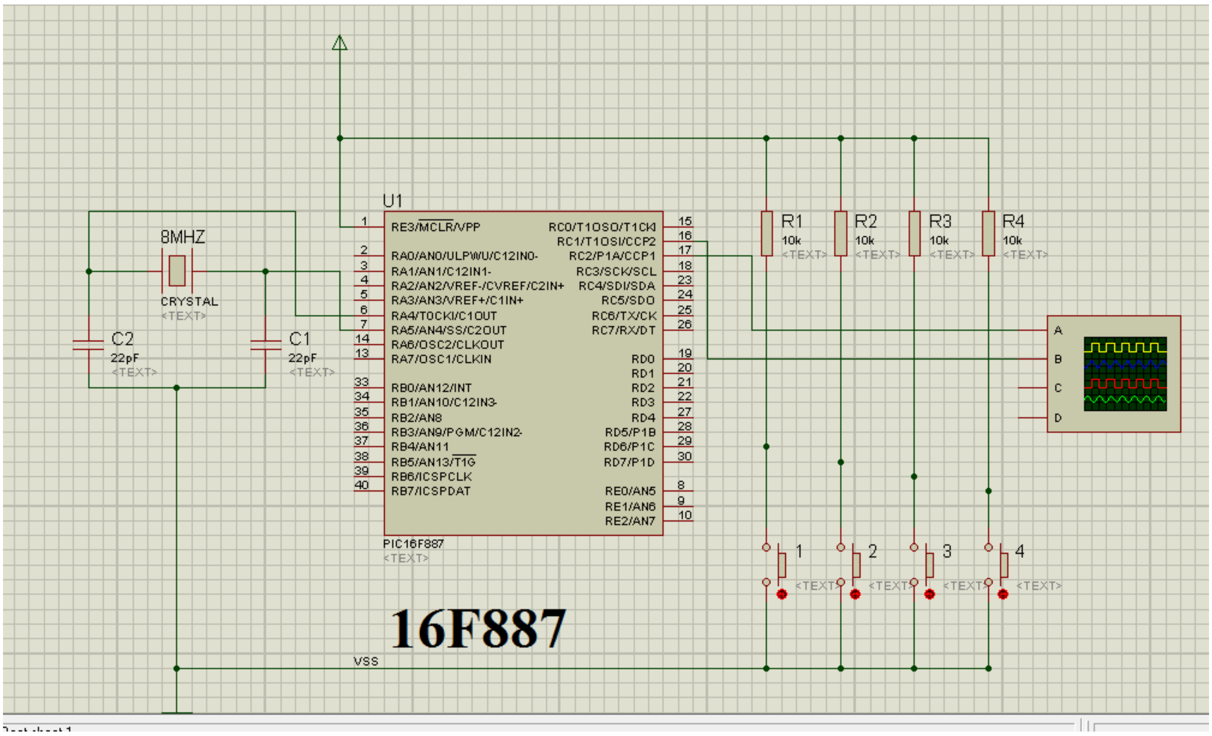

Figure 5.12: PIC simulation diagram in proteus software

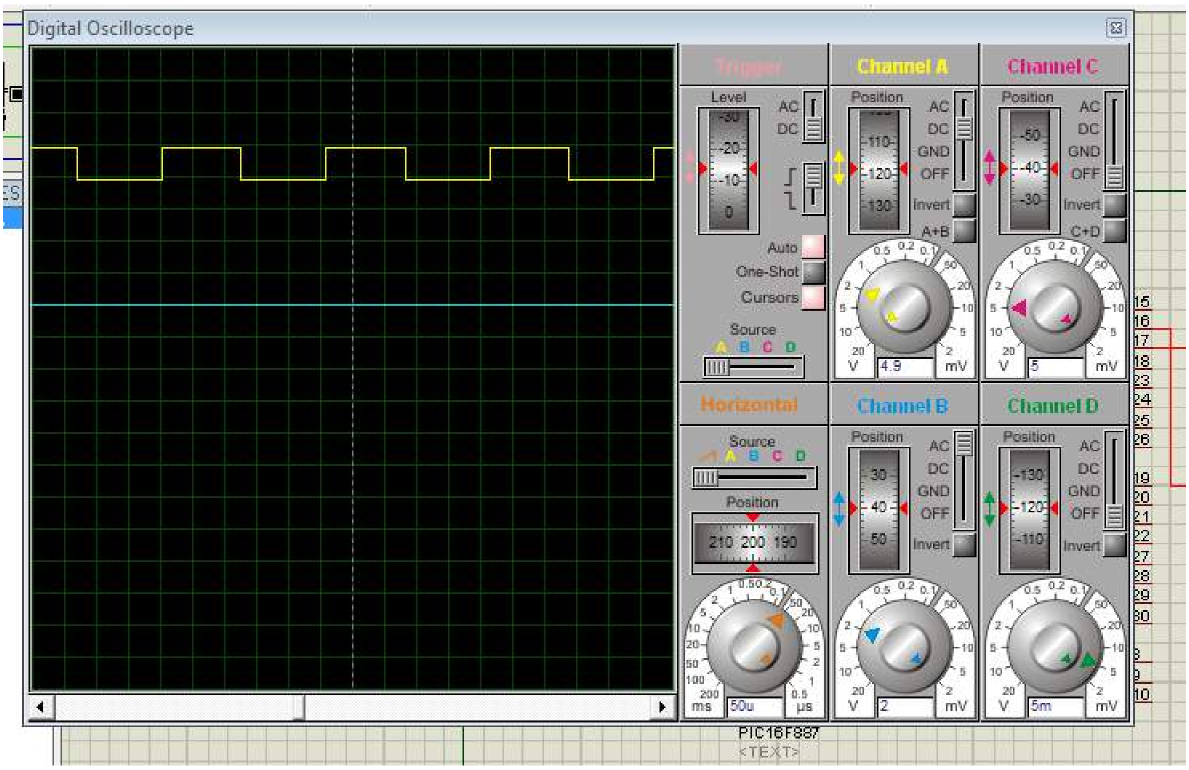

Figure 5.13: Pulses for boost converter from MPPT algorithms (from 16F887)

Chapter 6

Overview of PIC controller 16F887

6.1 Introduction

PIC 16F887 is enhanced flash based 8-bit CMOS microcontrollers eith nano Watt technology.Only 35 instructions are used.

6.2 Special microcontroller features

- Pricision internal oscillator
- Power saving sleep mode
- Operating voltage range (2.0-5.5 V)
- Enhanced low - current watchdog timer (WDT)
- Program memory read/write during run time
- In circuit debugger during run time
- Power on reset

6.3 Low power features

- Standby current 50 nA 2.0 V , typical
- Operating current :
  11 μ A 32 kHz , 2.0 V , typical
  220 μ A 4 MHz , 2.0 V , typical

6.4 Peripheral features

- 24/35 I/O pins
- Two analog comarators
- 10 bit A/D Converter
- In circuit serial programming
- Master synchronous serial port module supporting 3 - wire SPI

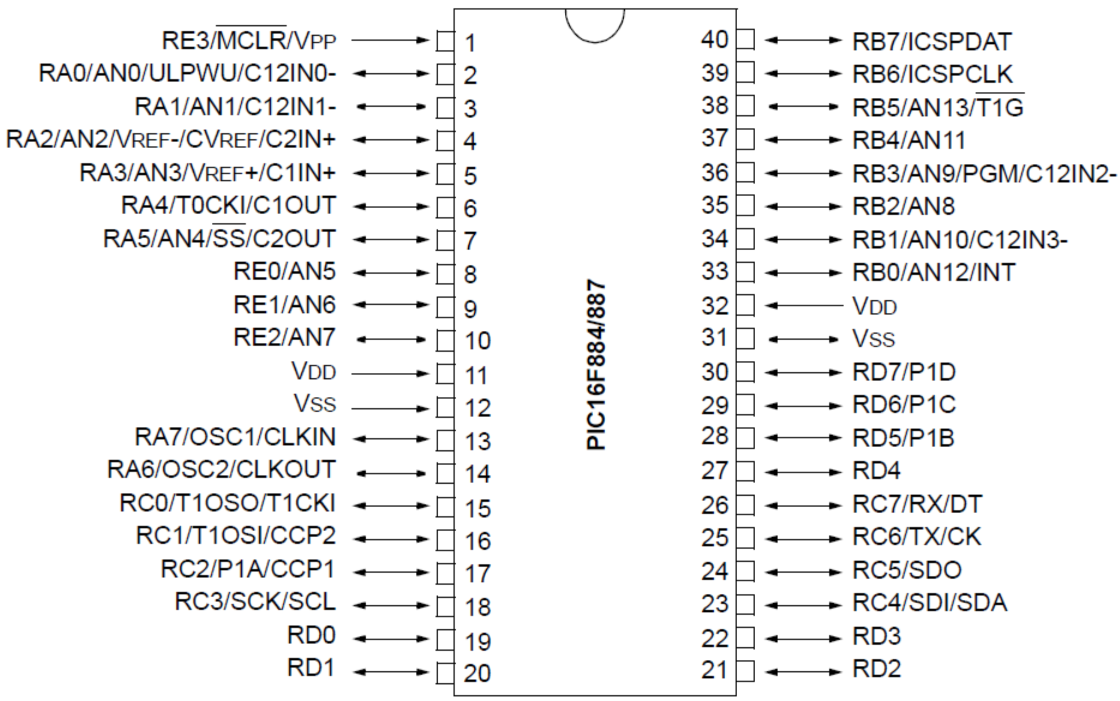

Figure 6.1: Pin diagram of PIC 16F887

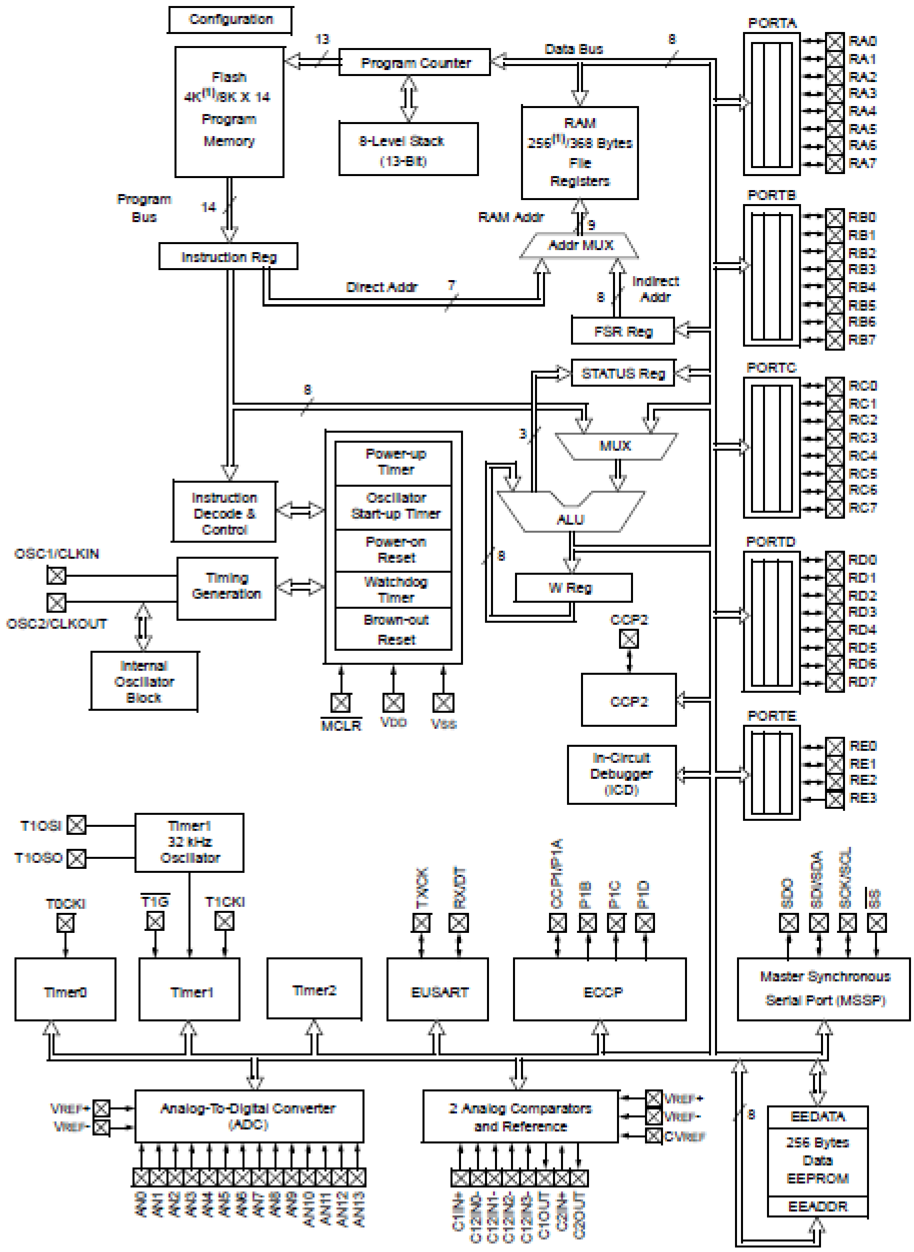

Figure 6.2: Block diagram of PIC 16F887

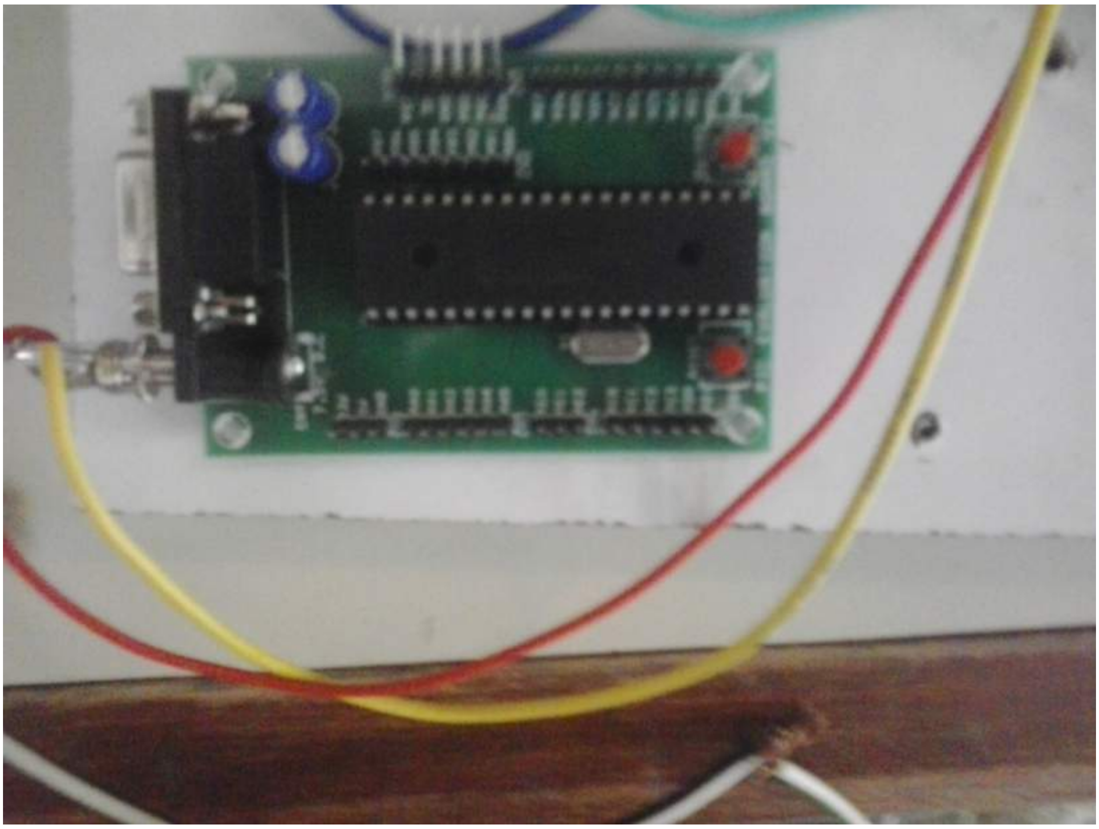

Figure 6.3: PIC 16F887 with developement board

Chapter 7

Conclusion and Future Work

7.1 Conclusion

With the help of modeling of PV panel in MATLAB, the DC output is taken for boost converter.With the help of boost converter with MOSFET as a switch,500 volt constant DC voltage was produced.With help of PLL block , the output of inverter is matched with grid voltage 220 voltage and 50 Hz frequency.In the Hardware part we get 30 Volt DC-DC Boost converter output with change of duty cycle 0.33 to 0.66.PV panel give 19.5 V.Using PIC Controller the pulses for boost converter is taken from MPPT algorithm.With the help of Dead Band Circuit we get 45 μ sec Dead band and 8 μ sec .With the integration of boost with inverter 15.5 V(A.C) is taken.

7.2 Future Work

Using PLL Block , design the close loop of system to match inverter voltage and frequency with grid voltage and frequency.Analyzed different weather condition of solar and from those data,calculate efficiency of BOOST converter with MPPT algorithm.

references

1 Soeren Baekhoej Kjaer,John K. Pedersen and Frede Blaabjerg,“ A Review of Single Phase Grid Connected Inverters for photovoltaic Modules”, IEEE Transaction on industry application, Vol.41 No.5, Oct/Nov

2 Alex Joseph, M.E Applied Electronics ECE Department, College of Engineering Guindy, Anna University Chennai ,India,“PV Array Characteristics Analysis Under Partial Shading Modelling of P O MPPT Applied Boost Converter Using Matlab/Simulink ”

3 Duy C.Huynh, Thu A.T. Nguyen,Power System Dept,University of Technology, Vietnam NationalUniversity,Hochiminh,Vietnam, “Maximum Power Point Tracking of Solar PV panels Using Advanced Perturbation and Observation Algorithm”,2013 IEEE 8th Conference on Industrial Electronics and Applications (ICIEA)

4 Snehamoy Dhar, PG Scholar,Department of Electrical Electronics Engineering, SRM University, Chennai, “Implementation of PV Cell Based Standalone Solar Power System Employing Incremental Conductance MPPT algorithm”,2013 International Conference on Circuits, Power and Computing Technologies[ICCPCT-2013]

5 Walker , Geoff R.,“Evaluating MPPT converter topologies using a MATLAB PV model”, Australasian University Power Engineering Conference,AUPEC 00, Brisbane, 2000

6 Wie Peiyu,Tan Boxue,Zhang Housheng,Zhao Yanlei“Research On maximum Power Point Tracker Based on Solar Cell Simulatior”

7 Zainal Salam, Kashif Ishaque , and Hamed Taheri,“An Improved Two-Diode PV Model for PV System”

8 Algorithm and Software Development-Delft University of Technology-BACHELOR THESIS, “Maximum Power Point Tracking”

9 David Sanz Morales-Faculty of Electronics,communications and Automation,“Maximum Power Point Tracking Algorithms for Photovolatic Application”

10 L Umanand,“A Textbook of Power Electronics Essentials Applications”

Appendix

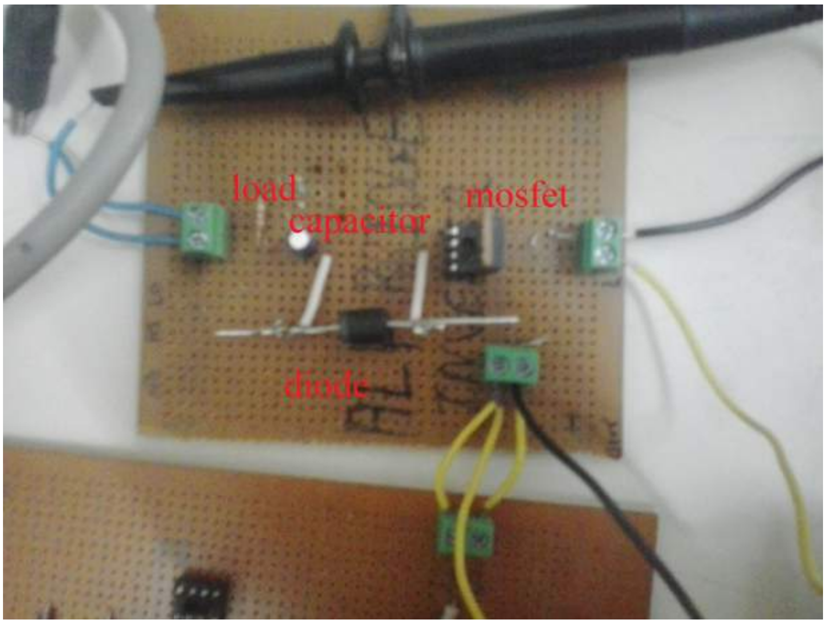

Figure 1: Boost Converter

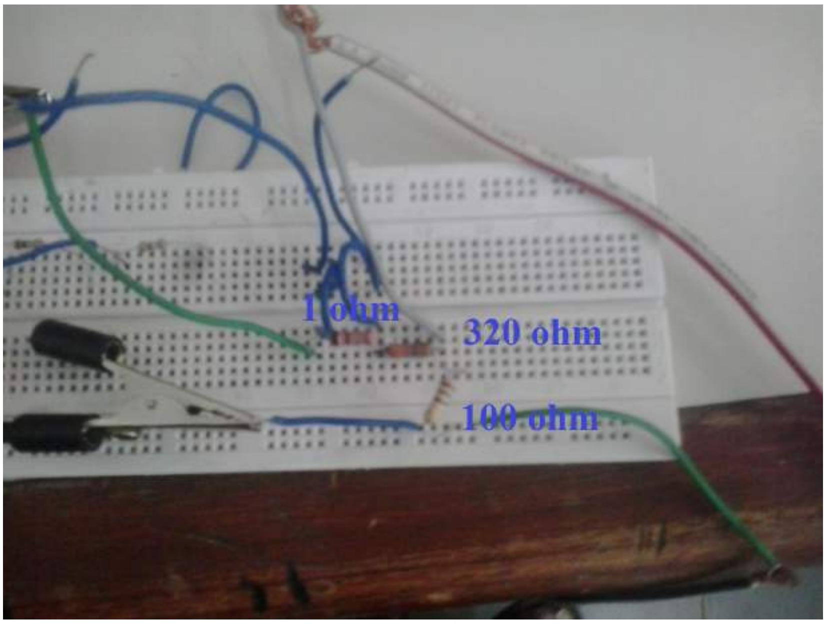

Figure 2: Voltage sensor and current for PIC controller

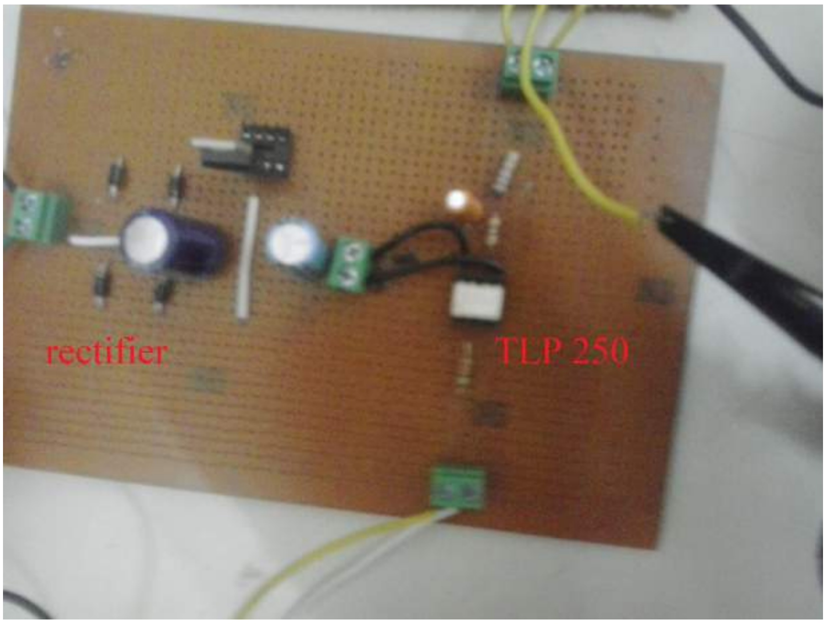

Figure 3: Control Circuit of Boost Converter

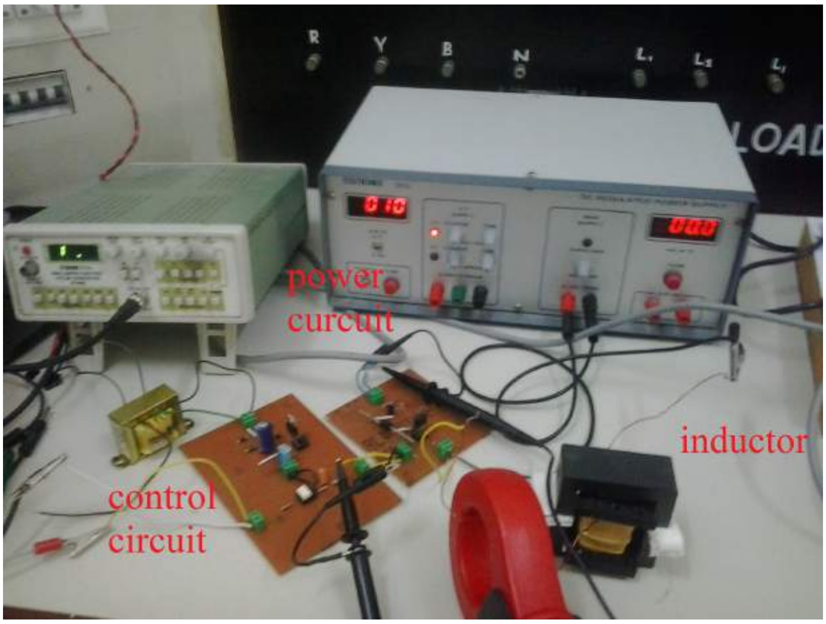

Figure 4: Circuit of Boost Converter

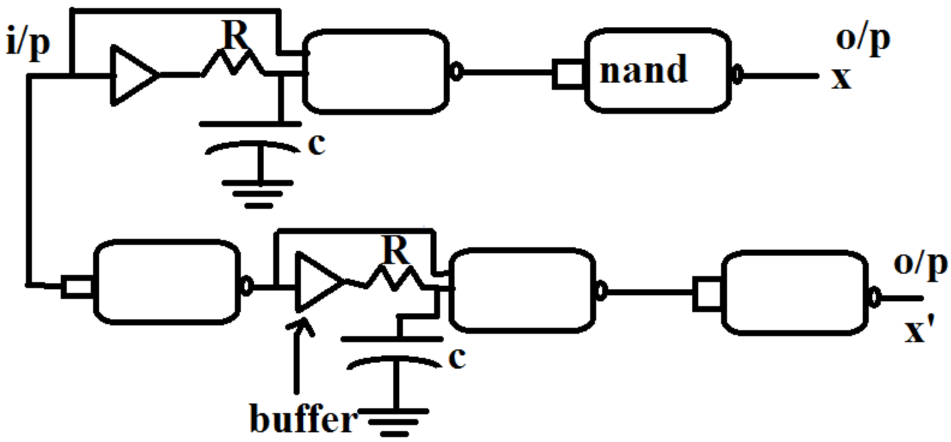

Figure 5: Circuit Diagram of Dead Band

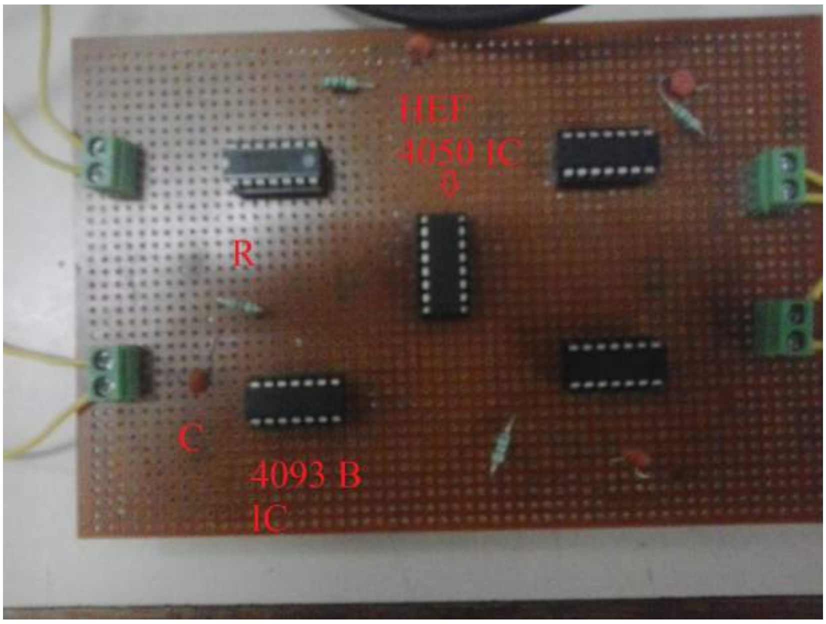

Figure 6: Circuit Diagram of Dead Band

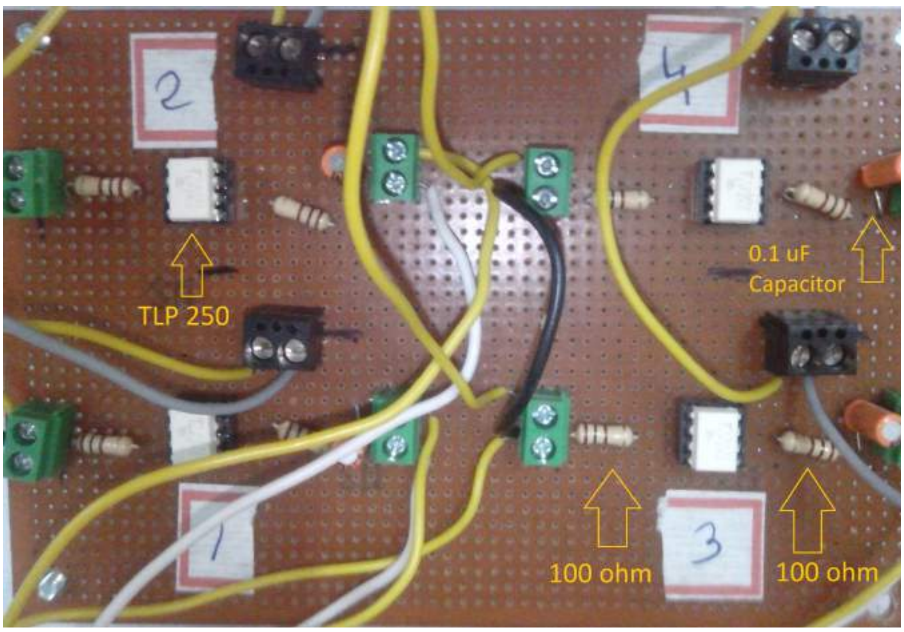

Figure 7: Control Circuit for Inverter

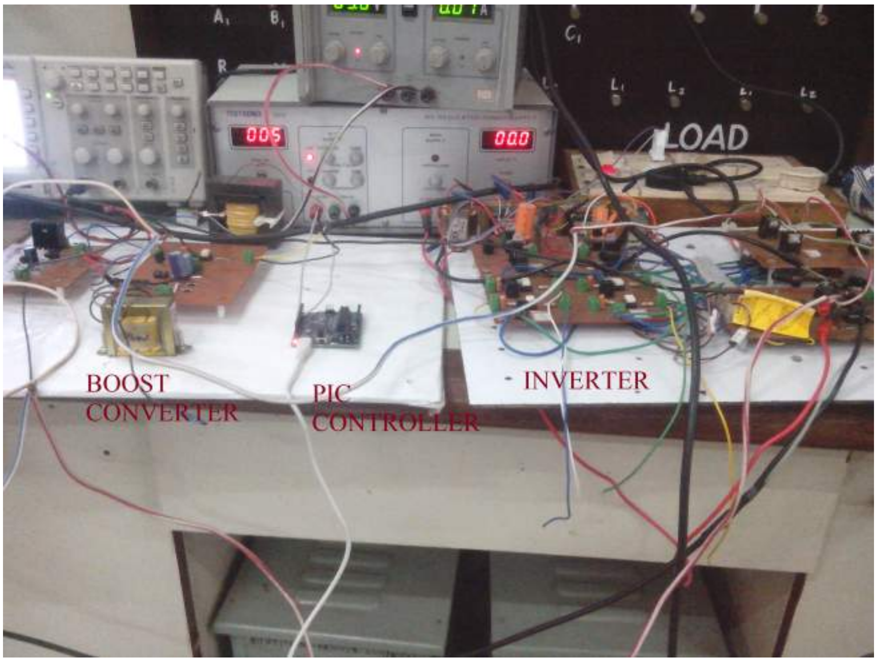

Figure 8: Integration of boost converter with inverter

Figure 9: Integration of PV panel with boost converter