An Efficient Solar Inverter with VAR Compensation and Bidirectional Metering Action

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

Payal Somani
(13MEEP11)

Department of Electrical Engineering
INSTITUTE OF TECHNOLOGY
NIRMA UNIVERSITY
AHMEDABAD 382 481

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Statement of Originality

I, **Payal Somani**, Roll. No. **13MEEP11**, give undertaking that the Major Project entitled **An Efficient Solar Inverter with VAR Compensation and Bidirectional Metering Action** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Power Electronics Machines & Drives** of Institute of Technology, Nirma University, Ahmedabad, contains no material that has been awarded for any degree or diploma in any university or school in any territory to the best of my knowledge. It is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. It contains no material that is previously published or written, except where reference 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:

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Department of Electrical Engineering

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CERTIFICATE

This is to certify that the Major Project Report entitled **"An Efficient Solar Inverter With VAR Compensation and Bidirectional Metering Action"** submitted by **Ms. Payal Somani (13MEEP11)**, towards the partial fulfillment of the requirements for the award of degree in **Master of Technology (Electrical Engineering)** in the field of **Power Electronics, Machines & Drives** of Nirma University is the record of work carried out by her 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.

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TO WHOMSOEVER IT MAY CONCERN

This is to certify that **Ms. Payal Somani** (Roll No-13MEEP11) Student of M.Tech in Electrical Engineering (Power Electronics Machines and Drives) of Institute of Technoogy, Nirma University, worked in Electrical Research and Development Association (ERDA), Vadodara as a Project Student during the period of July 2014 to May 2015.

During this period he carried out works pertaining to his thesis titled **"An Efficient Solar Inverter With VAR Compensation and Bi-Directional Metering Action"**, under my supervision.

He completed his project sucessfully with utmost dedicated and high level of engineering and analytical competence.

We wish her all the best for his future endeavours.

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Success of any work depends upon the dedication, sincerity and hard work. It also requires some ingredients such as motivation, guidance, encouragement and time.
With immense pleasure, I would like to present this report on the dissertation work related to "An Efficient Solar Inverter With VAR Compensation and Bi-directional Metering Action". I am very thankful to all those who helped me for the successful completion of the first phase of the dissertation and for providing valuable guidance throughout the project work.
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- Payal Somani
13MEEP11

Abstract

In a photovoltaic system connected to the grid, the main aim is to design an efficient solar inverter whose efficiency is greater than 90% and also to control the power that the inverter injects into the grid with bi-directional metering action. The efficiency of the overall PV system depends upon the efficiency by which the direct current of solar module is converted into the alternating current (i.e. Inverter efficiency). The basic requirement in order to interface the solar module to the grid with increased efficiency includes: Maximum power point, high power factor, low THD of current injected to the grid. In this project an algorithm for Maximum power point tracking (MPPT) is used to find maximum power point of the solar. The output voltage and current from MPPT is given to the DC-DC boost converter. This boosted voltage is fed to the HERIC inverter in order to convert DC voltage into AC voltage. The advantage of the proposed HERIC inverter is its efficiency (>92%).

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Abbreviations

HERIC .... Highly Efficient and reliable inverter concept
IC .... Incremental conductance
IGBT .... Insulated Gate Bipolar transistor
LFT .... Low Frequency Transformer
LPF .... Low pass filter
MPP .... Maximum Power point
MPPT .... Maximum Power Point Tracking
PV .... Photovoltaic Panel
P & O .... Perturb and observe
PWM .... Pulse width Modulation
THD .... Total Harmonic Distortion
VSI .... Voltage Source Inverter

Nomenclature

V_{dc}	DC link Voltage
I_{ph}	Cell photocurrent
R_s	Intrinsic series resistance
R_{sh}	Intrinsic shunt resistance
I_D	Saturation current of diode
I_{pv}	Output Current of PV module
V_{pv}	Output Voltage of PV module
T_r	Reference Temperature
I_{scr}	PV module short circuit current
N_s	Number of cell connected in series
N_p	Number of cells connected in parallel
T_{on}	On time for IGBT
f_{sw}	Switching frequency
T_s	Switching period
V_{in}	Input DC Voltage
P_O	Output power

Contents

Chapter 1

Introduction

1.1 Introduction

Energy demands are increasing at a rapid rate which has led to high consumption of fossil fuels, with negative environment consequences like global warming, acid rain, depletion of ozone layer etc[10]. In order to overcome the negative impact of fossil fuels and increasing fuel rate the renewable energy sources finds a wide application. Presently, renewable energy sources are the attractive source of energy due to the increased fuel consumption, exhausting fossil fuels and their impact on environment issues[2]. There are various renewable energy technologies that has been developed, which are reliable and cheap as compared with conventional power generation. Thus the research on non-conventional energy sources becomes the most significant among the clean and green environment power sources. Solar energy is one of the most significant source of renewable energy. Thus the photovoltaic solar energy comes up to be the most attractive alternative to supplement the generation of electricity due to numerous advantages.

Photovoltaic system converts the solar energy into electrical energy. PV system consists of several components, which includes solar panels (PV panels), DC-DC boost converter, DC-AC converter. PV panels absorbs the sunlight and converts it directly into electricity (DC). The output voltage generated from the PV panel is very low, thus a boost converter is required in order to increase the voltage level. This boosted voltage is then fed to the inverter. The main function of inverter is to generate a sinusoidal output voltage at a certain level as well as frequency.

1.1.1 Advantages of PV System:

a. Everlasting renewable energy source.

b. Low maintenance.

c. Noise free due to absence of rotating parts.

d. Fuel cost is nil.

e. Clean energy source.

f. Long life

g. Large source of energy.

h. Suitable for remote loads away from main electrical network and at places where other fuels are scare and costly. Cost of distribution lines can be eliminated.

1.1.2 Disadvantages of PV System:

a. High capital cost

b. Need for battery storage.

c. Not reliable

d. Low efficiency.

Photovoltaic system can be used as standalone systems and grid-connected systems and their application includes water pumping, home power supplies, street lightning, telecommunications etc.

The efficiency of a PV plant is mainly dependent upon three factors:

a. Efficiency of PV panel (commercially it is between 8-15%).

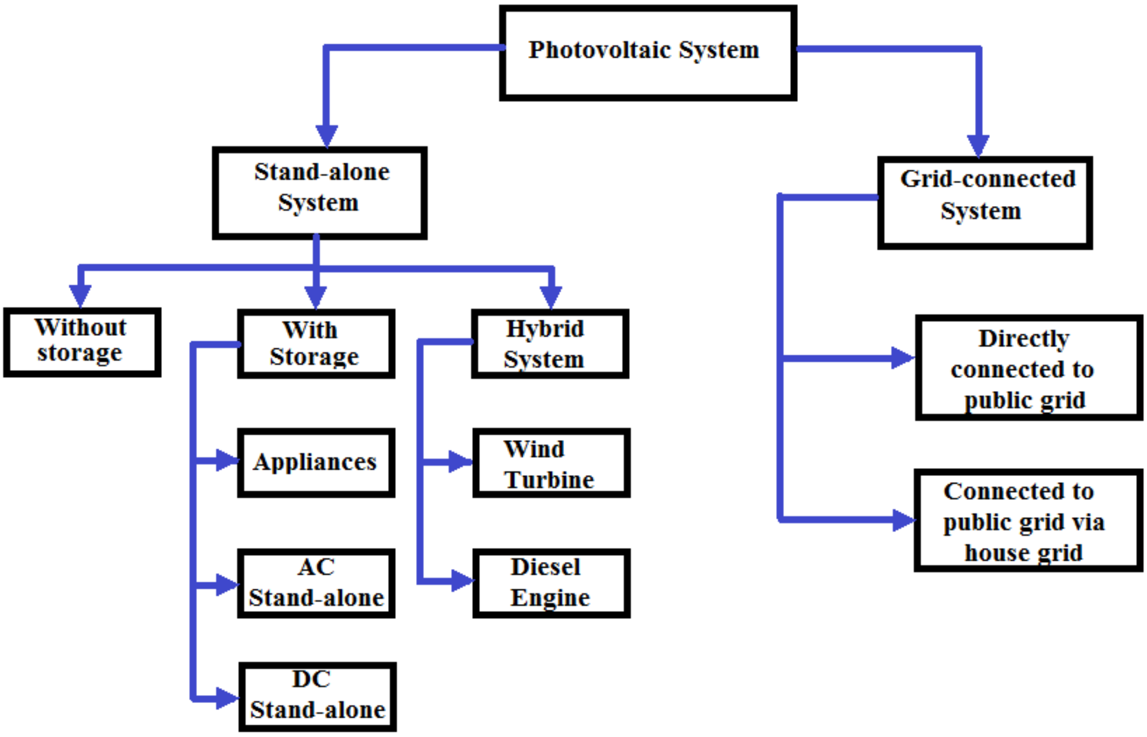


Figure 1.1: Applications of PV System

b. Efficiency of MPPT algorithm (which is over 98%).

c. Inverter efficiency ($> 92\%$).

Improving the efficiency of PV panel is not as easy. Infact improving the tracking of the maximum power point (MPP) is easier by using new control algorithms and can be done in plants which are already in use and this will lead to an immediate increase in PV power generation.

1.2 Problem Identification

a. Grid connected photovoltaic inverter with galvanic isolation suffers from high cost, weight and size and comparatively low efficiency due to presence of transformer.

b. Generally PV inverters fails to achieve higher efficiency at partial load i.e. at the time of reduced irradiation level.

c. MPPT controller tacks the maximum power during constant irradiation and temperature but fails to track at varying irradiance and temperature.

1.3 Objective of the Work

Following are the objectives selected for this work:-

- To design an efficient solar inverter which converts solar energy into electrical energy and also controls the power that the inverter injects into the grid.
- To design an efficient MPPT algorithm suitable for PV application in order to extract the maximum possible energy from the panel.
- To provide an optimized MPPT algorithm with fast tracking and low power fluctuation characteristics under changing environmental operating conditions.

1.4 Methodology

a. To investigate and understand the merits and demerits of various inverter topologies through literature survey.

b. To investigate and understand the strength and weakness of various MPPT algorithms under varying operating conditions.

c. Simulation module by module.

d. Hardware implementation module by module.

e. Testing of modules.

f. Results.

g. Integrating the system.

h. Testing of system.

i. Results.

1.5 Scope of work:

The scope of the project is:

a. To develop a transformerless photovoltaic inverter which can provide the solution to the mentioned issues.

b. To design and select the components of inverter such that it can obtain the highest performance with minimum losses and better efficiency.

c. To develop an optimum MPPT algorithm.

d. The designed inverter must control the power factor.

e. Development of the prototype module for testing and verification.

1.6 Literature survey:

For the better understanding of project literature survey plays an important role. Literature survey consists of papers referred and gives the fundamental knowlegde of photovoltaic system, boost converter and inverter.

a. Paper [5] gives the data about the practical factors that may impact the inverter size. These elements incorporate irradiance and temperature states of the photovoltaic (PV) establishment area, PV incentives, power rates, and inverter intrinsic parameters, for example, overload protection schemes and effectiveness bends.

b. Paper [2] gives us the brief idea about cascaded multilevel single phase with grid connected inverter having least number of switches for PV systems, power conversion based MPPT algorithm. Gate driving circuit has been reduced, hence size & the power consumption in driving circuits is reduced which results in reduced THD of output waveforms[2].

c. Paper [6] gives brief idea about the control scheme for a grid-connected photovoltaic (PV) inverter featuring maximum power point tracking (MPPT) and grid current shaping.

d. Paper [3] discusses about a digital control strategy based on the phase shifting of the inverter output voltage with respect to the grid voltage, in order to control the power factor with a minimum number of Digital Sinusoidal Pulse Width Modulation (DSPWM) patterns and for a wide range of the inverter output current.

e. Paper [7] focuses on comparison of different aspects of single stage and two stage photovoltaic inverter topologies. Advantages and disadvantages keeping the application point of view are discussed.

f. Paper [8] discusses different topologies for single phase grid connected system.

g. Paper [4] discusses inverter based on the number of power processing stages in cascade, the type of power coupling between the single phase grid and PV module, whether they utilizes a transformer or not and the type of grid-connected power stages.Various inverter topologies are compared against component ratings, demands, lifetime, and cost[4]. Finally, some of the topologies are pointed out as the best topology for single phase PV modules.

h. Paper [9] gives information that some amount of energy is wasted at steady state when working point sways around the MPP. Possible arrangement is required to overcome this maximum Ta value valid for specific range of voltage & current PV array. During changing atmospheric conditions, P& O algorithm can be confused.

i. Paper [1] gives information about various classical and multilevel topologies. A comparative study is given.

1.7 Topology selection:

The photovoltaic system can be classified as:

a. **On the basis of Power Processing Stage**

(1) Two stage:

Generally the output from the PV panel is very low and varying with the environmental conditions. Hence a voltage booster is required whose output remains constant irrespective of the input. Thus this topology requires an additional DC-DC converter as shown in fig.

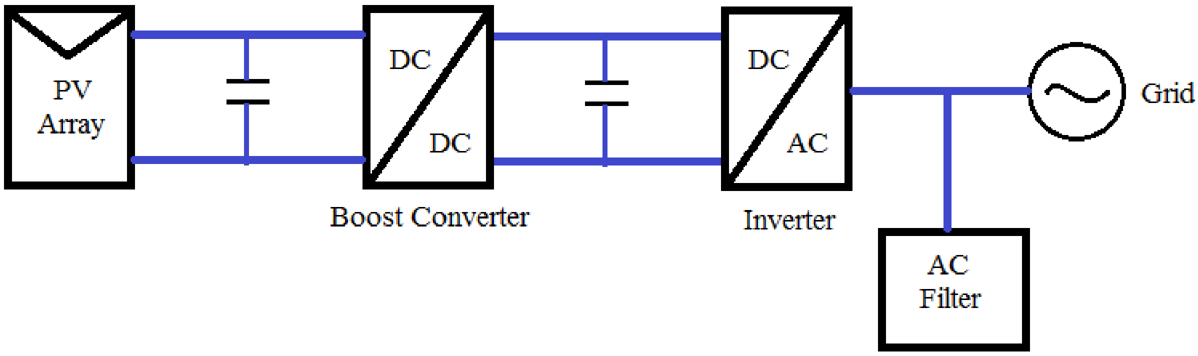


Figure 1.2: Two Stage Power Processing Stage

(2) Single Stage:

Although there are numerous advantages of two stage but there are some drawbacks of it such as: As the number of stage increases power losses increases and thus efficiency decreases, it also increases system complexity and hence reliability reduces. These drawbacks can be overcome by the single stage topology in which the system relies only on inverter.

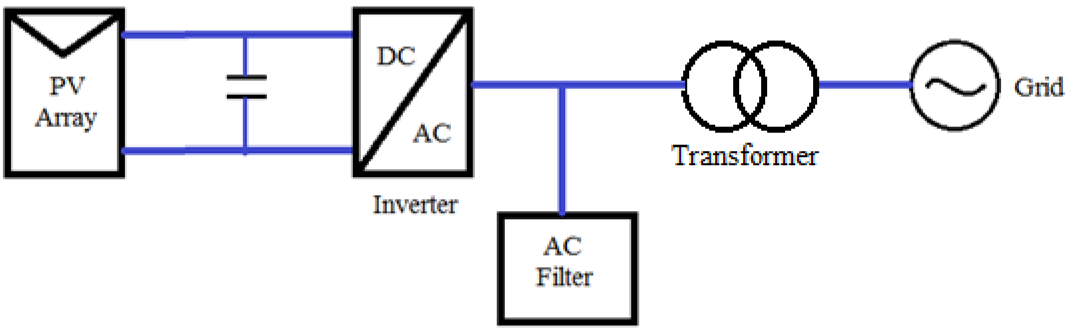


Figure 1.3: Single Power Processing Stage

b. **On the basis of galvanic isolation to the grid**

(1) With galvanic isolation :

Fig. below shows the block schematic of grid connected photovoltaic inverter with transformer.

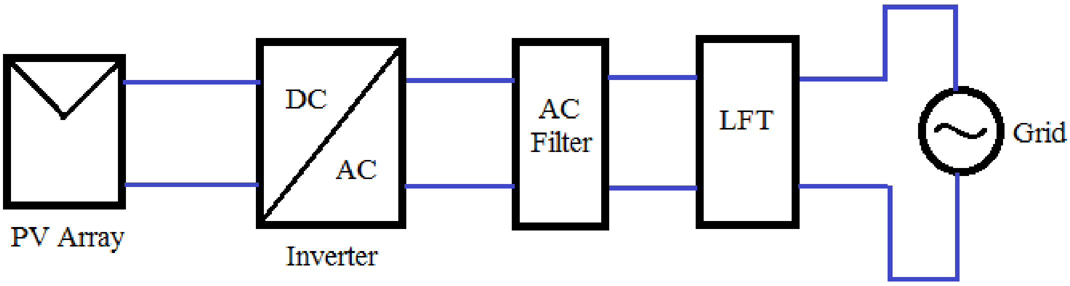


Figure 1.4: Topology with Galvanic Isolation

i. Advantages:

A. Robust construction

B. Provides galvanic isolation to the grid

ii. Disadvantages:

A. Overall efficiency decreases due to transformer.

B. Increased size and cost due to the addition of the transformer.

(2) Without galvanic isolation:

Fig below shows the block diagram of the grid connected photovoltaic system without transformer, which does not provide galvanic isolation with the grid. Since the PV panel voltage varies throughout the day due to change in temperature, thus a boost stage is required in order to make DC link voltage of inverter constant.

i. Advantages:

A. Weight and cost reduces.

B. No transformer hence the size reduces.

C. Improved efficiency due to absence of transformer.

D. Reliability increases due to less number of components.

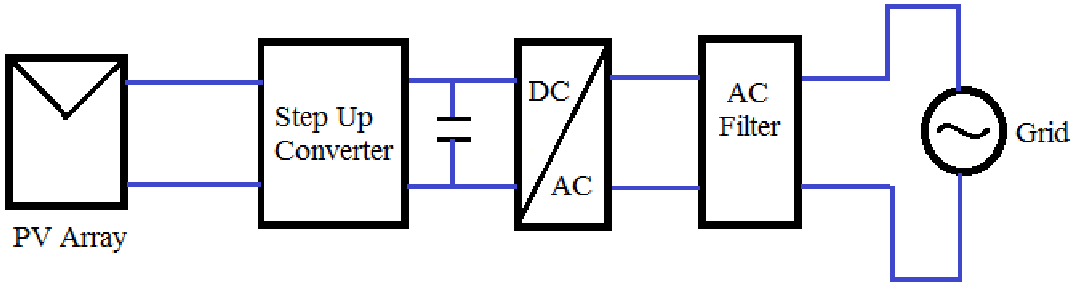


Figure 1.5: Topology Without Galvanic Isolation

ii. Disadvantages:

A. No electrical separation to the grid.

B. Common mode voltage and leakage current problem arises.

1.8 Power Schematic:

Fig. shows the block diagram of the PV system. Since the output voltage of PV panel is very low and practically it is not possible to keep large number of panels because it is not cost effective hence an additional boost stage is required in order to increase the voltage level. For low power application single phase full bridge inverter is used, but the efficiency of it is very low. Output from the inverter is not sinusoidal hence it cannot be connected directly to the grid, thus a filter stage is required. Brief

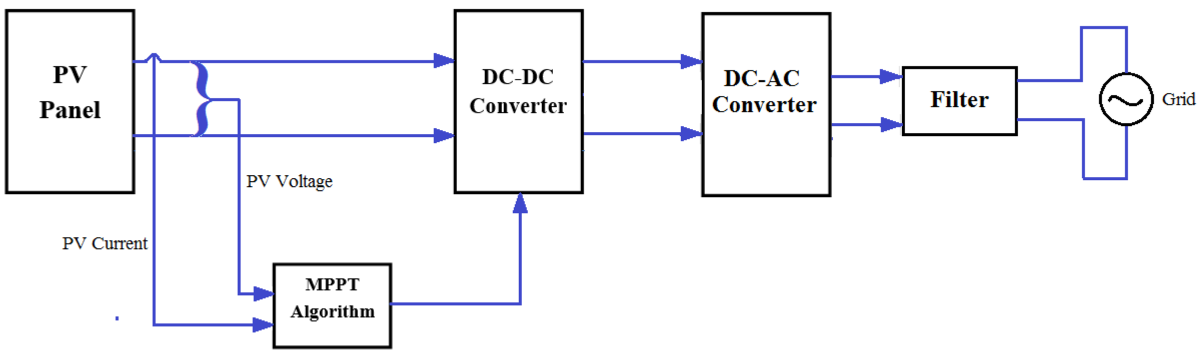


Figure 1.6: Block Diagram of PV System

description of individual power processing stage:

a. PV Panel:

Optimum choice and rating of PV panel depends upon the power rating of the system. Arrangement of PV Panel(i.e Series or parallel) is made according to the voltage and current requirement . If the system demands for high voltage then the series connection of PV panels is made and if the system demands for the current, parallel connection is made.

b. DC-DC Converter:

noindent Generally the output of the PV panel is very low and it?s varying according to the climatic condition. So the two stage topology is selected so as to keep the DC output voltage constant. A proper value of inductor and capacitor are selected and the voltage variation are examined throughout the day. The constant DC output from the boost converter is fed to the inverter.

c. DC-AC Converter:

noindent The most essential requirement in order to interface the grid with the system is to have sinusoidal voltage and current at the output terminal. So to convert the DC into AC an inverter stage is required. In this project Heric inverter with suitable control technique is used to improve the efficiency of the system.

Chapter 2

Photovoltaic Panel

2.1 Introduction

The output of one crystalline silicon photovoltaic cell is approximately 0.5V. In order to produce a specific output voltage solar cells are connected in series. They are electrically connected and mechanically mounted in a frame to form a panel. When panels are wired in series or parallel the form an array. The solar panels are also equipped with necessary protective devices, such as bypass and blocking diodes in order to protect cells from the temperature rise under shady condition or to prevent it from reverse current flowing back during night.

Photovoltaic cells uses the "photovoltaic effect" phenomenon to produce the electricity. The physics of PV cell is similar to conventional PN junction diode. Whenever the light falls on the junction, the energy of it is transferred to the electron-hole pair, thus the free charge carriers are generated. These charge carriers creates the potential gradient and gets accelerated under the electric field. This will cause the current to flow through the external circuit.

2.2 Mathematical Model of PV Module:

Equivalent circuit for PV module showing the diode and ground leakage currents.
where, I_{ph} = Cell photocurrent,
R_s=intrinsic series resistance,

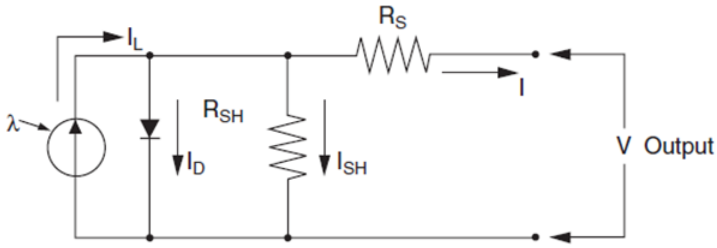


Figure 2.1: Basic model of Solar cell

R_{sh}= Intrinsic shunt resistance

Ideally $R_s = 0$ (i.e series resistance is not there) and $R_{sh} = \infty$ (i.e leakage to ground)

Variation of R_s practically lies between 0.05 and 0.01 Ω and R_{sh} lies between 200-300 Ω

Open circuit voltage of PV cell is given as:

$$V_{oc} = V + IR_{sh} \tag{2.1}$$

Diode current is given as:

$$I_d = I_D[e^{\frac{QV_{oc}}{AkT}} - 1] \tag{2.2}$$

Where,

I_D =Saturation current of diode;

Q = electron charge = $1.6 * 10^{-19}C$

K= Boltzmann constant= $1.38 * 10^{-23}J/^oK$

PV cell are grouped in a large units which are known as PV module and they are further interconnected in a series parallel pattern to form PV array.The photovoltaic panel can be modelled mathematically by equation as:

Module photo current:

$$I_{ph} = [I_{scr} + K_i(T - 298)] * \lambda/1000 \tag{2.3}$$

Module reverse saturation current:

$$I_{rs} = I_{scr}/[exp(qV_{oc}/N_skAT) - 1] \tag{2.4}$$

The module saturation current I_0 varies with the cell temperature, which is given by

$$I_0 = I_{rs}[\frac{T}{T_r}]^3 exp[\frac{Q * E_{go}}{Bk}(\frac{1}{T_r} - \frac{1}{T})] \tag{2.5}$$

The current output of PV module is:

$$I_{pv} = N_p * I_{ph} - N_p * I_0[exp(\frac{Q * (V_{pv} + I_{pv}R_s)}{N_s kAR}) - 1] \tag{2.6}$$

where,

I_{pv} = PV module output current(A)

V_{pv} = PV module output voltage (V)

T = operating temperature of module in Kelvin

T_r = reference temperature = 298 K

I_{ph} = light generated current in a PV module (A)

I_0 is PV module saturation current (A)

Q is Electron charge = $1.6 * 10^{-19}$ C

A = B is an ideality factor = 1.6

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

R_s = the series resistance of a PV module

I_{scr} = PV module short-circuit current at 25^oC and $1000W/m^2$ = 2.55A

Ki = the short-circuit current temperature co-efficient at

I_{scr} = 0.0017A / ^oC

λ = the PV module illumination (W/m^2)= $1000W/m^2$

Ego is band gap for silicon = 1.1 eV

Ns = No. of cells connected in series

Np = No. of cells connected in parallel

2.3 Simulation for PV Panel

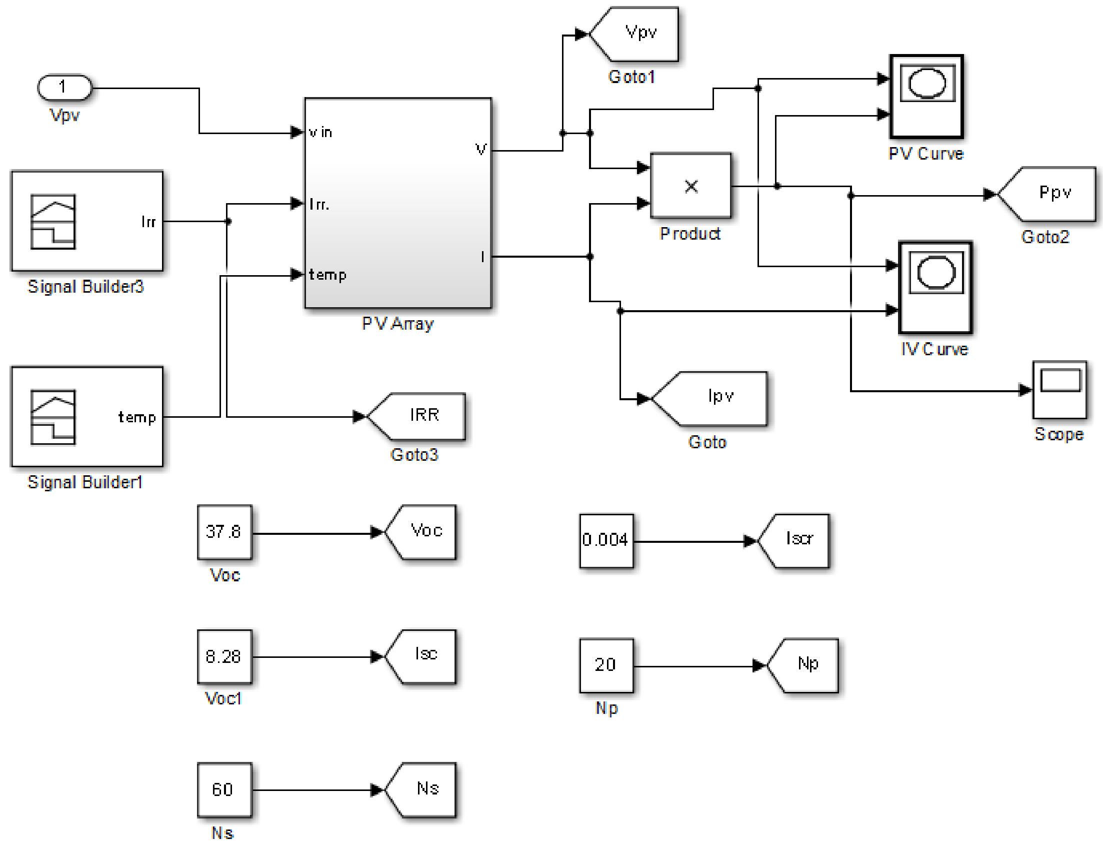


Figure 2.2: Matlab simulation for PV Panel

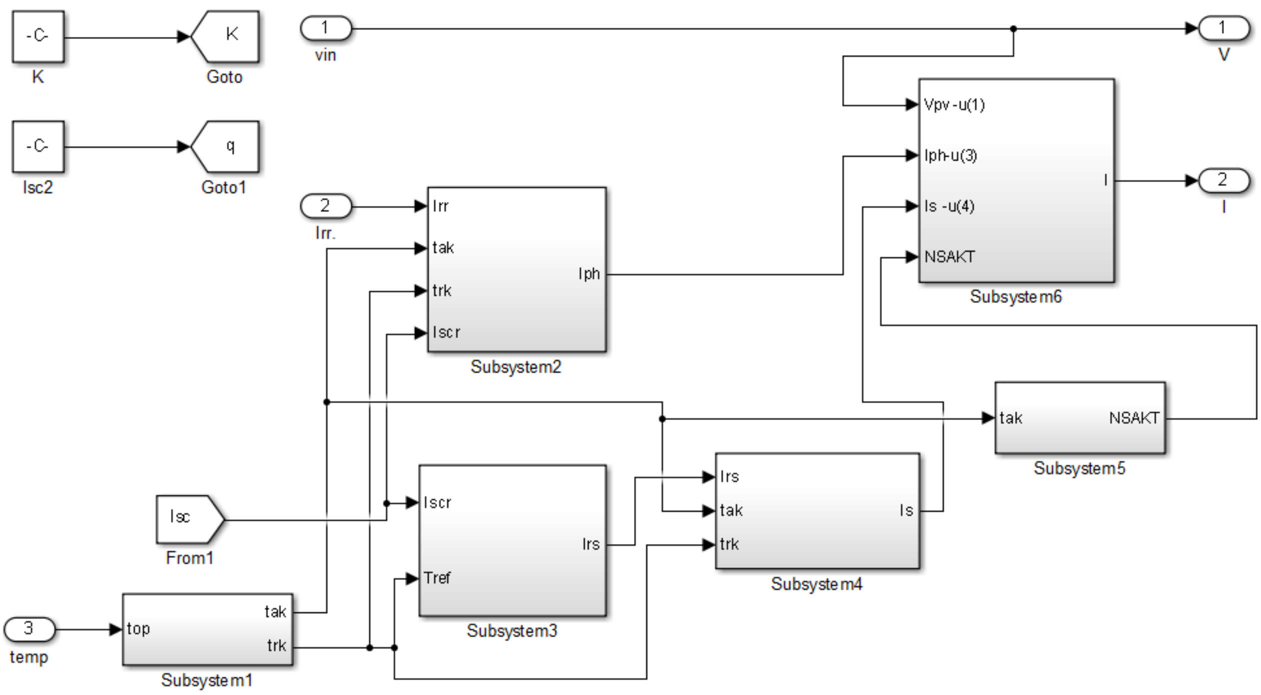


Figure 2.3: Subsystem (PV Array)

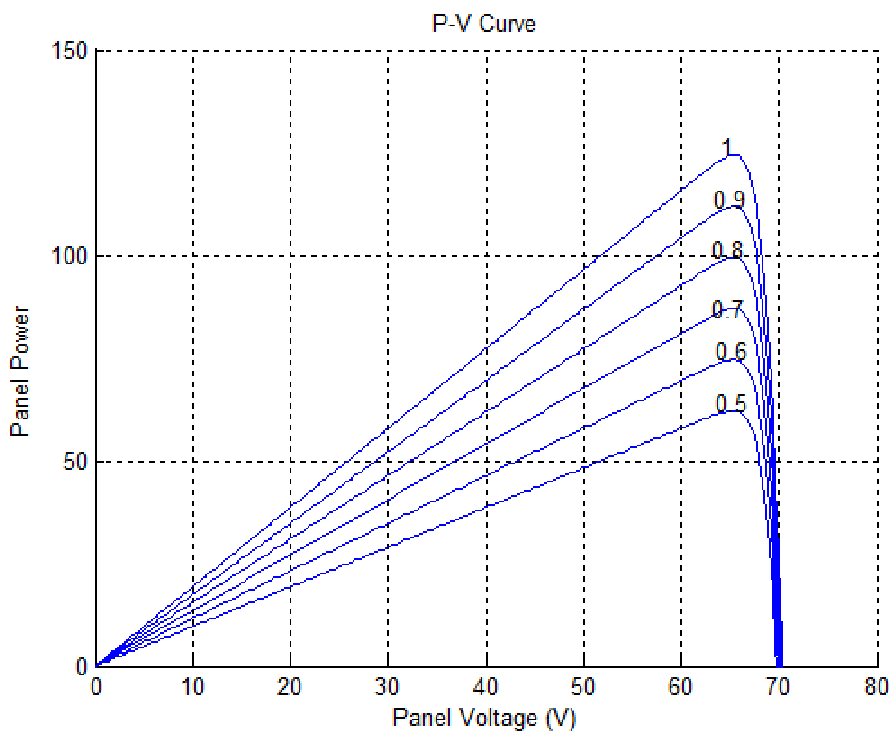


Figure 2.4: P-V Curve with variable Irradiance

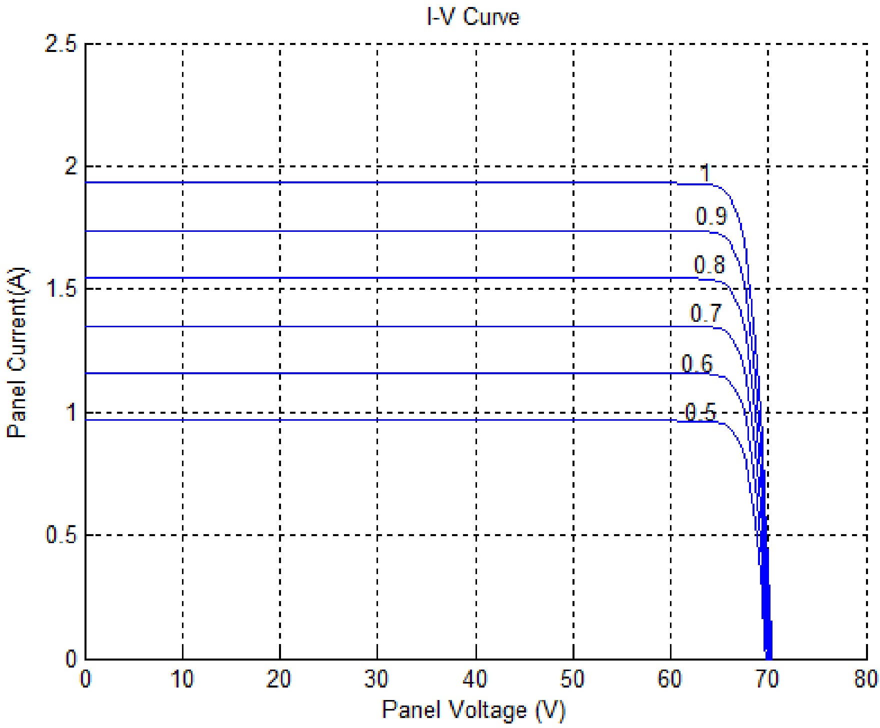


Figure 2.5: I-V curve with variable Irradiance

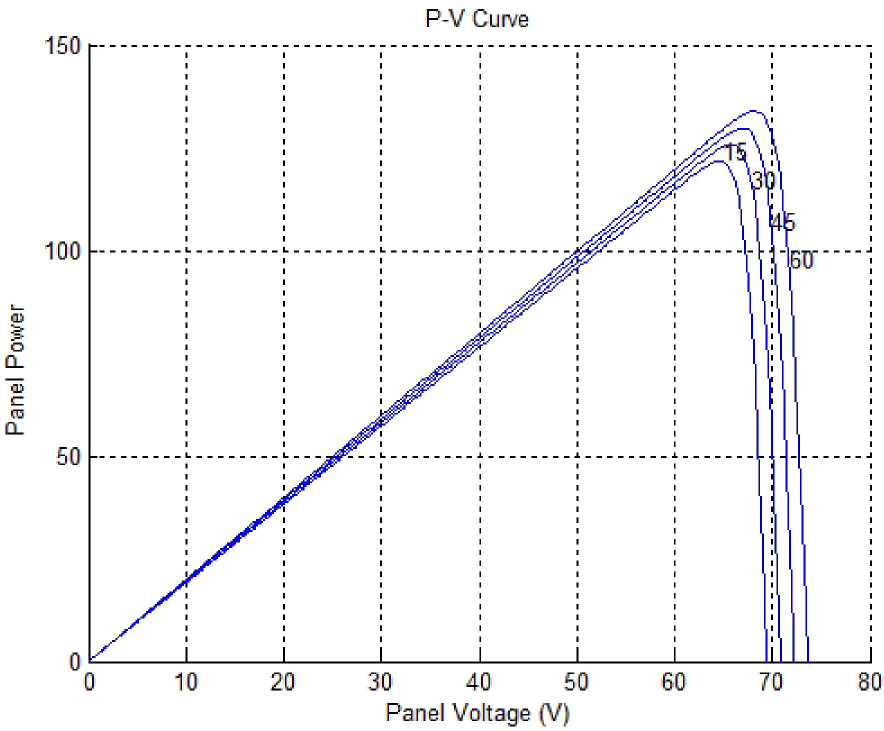


Figure 2.6: P-V curve with variable Temperature

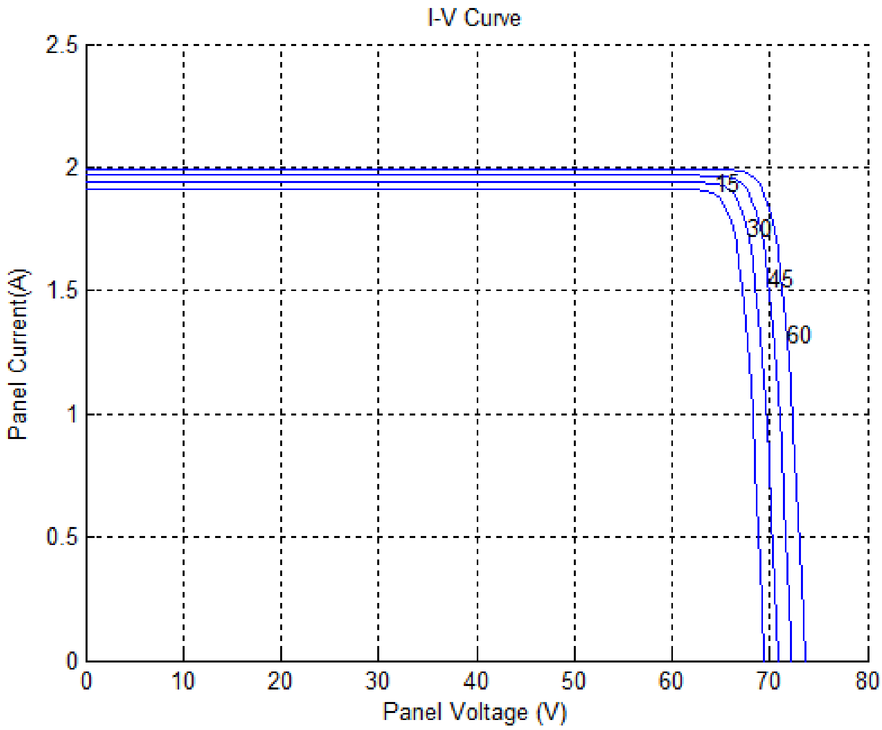


Figure 2.7: I-V curve With Variable Temperature

Chapter 3

DC-DC Boost Converter

3.1 Boost Converter

Generally the output of PV panel is very low and it changes according to the atmospheric condition. So in order to make DC link voltage V_{dc} constant irrespective of the change in input from PV panel an additional stage is used i.e. Boost converter is used to boost up the voltage at a constant level irrespective of the change in input. Fig. below shows the circuit diagram of boost converter. A proper design and selection of each componnent is done.

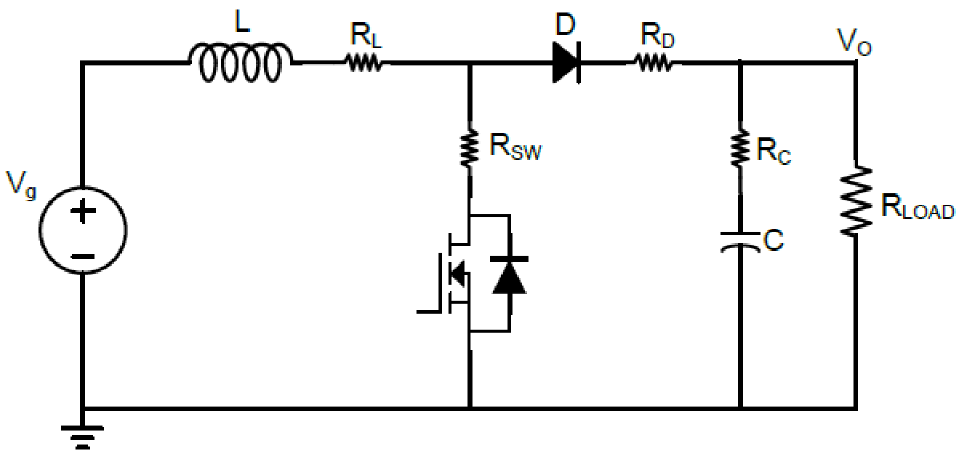


Figure 3.1: Circuit Diagram Of Boost Converter

3.1.1 Inductor Design

Specification of Boost Converter:

Output Power, P_O(kW): 5kW

Output Volatge, V_{out}(V) : 330V

Load Current, I(A) : 16.4

Input Voltage, V_{in}(V) : 90V

Switching Frequency, f_{sw}(kHz) :20

Load Resistance : 20Ω

For the given V_{in} D is given as:

$$V_{out} = \frac{1}{1-D} * V_{in} \tag{3.1}$$

$$330 = \frac{1}{1-D} * 90 \tag{3.2}$$

$$D = 0.9293 \tag{3.3}$$

Switching frequency (f_{sw})= 20kHz

Therefore Switchind time (T_s)= 50μsec

On Time for IGBT:

$$T_{on} = D * T_s \tag{3.4}$$

$$T_{on} = 72.73\mu sec \tag{3.5}$$

$$L_s = \frac{R * D(1-D)^2}{2 * f_{sw}} \tag{3.6}$$

$$L_s = 0.3633mH \tag{3.7}$$

3.1.2 Capacitor Design

$$C = \frac{V_{out} * D}{f_{sw} * \Delta V_{out} * R} \tag{3.8}$$

Where,

D= Duty Cycle

V_{out}= output voltage of boost converter

R= Load resistance

ΔV_{out}= Amplitude of allowed voltage ripple.

Therefore

$$C = 181\mu F \tag{3.9}$$

3.2 Simulation Results

The simulation of DC-DC boost converter is being carried out using MATLAB/Simulink. Open and closed loop simulation is done in order to maintain the constant output voltage.

3.3 Open loop DC-DC boost Converter

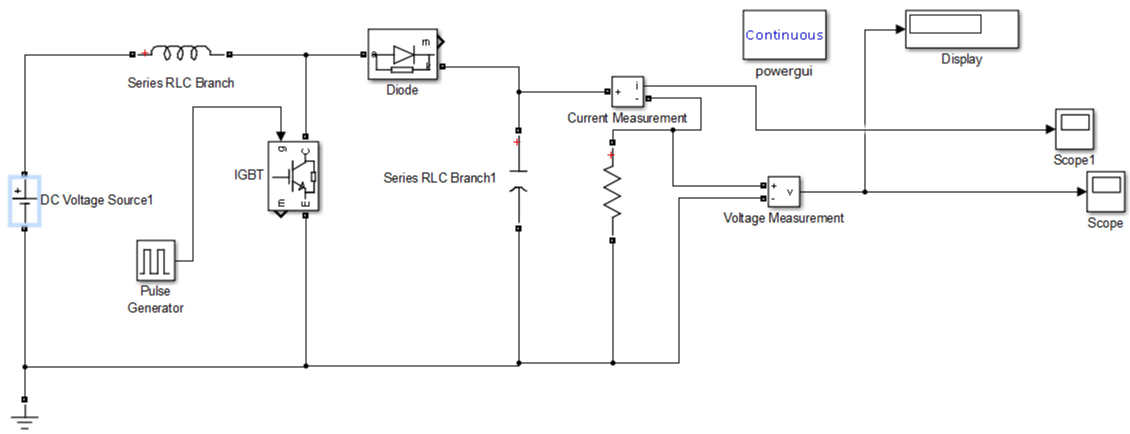


Figure 3.2: Open Loop DC-DC boost converter

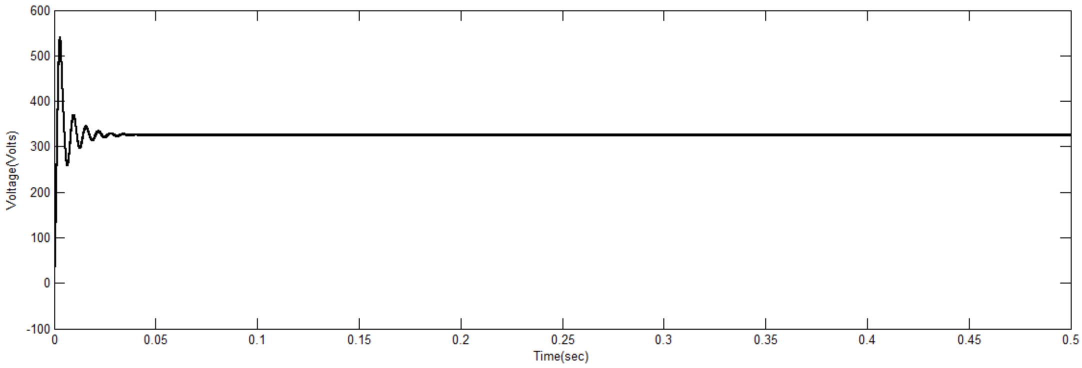


Figure 3.3: Output Voltage of Open Loop DC-DC boost converter

3.4 Closed loop DC-DC boost converter

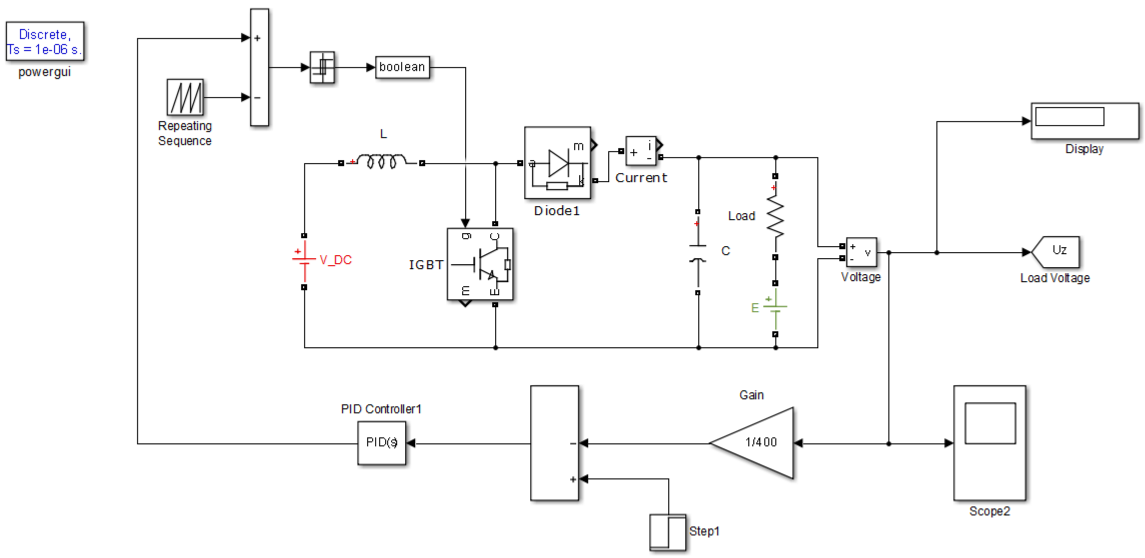


Figure 3.4: Simulation of Closed loop DC-DC boost converter

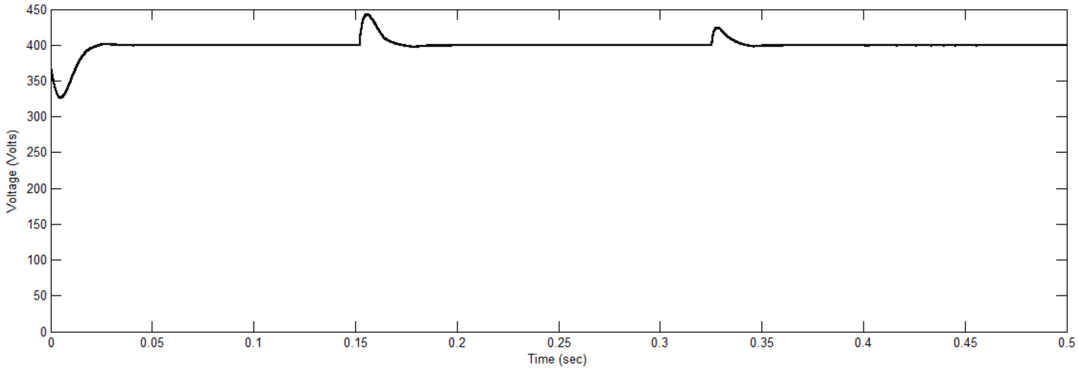


Figure 3.5: Output Voltage of closed loop DC-DC boost converter

3.5 Hardware Implementation Of Boost Converter

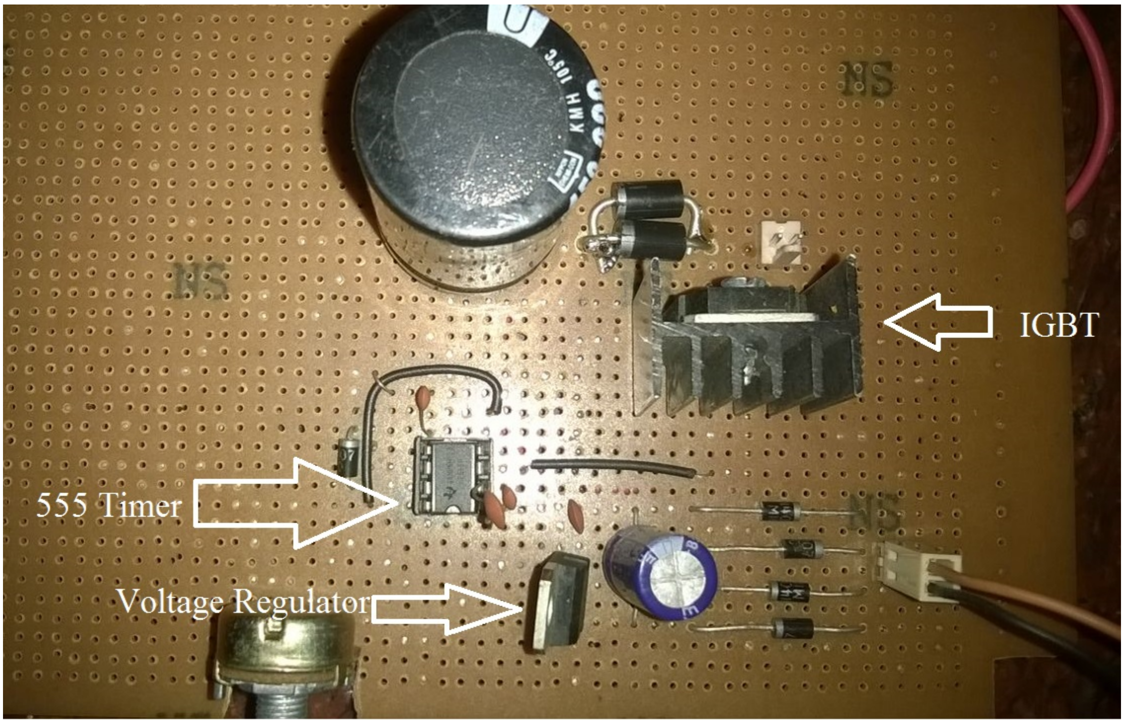


Figure 3.6: HardwareModule for Boost Converter

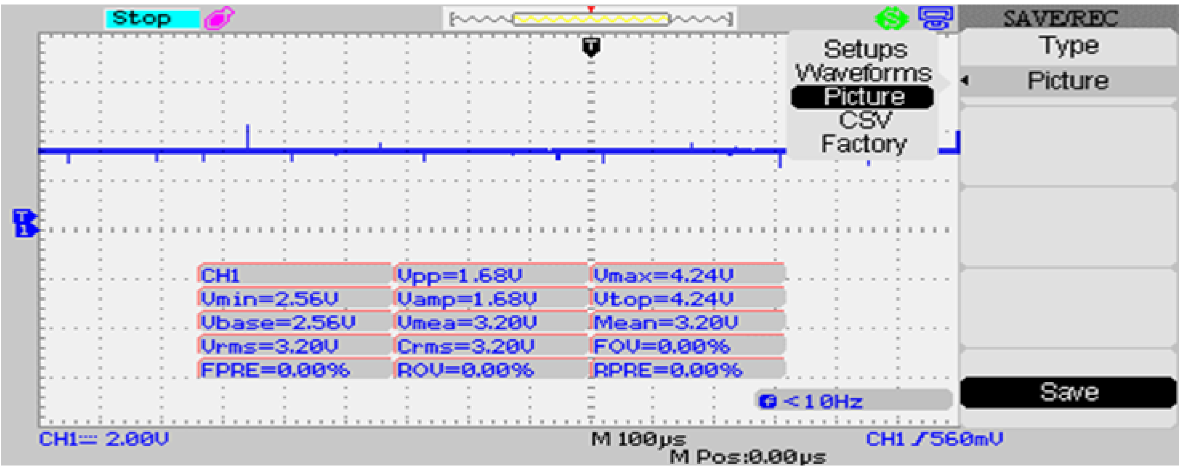


Figure 3.7: Input voltage to boost converter

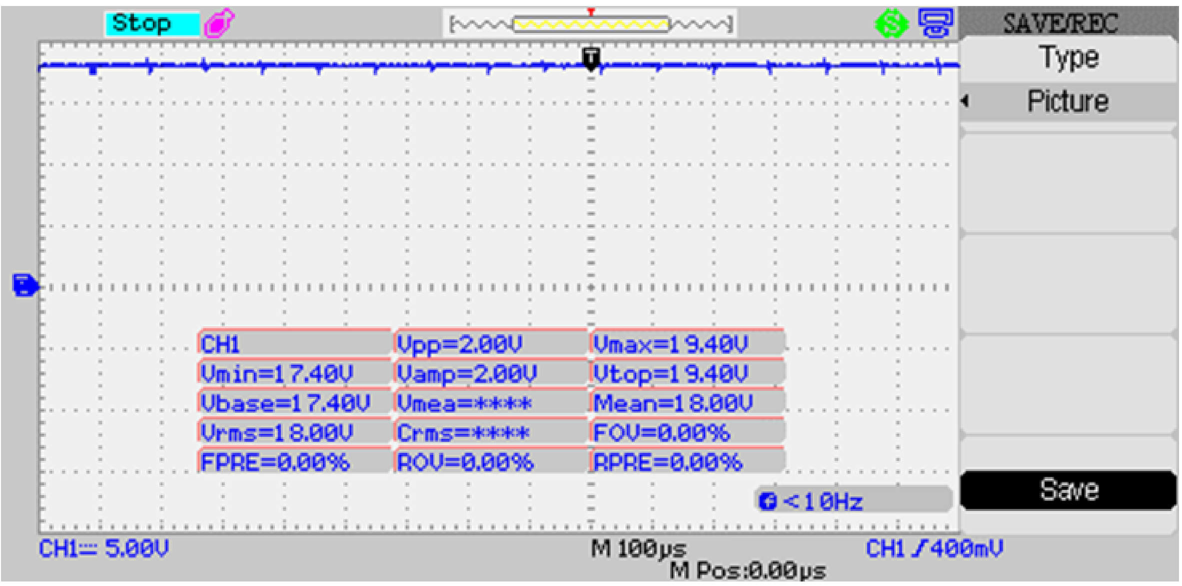


Figure 3.8: Output Voltage of boost converter

Chapter 4

Maximum Power Point Tracking System

4.1 Introduction

MPPT Calculations are essential on the grounds that the PV array have a non-linear V-I Characteristics with a special point where the power produced is maximum. This point basically depends upon the two factors that is irradiance and temperature of the panel[10]. Both these factors changes according to climatic condition and also depends upon the seasons in a year. Morever, irradiance can change quickly because of evolving climate conditions, for example, mists. . Hence it is imperative to track the MPP precisely during dierent climatic condition with a specific end goal to obtain maximum power. . In the late years numerous MPPT calculations have been distributed. They dier in numerous prospective, for example, intricacy, expense, sensors required. However, it is worthless to use a more expensive and complicated method if the same results are obtained from the simpler and less expensive one. This is the reason why some of the proposed techniques are not used. Some of the methods are discussed below-

4.2 Perturb and Observe

The Perturb and observe (P& O) algorithm is one of the most used algorithms due to its simplicity and easy implementation. This MPPT met hod is also known as the Hill Climbing (HC) algorithm[10][12]. The difference between P& O and HC may be explained by the fact that the HC requires a change in the converter duty cycle, while the P& O perturbs the operating voltage of the PV panel; but the working principle is the same for both.

4.2.1 Working Principle

The operation of P& O consists in periodically perturbing the panel operating voltage incrementally, so that the power output can be observed and compared at consecutive perturbing cycles. If the power difference is positive, further perturbation is added to the operating voltage with the same increment, and again the output power is observed. This perturbing process is maintained until the power difference is negative. Thus, the direction of perturbation in operating voltage must be reversed. At the point when the working point is situated on the left of MPP as indicated in Figure, the P& O method works by increasing the voltage, which results in an increase in the power output. At the point when the working point is on the right of the MPP, P& O will work in the opposite direction by decreasing the voltage; this results in an increase in power output. If a perturbation results in an increase of power $dP/dV > 0$, it implies that the working point is moved nearly towards the MPP. The subsequent perturbation must be kept in the same direction to bring the operating point closer towards the MPP until MPP is reached. Conversely, if a perturbation results in decrease of power $dP/dV < 0$, implying that the working point has moved far from the MPP, the direction of perturbation must be reversed. The P& O algorithm regulates the PV panels voltage to the voltage corresponding to MPP (VMPP). This MPP is tracked and updated to satisfy the mathematical equation of the power slope $dP/dV = 0$.

The slope dP/dV can be calculated digitally by sampling the PV panel output

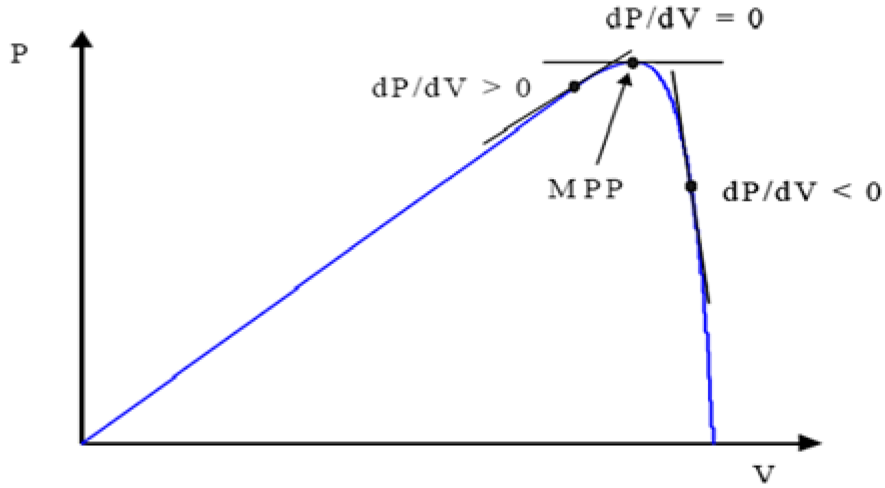


Figure 4.1: MPP point in P-V Curve

current I and voltage V at previous and current time intervals (i-1) and (i), as follows:

$$\frac{dp}{dv}(i) = \frac{(P(i) - P(i-1))}{(V(i) - V(i-1))} \tag{4.1}$$

In the above equation, P (i) is the power product of voltage V (i) and current I (i) measurements. The P& O algorithm works with only two sensors for measuring the panels operating voltage V and current I. A summary of this algorithm is provided in Table.

Table 4.1: Perturb & Observe Operation

Case	Perturbation dV	Change In Power dP	Next Perturbation (Action)
1	dv>0	dp>0	Positive
2	dv>0	dp<0	Negative
3	dv<0	dp>0	Negative
4	dv<0	dp<0	Positive

The details of P& O algorithm can be understood according to the flowchart displayed in Figure: According to the P& O algorithm, the power is calculated consecutively at previous and current states with the help of voltage and current measurements. A test is then undertaken to assess the level of variation of power and voltage at consecutive perturbing cycles. If the power and voltage difference is pos-

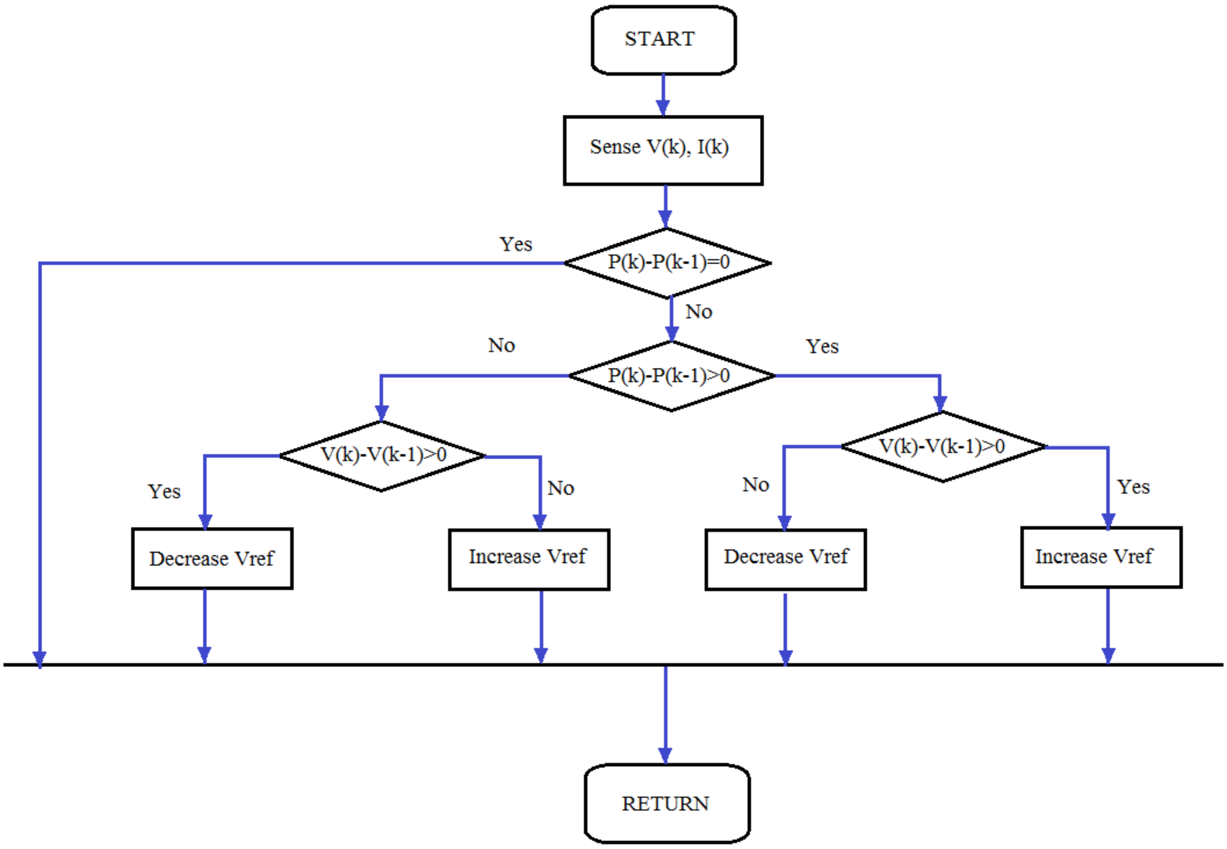


Figure 4.2: Perturb and Observe Algorithm

itive, the algorithm increases the operating voltage, if not, it decreases the voltage. Conversely, if the power and voltage difference is negative, the algorithm increases the voltage; if not, it decreases the operating voltage.

4.2.2 Advantages of P & O Algorithm

The benefits of the P& O method are as follows:

a. It is simple and easy to implement.

b. It is cheap, requiring only panel voltage and current measurements.

c. It is effective when the insolation changes slowly over time.

4.2.3 Disadvantages of P & O Algorithm

The drawbacks of P& O method are as follows:

a. Although the MPP is reached, the operating point continues to oscillate around the MPP, resulting in PV power losses.

b. The P& O fails to work properly under a sudden increase in insolation level, exhibiting erratic behavior.

c. It lacks accuracy in finding whether the MPP is reached.

d. A small constant step perturbation size leads to high accuracy but hampers dynamic performance.

e. A large constant step perturbation size leads to fast tracking, but the accuracy of the tracking suffers (poor steady-state performance).

4.3 Incremental Conductance

The Incremental Conductance (IC) method was proposed in order to overcome the drawbacks of the PO algorithm when subjected to fast changing environmental conditions. With the help of voltage and current measurements, the conductance I/V and incremental conductance dI/dV are determined so that the decision can be made to increase or decrease the operating voltage according to the operating point on the left or the right of the MPP respectively.

4.3.1 Working Principle

The operating principle of the IC method relies on the fact that the slope of the PV panel power curve is positive on the left of the MPP, zero at the MPP and negative on the right of the MPP as follows:
dP/dV $>$ 0 Left of MPP (V$<$VMPP)
dP/dV = 0 at MPP (V=VMPP)
dP/dV $<$ 0 Right of MPP (V$>$VMPP)
As we know that P = V*I, the power curve slope at MPP can be written as:

$$\frac{dP}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} = 0 \tag{4.2}$$

Therefore, $\frac{dI}{dV}$= - I/V , From this may be written as:
dI/dV $<$ - I/V Right of MPP
dI/dV = - I/V At MPP
dI/dV $>$ - I/V Left of MPP
According to equation, the incremental conductance (IC) algorithm provides enough data to locate the MPP. Hence it is made possible by means of the respective measurement and comparison of, I/V and dI/dV. PV mdule is required to operate at the set point refernce voltage VMPP corresponding to the MPP. The detailed operating principle of the IC algorithm can be well understood by means of the following flowchart.

As per the IC algorithm given in Figure, the current & voltage are measured at present and previous states, then to evaluate a test is directed on one side is required for the difference in voltage and current equivalent to zero individually, than other side is measured if the variety of voltage is close to zero and balancing condition dI/dV + I/V = 0 at MPP is acquired. No change is required for this condition.After seeing this conditions the increment or decrement acted by INC algorithm in the voltage.

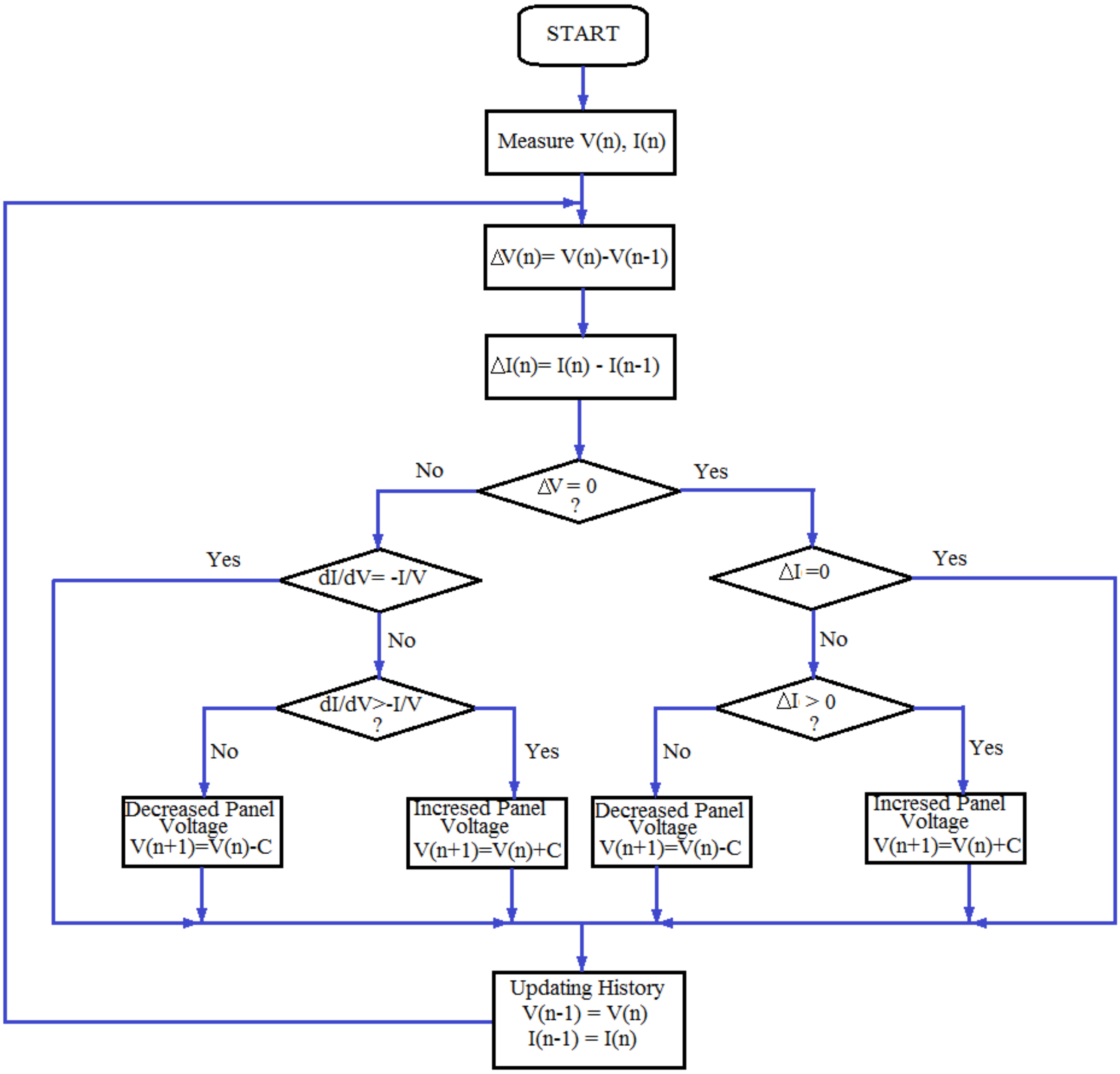


Figure 4.3: Incremental Conductance Algorithm

4.3.2 IC Algorithm-Advantages

The benefits of the IC method can be summarized as follows:

a. More effective at high solar irradiation than other algorithms.

b. MPP can be reached and located theoretically hence perturbation can be stopped and bypassed .

c. It just requires panel current & voltage measuring sensors, on the ground by comparing current the incremental changes can be approximated .

4.3.3 IC Algorithm-Disadvantages

The drawbacks of the IC method are as follows:

a. Complex to Implement IC method as compared to other algorithms.

b. PV current & voltage measurement is Compulsorily required.

c. in order to improve the accuracy of tracking at a point when the fixed step increment is decreased , due to dynamic performance the system becomes slows.

4.4 Simulation Results

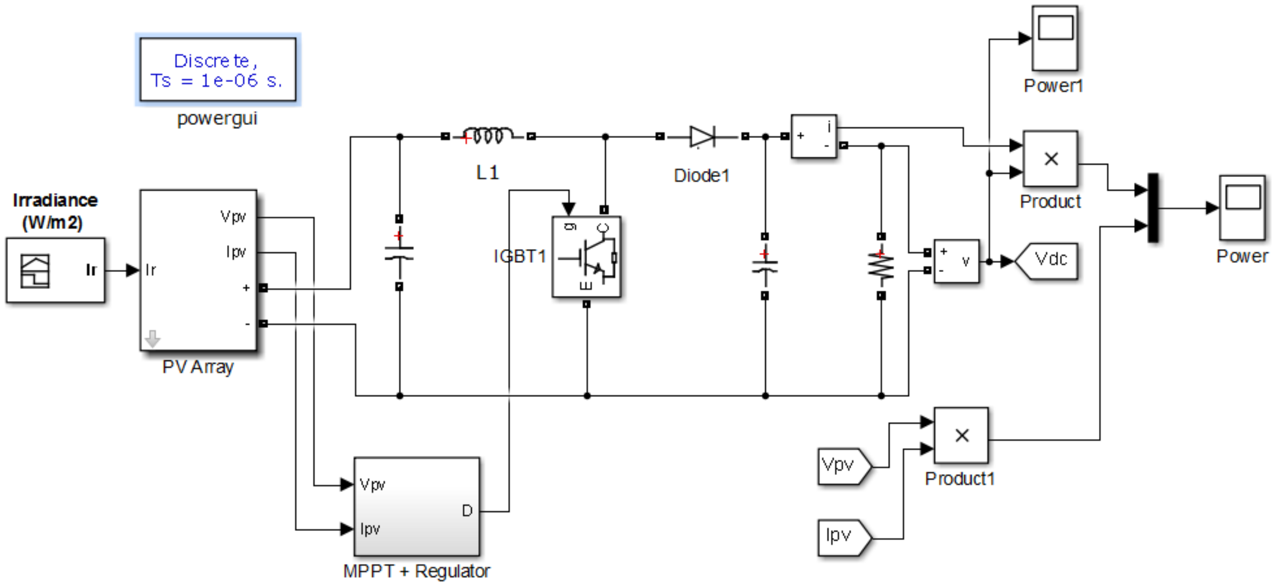


Figure 4.4: Simulation Model of PV System with MPPT Controller

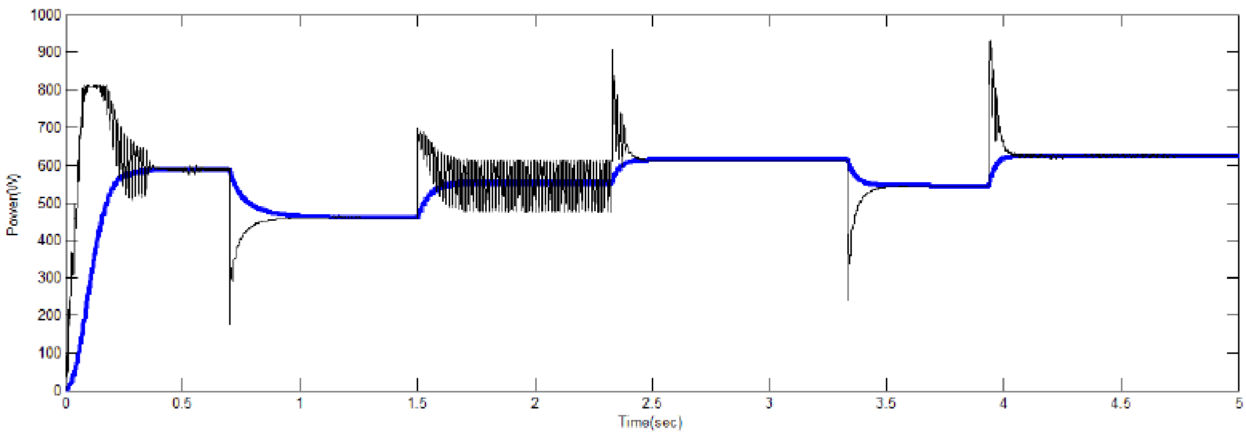


Figure 4.5: Incremental Conductance MPPT Tracking at Variable Irradiance

4.5 Hardware Implementation and Results

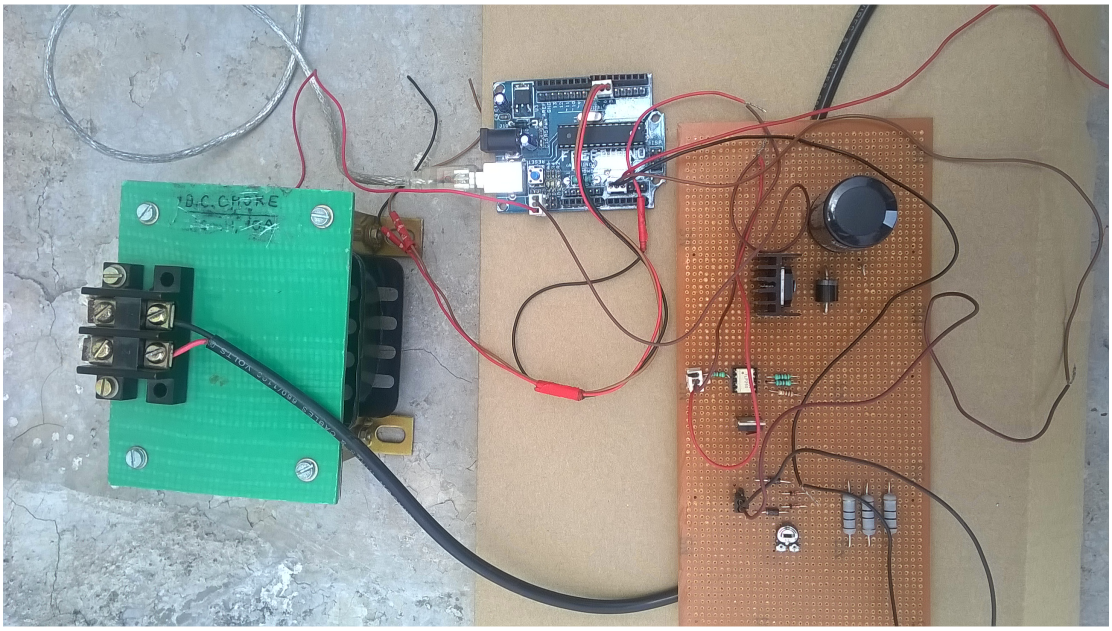


Figure 4.6: Hardware module of boost converter With MPPT

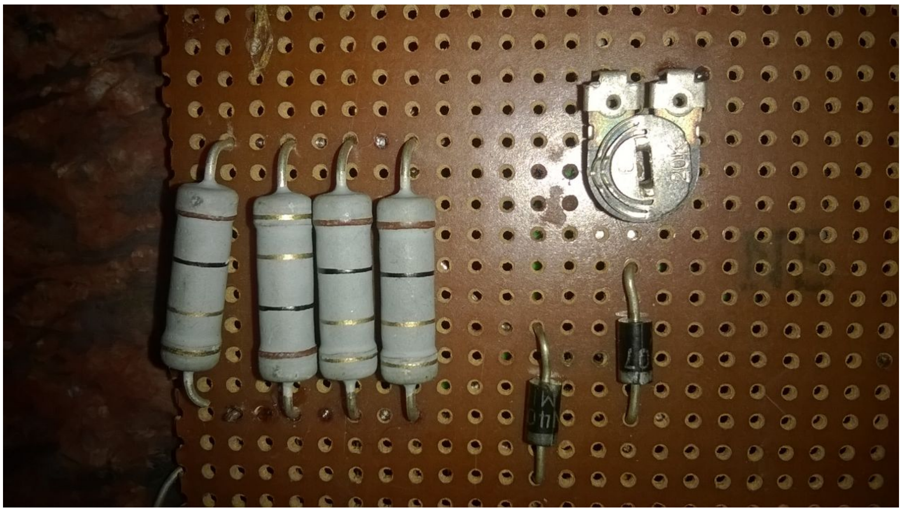
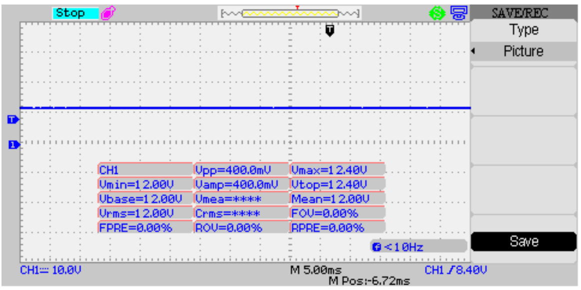
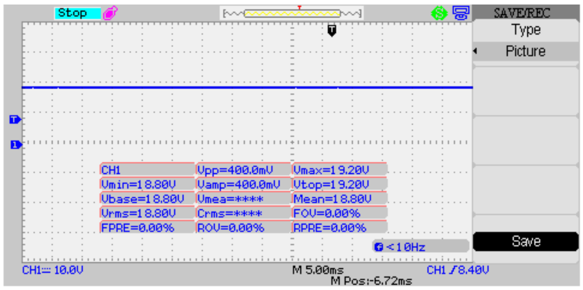


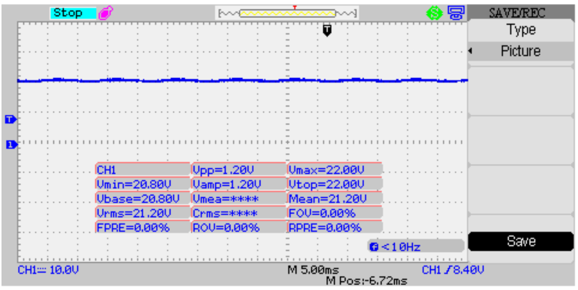
Figure 4.7: Voltage and Current Sensor



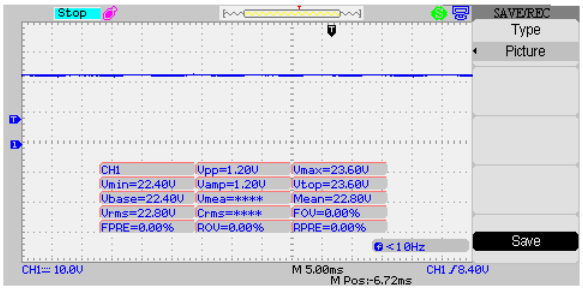
At Input Voltage 15.6 V



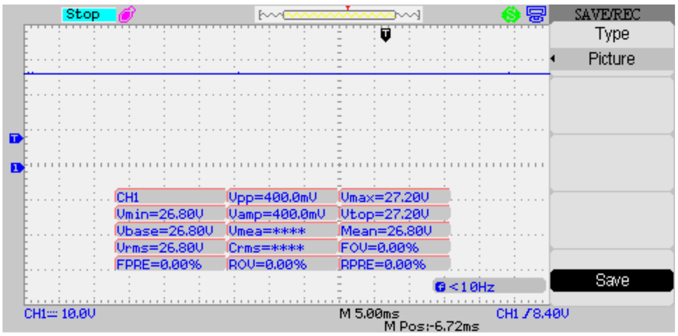
At Input Voltage 19.1 V



At Input Voltage 21.3V



At Input Voltage 22.13V



At Input Voltage 25.9V

Figure 4.8: Output Voltage of boost converter Using MPPT at various Input Voltage

Chapter 5

DC-AC Converter

5.1 Single Phase Transformerless PV converters Derived From Bridge Topology

The PV inverters, efficiently converts the DC source generated from the PV panels to alternating source (AC). In order to feed sinusoidal current and voltage into the grid, the DC link voltage at the output of the boost converter is to be converted into AC, thus an DC-AC conversion stage (Inverter) is required into the system. In this section three power converter topologies are discussed.

5.1.1 Full-Bridge topology

Full Bridge topology is the most widely used technique for single phase grid connected photovoltaic inverter. As depicted in Fig. 5.1 it is develop by four transistor and through LCL filter it is connected to the grid. These topology is normally used in commercial purpose along with low frequency transformers. However due to lower efficiency and higher cost it is fascinating to study its application to transformerless inverters. There are two types of modulation schemes which are basically used for this inverter: 1) unipolar modulation scheme and 2) bipolar modulation scheme. In transformer less topologies.

The most well-known modulation scheme used is unipolar PWM, because it has various advantages over bipolar PWM scheme (for example, better efficiency, lower

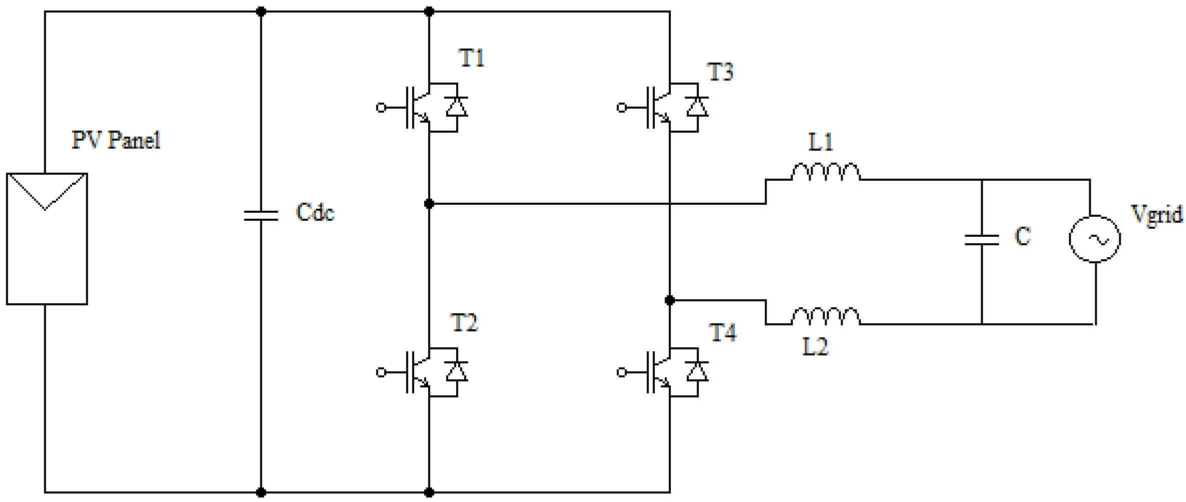


Figure 5.1: A Single Phase Full Bridge Inverter

current ripple at higher frequency etc). However these scheme is less suitable for full bridge transformerless inverter since it requires common mode voltage of high frequency of amplitude Vdc/2, in order to minimize the leakage current that appears because of photovoltaic panels parasitic capacitance.

5.1.2 Half-Bridge topology

As depicted in Fig. 5.2 it is develop by a capacitor divider circuit & two transistors connected to the PV side. Constant common mode voltage is realized by making connection between the midpoint of the grid neutral and capacitor divider circuit, hence leakage current intercepted through parasitic capacitance of PV module.

Although this topology is simple & less expensive compared to full bridge, it is rarely due to the drawbacks such as highly distorted output current, output waveform has only two levels and increased voltage stress, which are difficult to solve Thus power transistors with higher blocking capacities are required, which increases the switching losses.

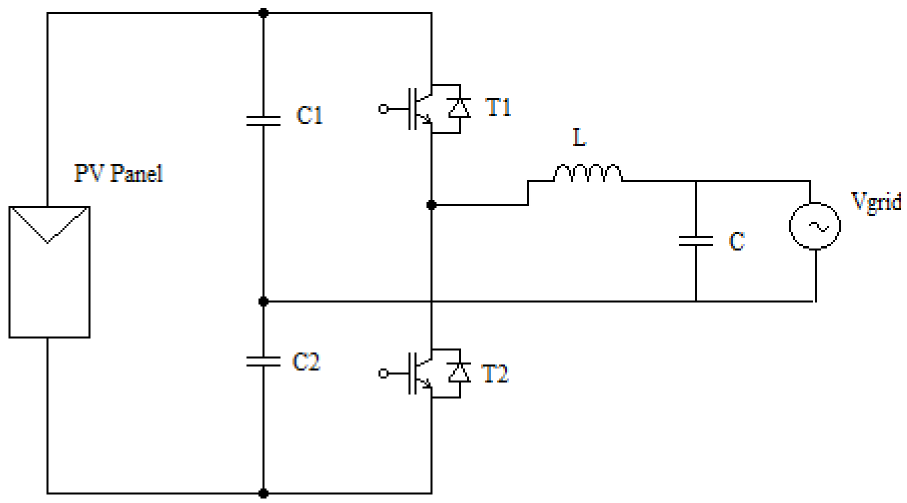


Figure 5.2: A Single Phase Half Bridge Inverter

5.2 High efficient and reliable inverter concept:

Large number of inverter topologies and control techniques have been developed in recent years[1]. The inverter topology and control logic are chosen based on the type of application. The HERIC inverter finds a wide application and becoming increasingly more popular due to its higher efficiency[11]. The HERIC topology commercialized by Sunways, integrates the advantages of the unipolar PWM modulation with high efficiency and diminish leakage. These technique is derived from the full-Bridge converter where AC bypass leg has been added by means of back-to-back IGBTs connected in parallel to bridge. These additional switches operate at the grid frequency (i.e 50 Hz)[1].

Fig. 5.3 shows the HERIC inverter where Cin is the DC-link capacitor, L1 and L2 are filter inductance at grid side and C is the filter capacitor. These additional switches has the two major function: isolating the photovoltaic panel from the grid, and preventing the reactive power exchange between the filter inductors and capacitors during the zero voltage state, thus increasing efficiency.

The converter operates as shown in table 1. During positive half cycle T1 and T4 operates whereas T6 remains connected in order to obtain active and zero vectors. As shown in the figure when T1 and T4 are ON, current flows through the path PV T1 L1 grid L2 T4 and thus active vector is obtained, whereas when T1 and T4 are

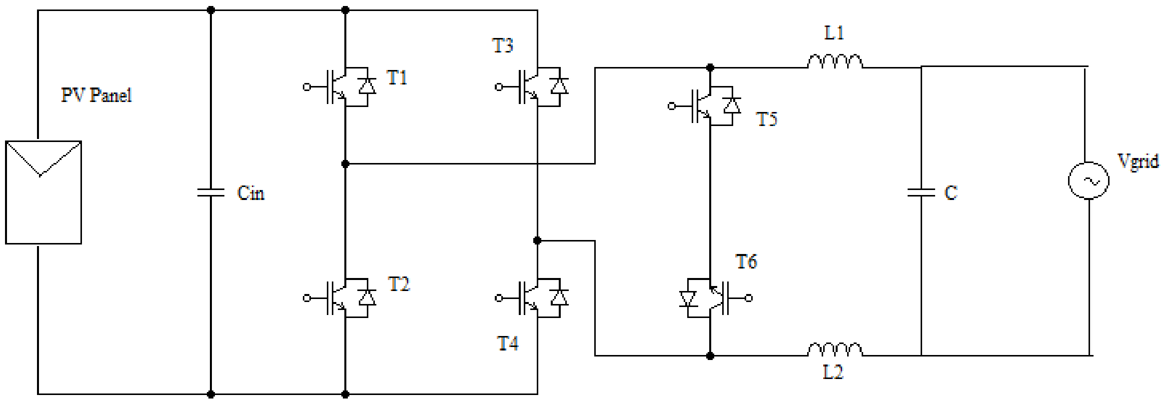


Figure 5.3: Highly efficient and Reliable Inverter Concept topology

Table 5.1: Switching Pattern for HERIC Inverter

Mode	**Half Period**	**Conducting Devices**
Active	Positive	S_1, S_4, S_5
Free Wheeling	Positive	S_5, D_6
Active	Negative	S_2, S_3, S_6
Free Wheeling	Negative	D_5, S_6

OFF, the current freewheels through T6 and D5 and thus zero vector occurs.

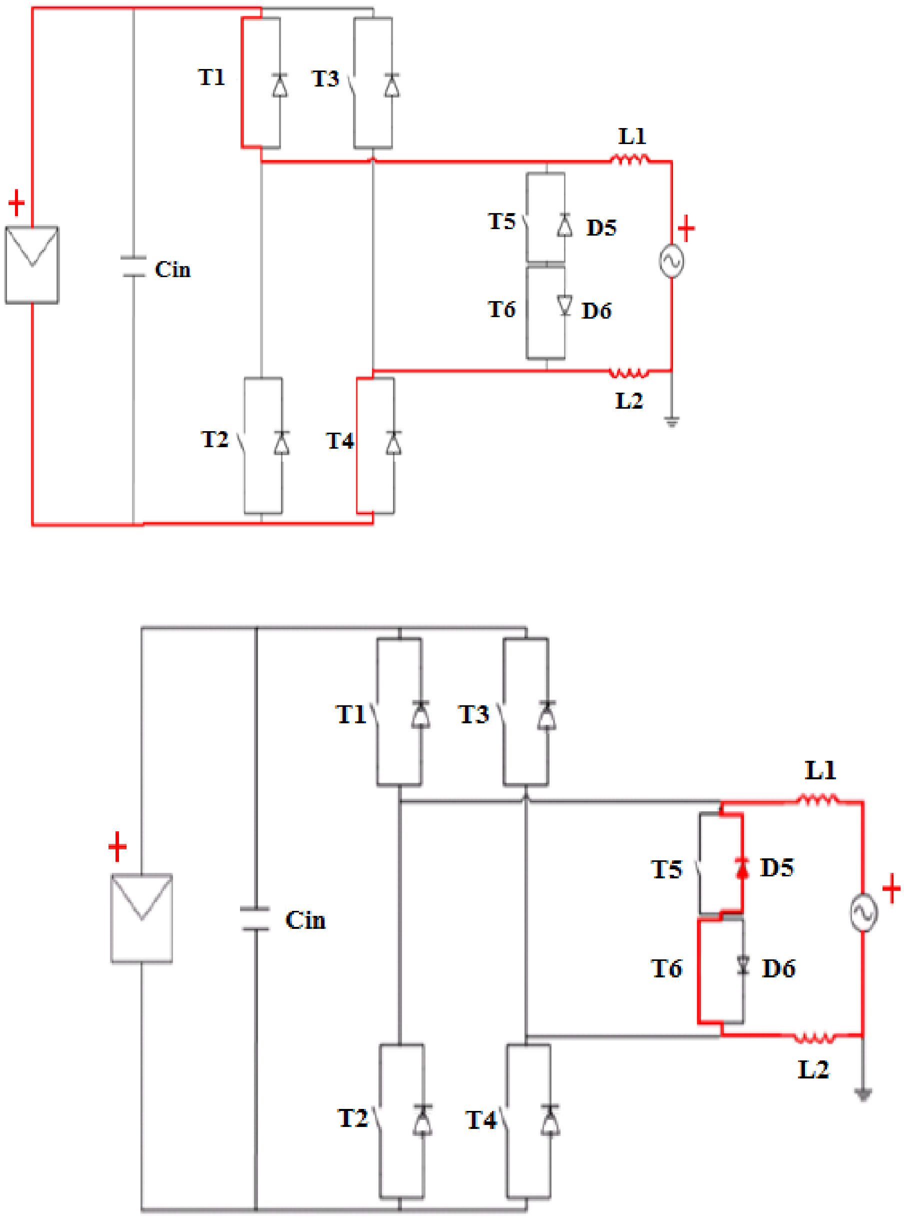


Figure 5.4: Operation of HERIC Inverter during positive half cycle

On the other hand during negative half cycle T6 remains OFF and T5 remains connected, whereas T3 and T2 operates. Active vector is obtained when T3 and T2 are ON and the current flows through the path PV T3 L2 grid L1 T2, and the zero vector is obtained when T3 and T2 are OFF and the current freewheels through T5 and D6.

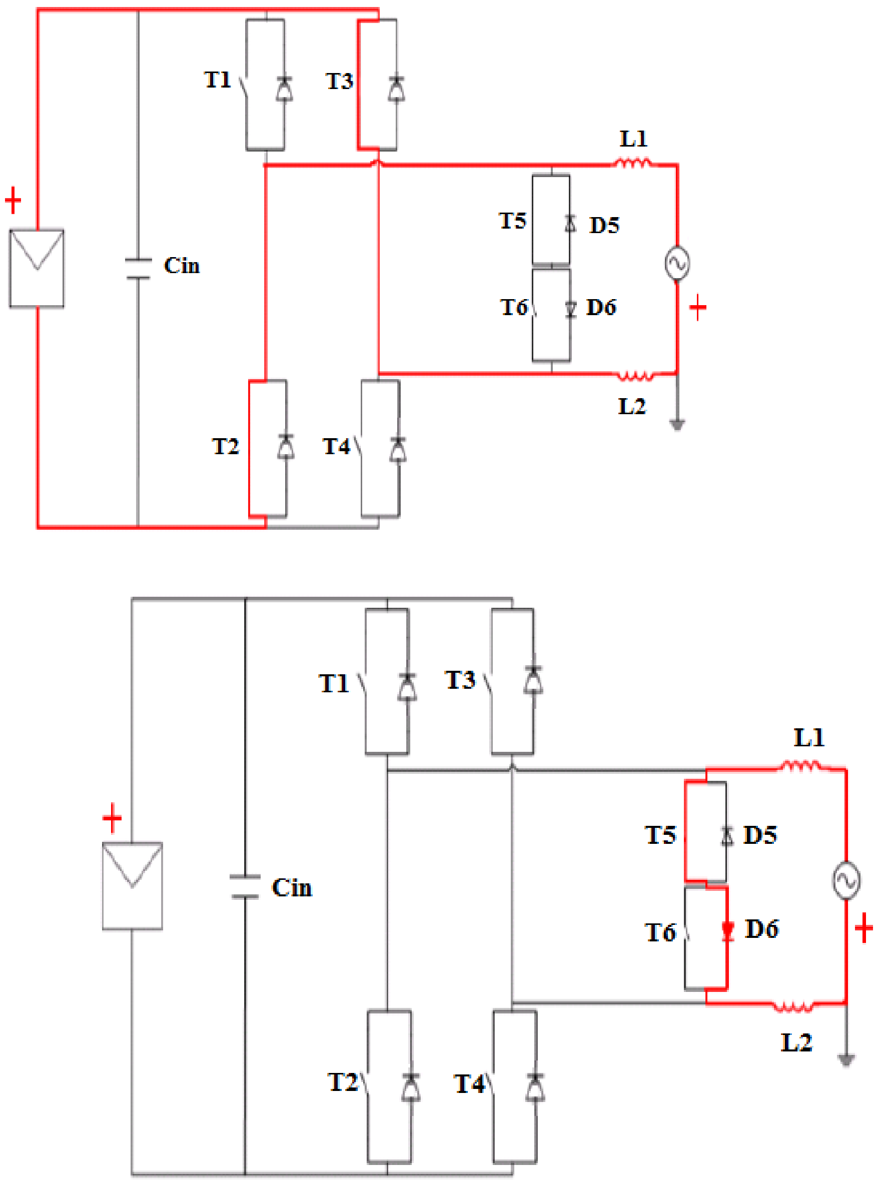


Figure 5.5: Operation of HERIC Inverter during negative half Cycle

5.2.1 Advantages of HERIC Inverter

Following are the advantages of the HERIC inverter:

a. Higher efficiency as compared to convetional H-bridge.

b. Lower leakage current

c. Efficiently handles the reactive power

d. Practically constant common mode voltage.

5.2.2 Disadvantages of HERIC Inverter

Following are the disadvantages of HERIC inverter:

a. Higher Number of switches, Switching losses increases.

b. Increased complexity due to additional switches.

5.3 Simulation Results

The simulation of HERIC inverter is being carried out using MATLAB/Simulink. The simulation consist of a DC source followed by modified H-bridge and an output filter. Simulation results are carried out at a load of 5kW.

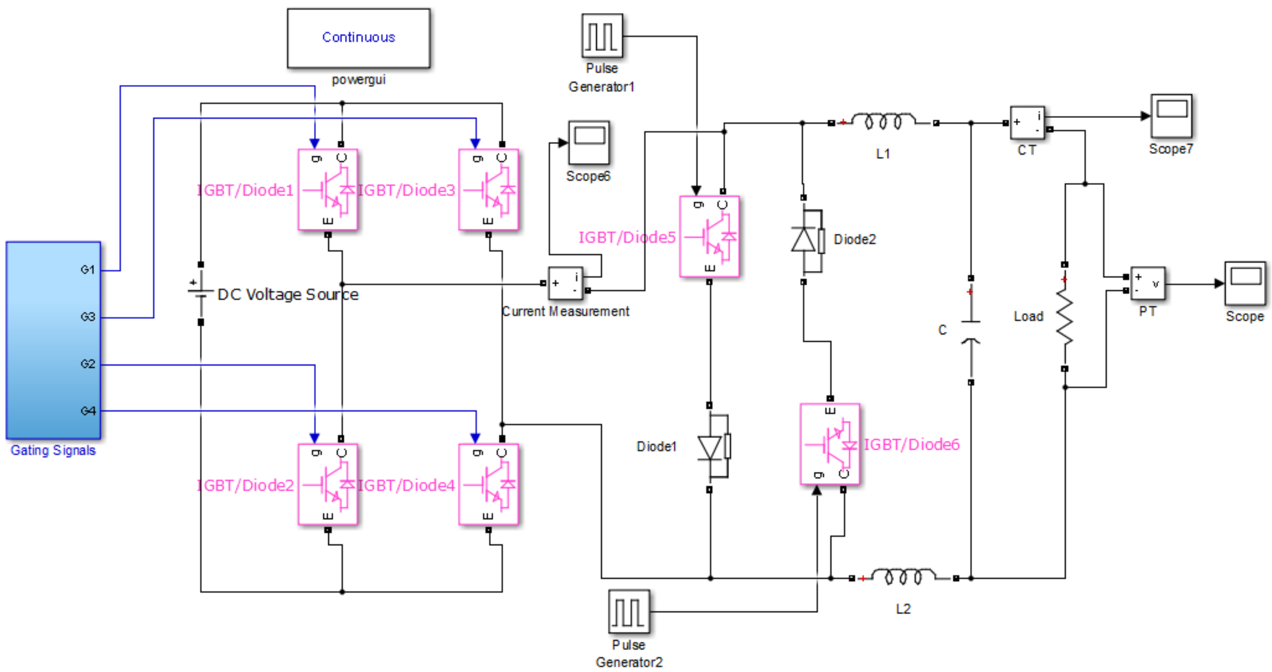


Figure 5.6: Simulation of HERIC Inverter

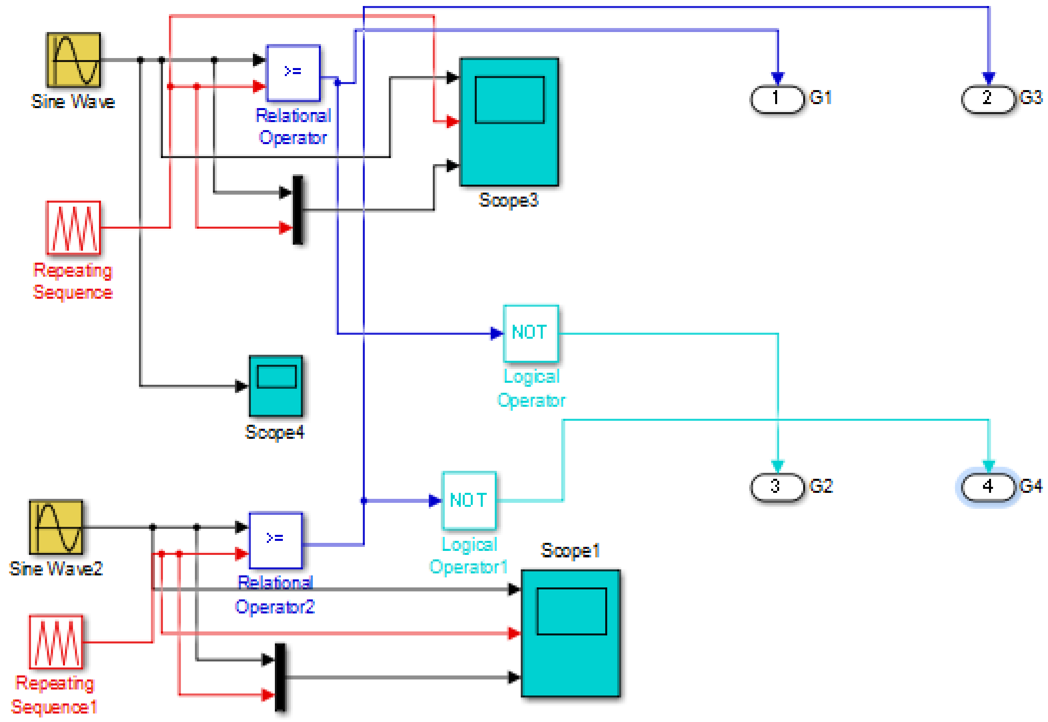


Figure 5.7: SPWM Technique used for Gating signals of H-bridge

5.4 Complete Model Of PV System

The simulation of complete PV system is being carried out without MPPT using MATLAB/simulink. The simulation model includes PV panel followed by DC-DC boost converter and HERIC inverter. Simulation results are carried out at a load of 5kW.

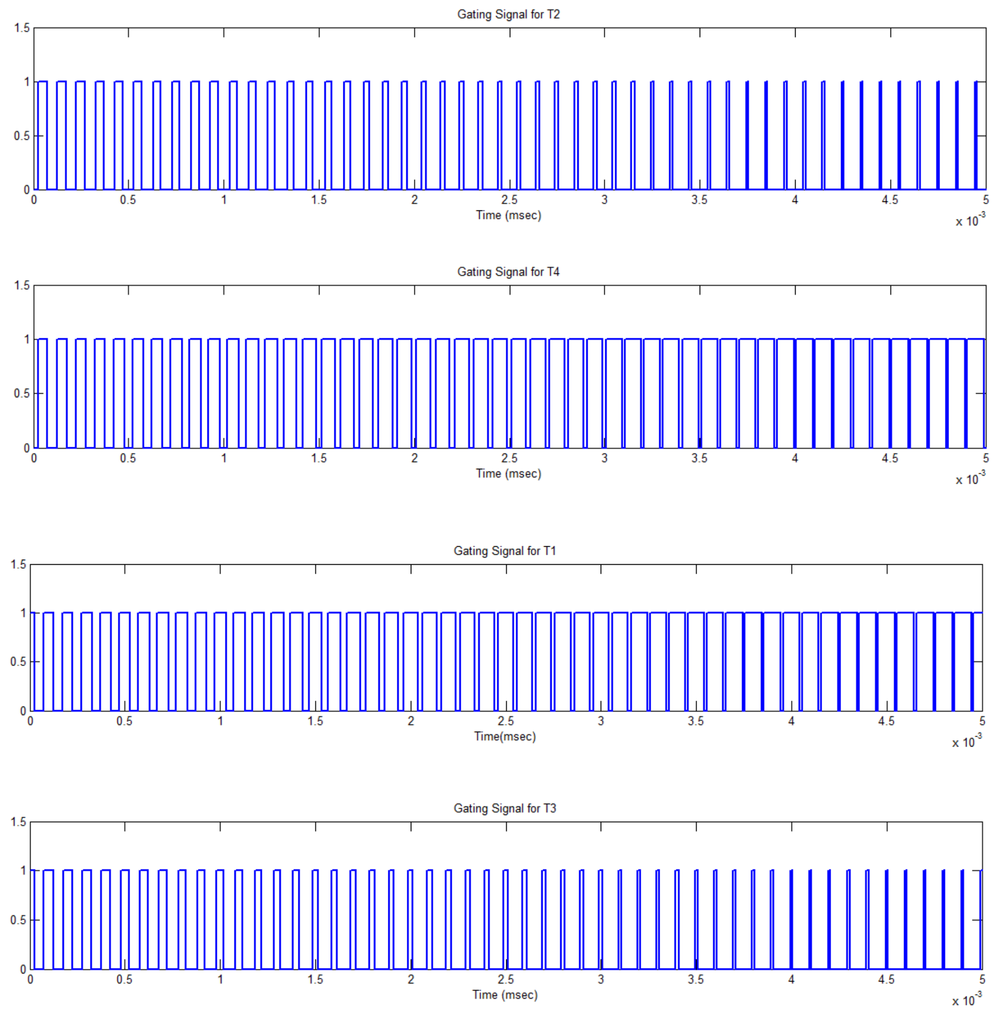


Figure 5.8: Gating Signals for H-bridge

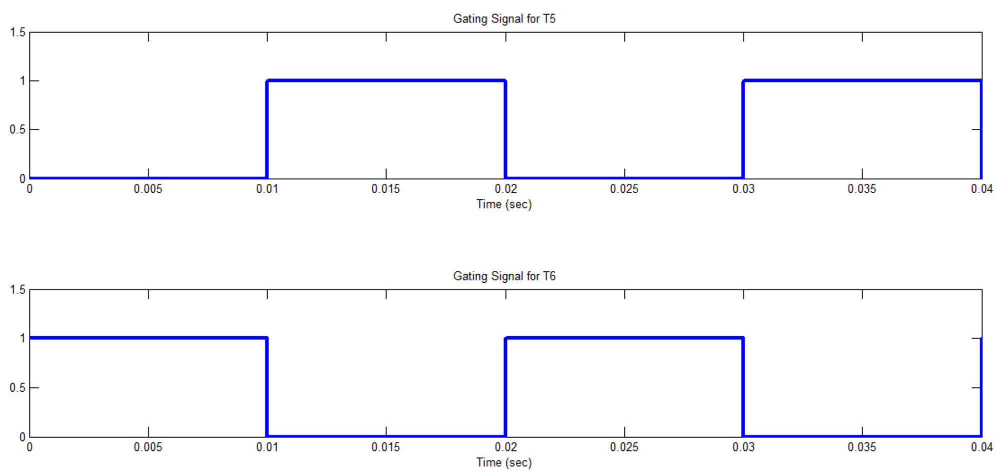


Figure 5.9: Gating signal of AC Coupling Switch

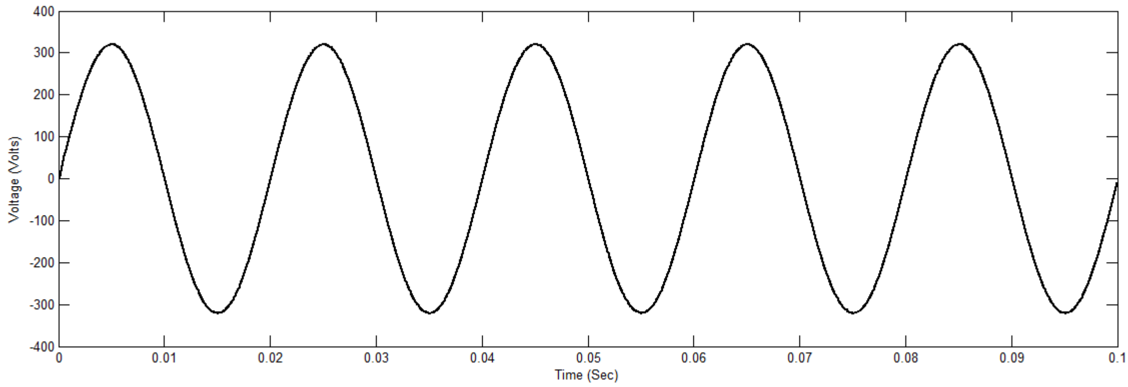


Figure 5.10: Output Voltage Of HERIC Inverter

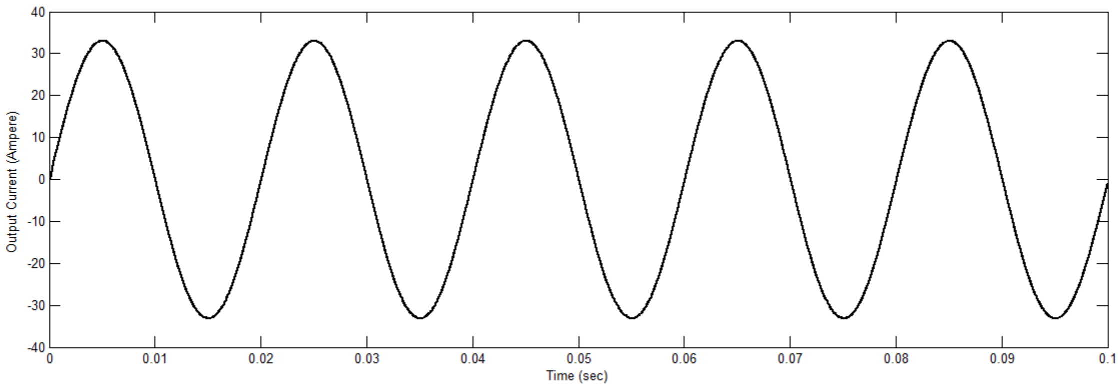


Figure 5.11: Output Current Of HERIC Inverter

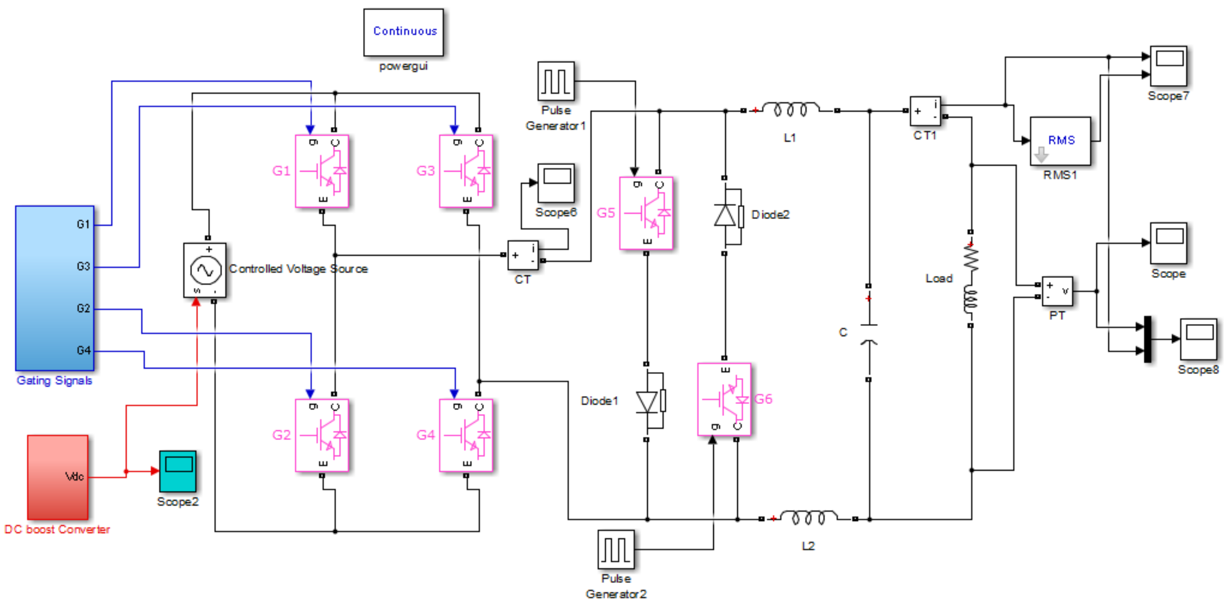


Figure 5.12: Simulation For complete PV system without MPPT

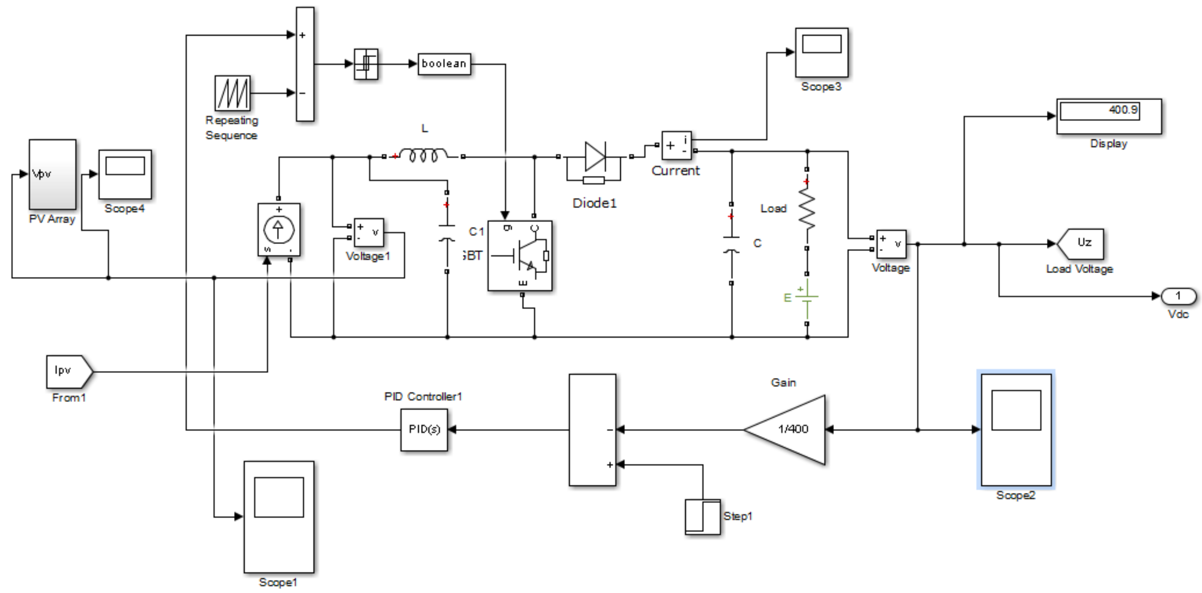


Figure 5.13: Subsystem (DC boost Converter)

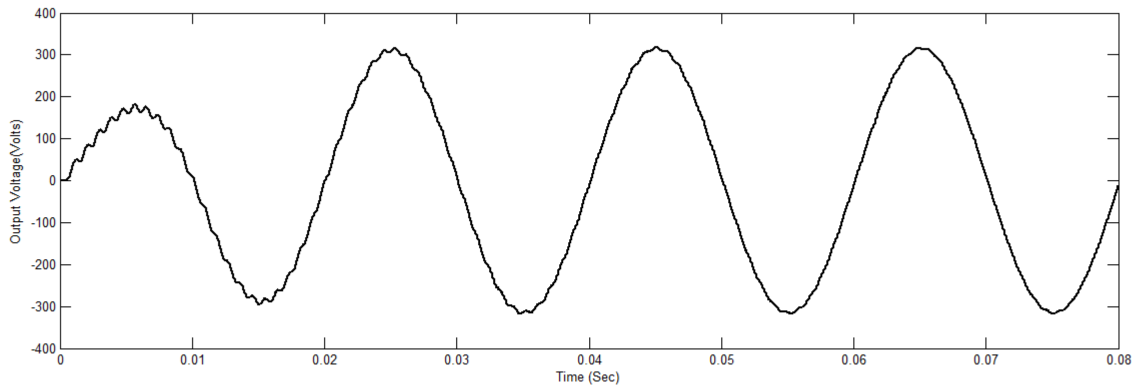


Figure 5.14: Output Volatge at variable irradiance Without MPPT

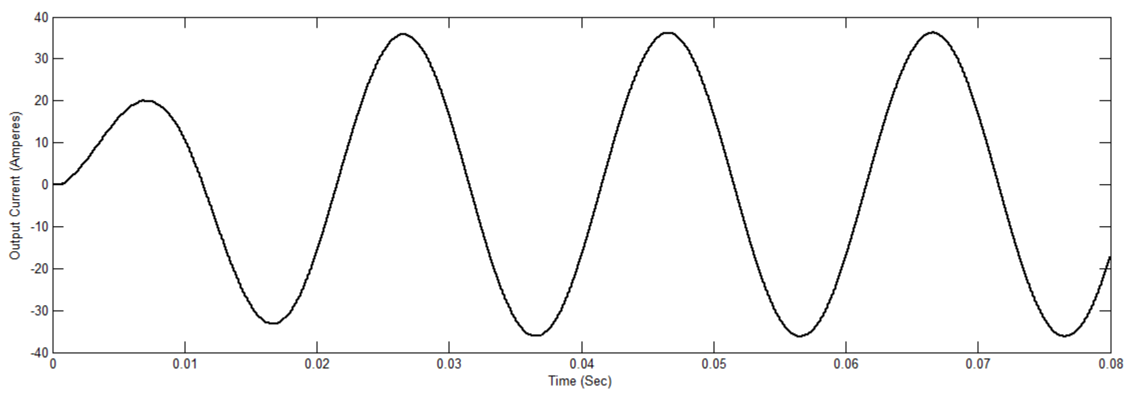


Figure 5.15: Output current at variable irradiance without MPPT

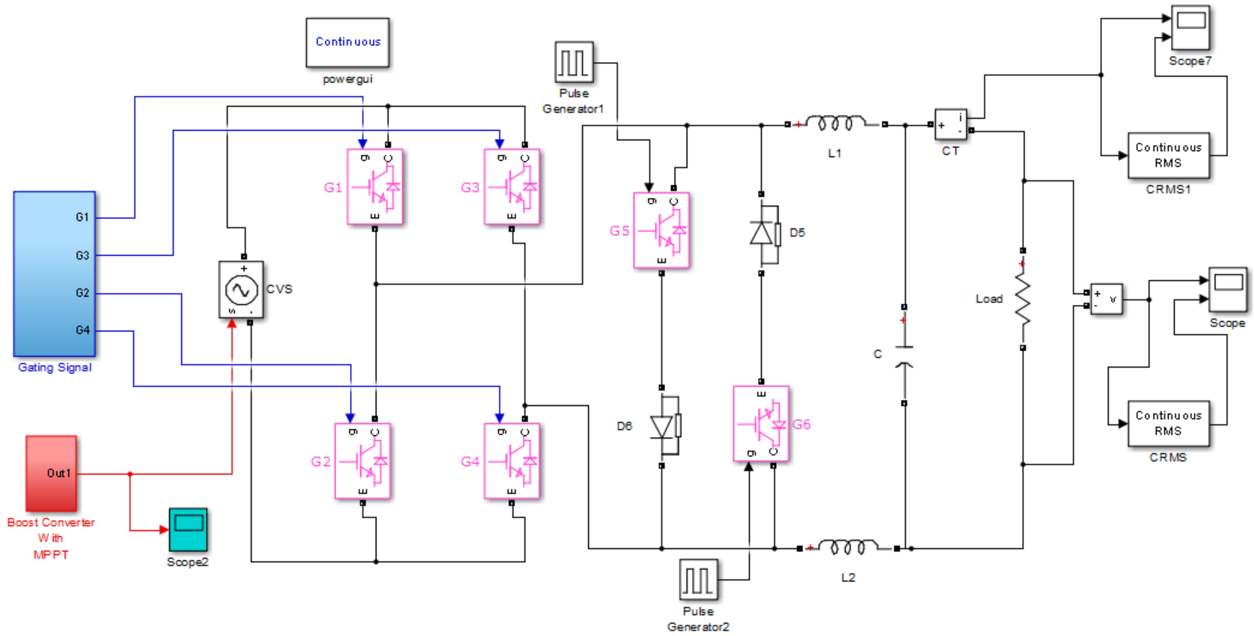


Figure 5.16: Simulation of complete model with MPPT

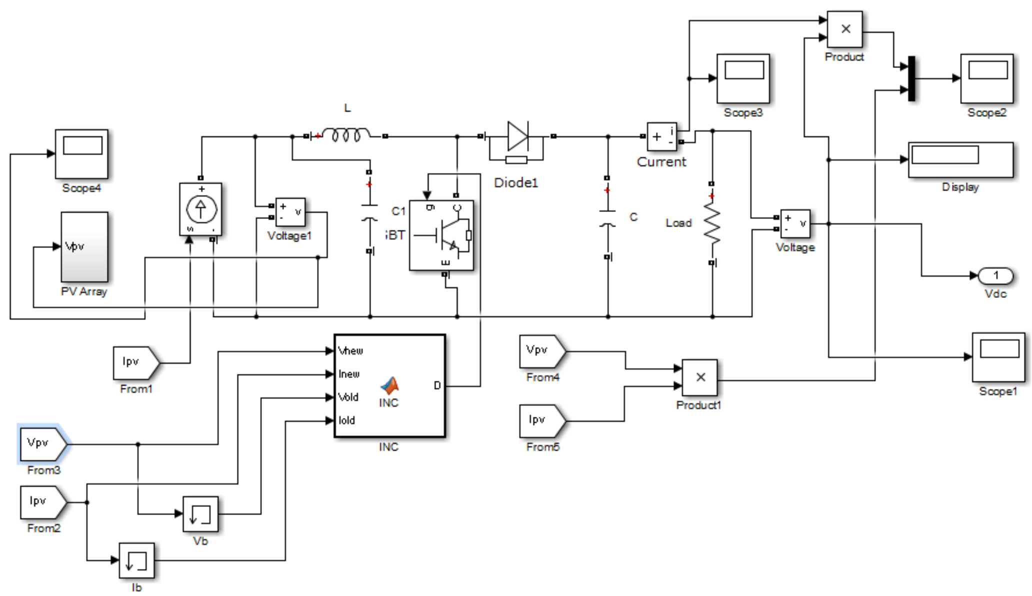


Figure 5.17: Subsystem (DC boost converter)

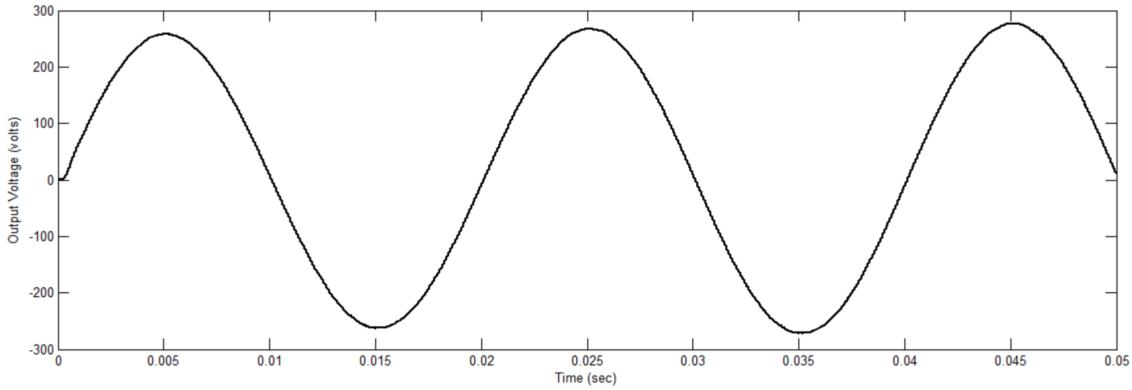


Figure 5.18: Output Voltage of PV System with MPPT

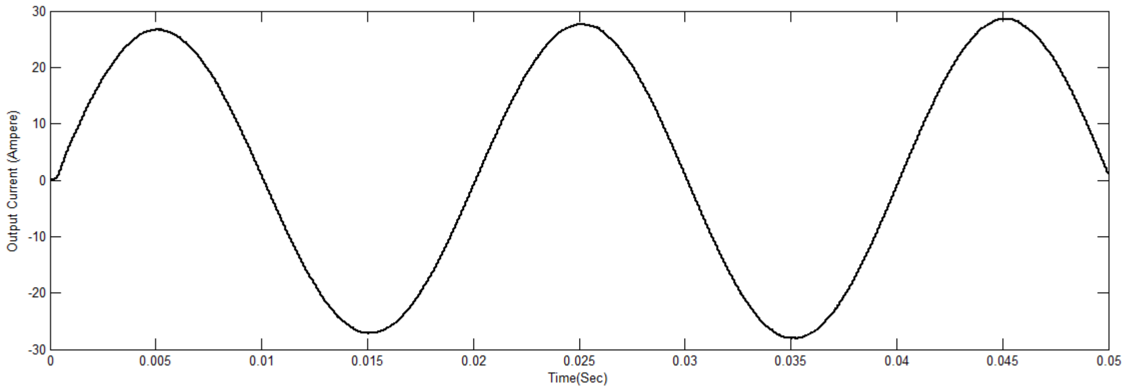


Figure 5.19: Output current of PV System with MPPT

Chapter 6

Hardware Module and Result for PV system

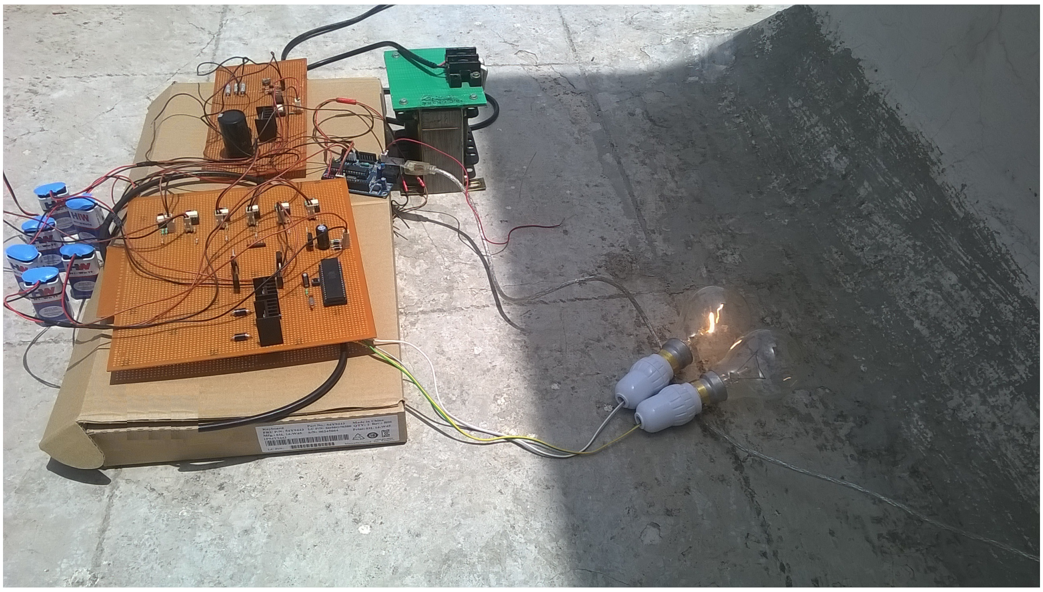


Figure 6.1: Hardware module for complete PV system

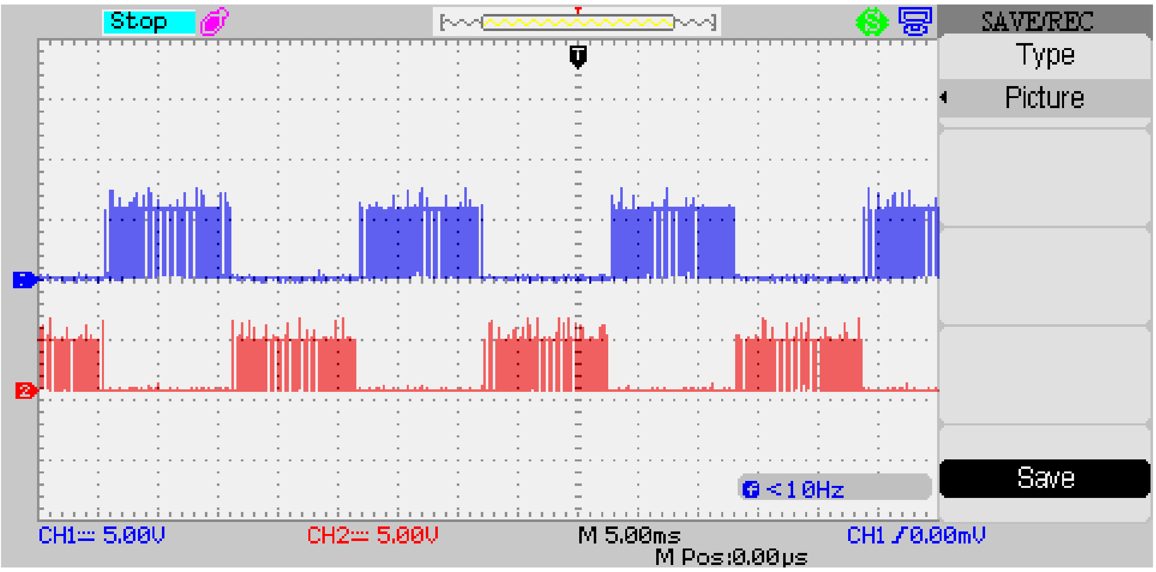


Figure 6.2: Gating Signals for bridge inverter

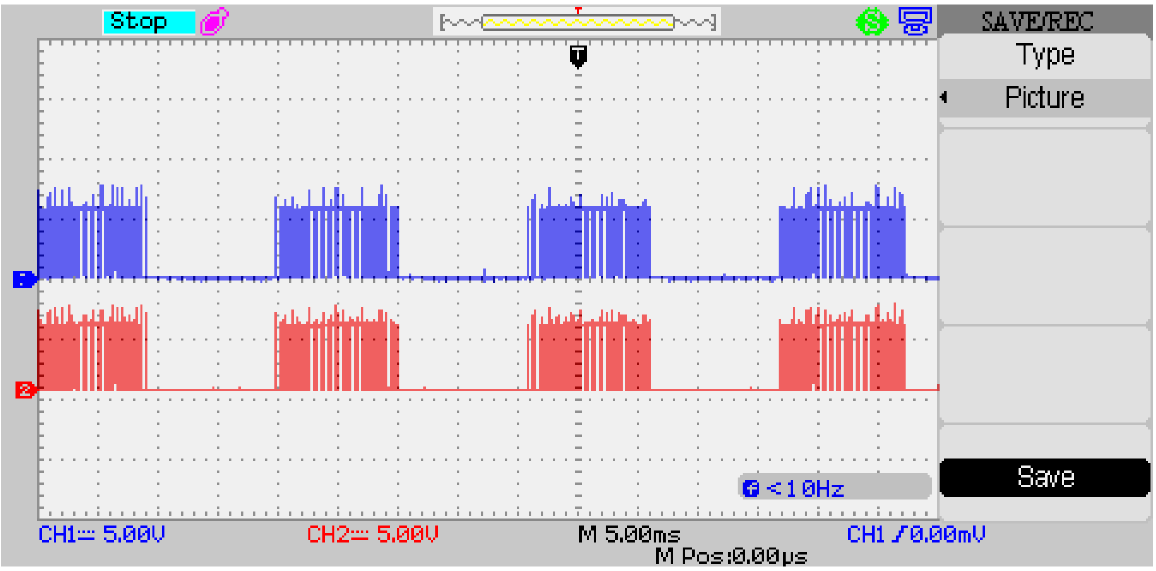


Figure 6.3: Gating Signals For T1 and T4 Switch

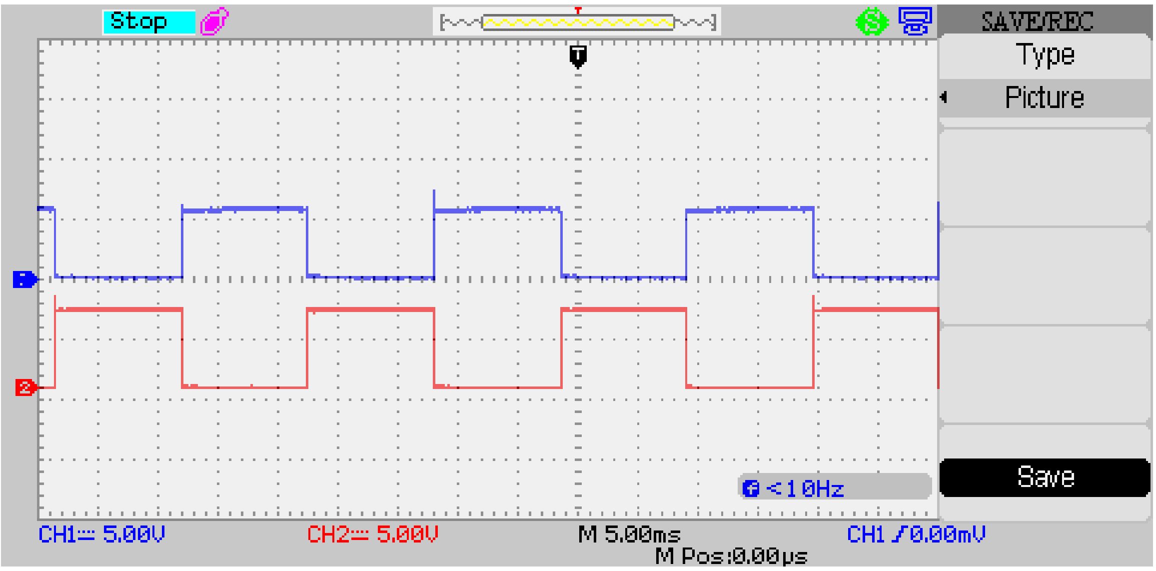
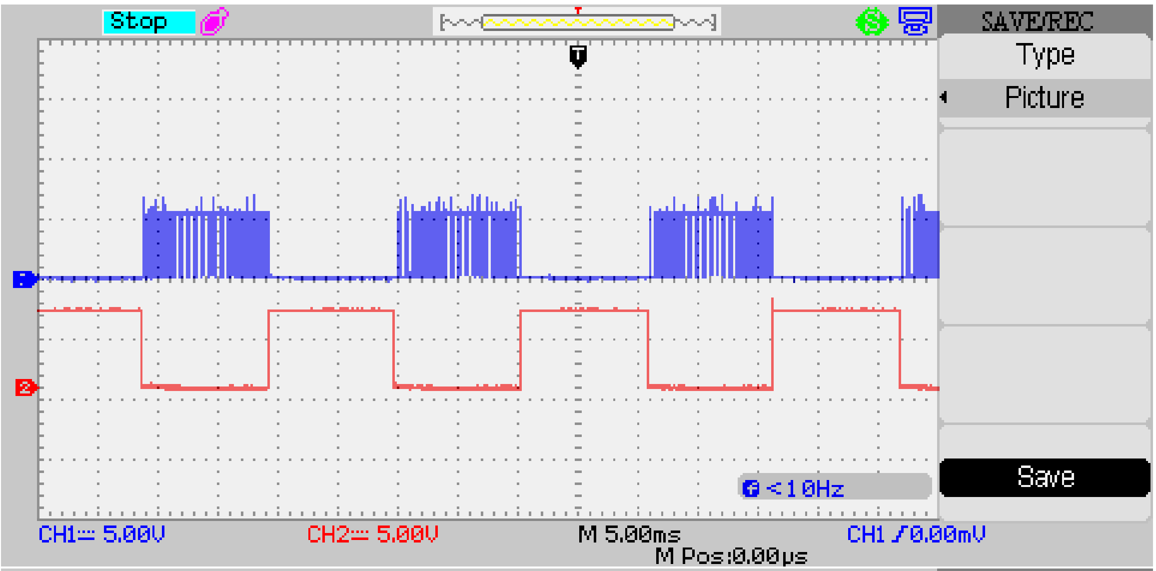


Figure 6.4: Gating signals for AC coupling Switch



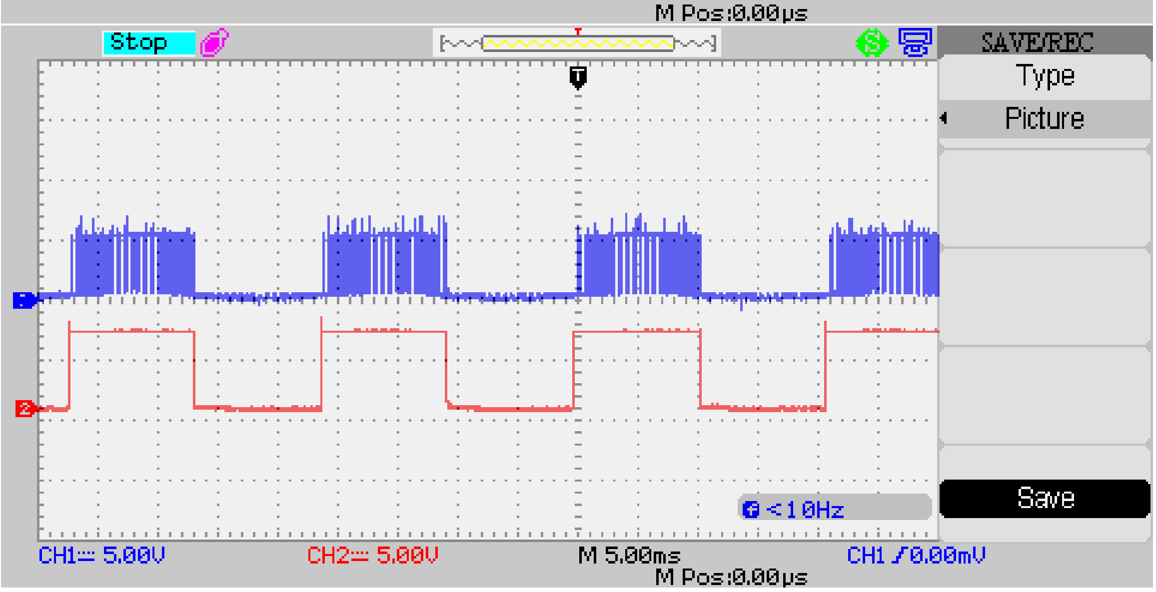


Figure 6.5: Gating Signals For Complete HERIC Inverter

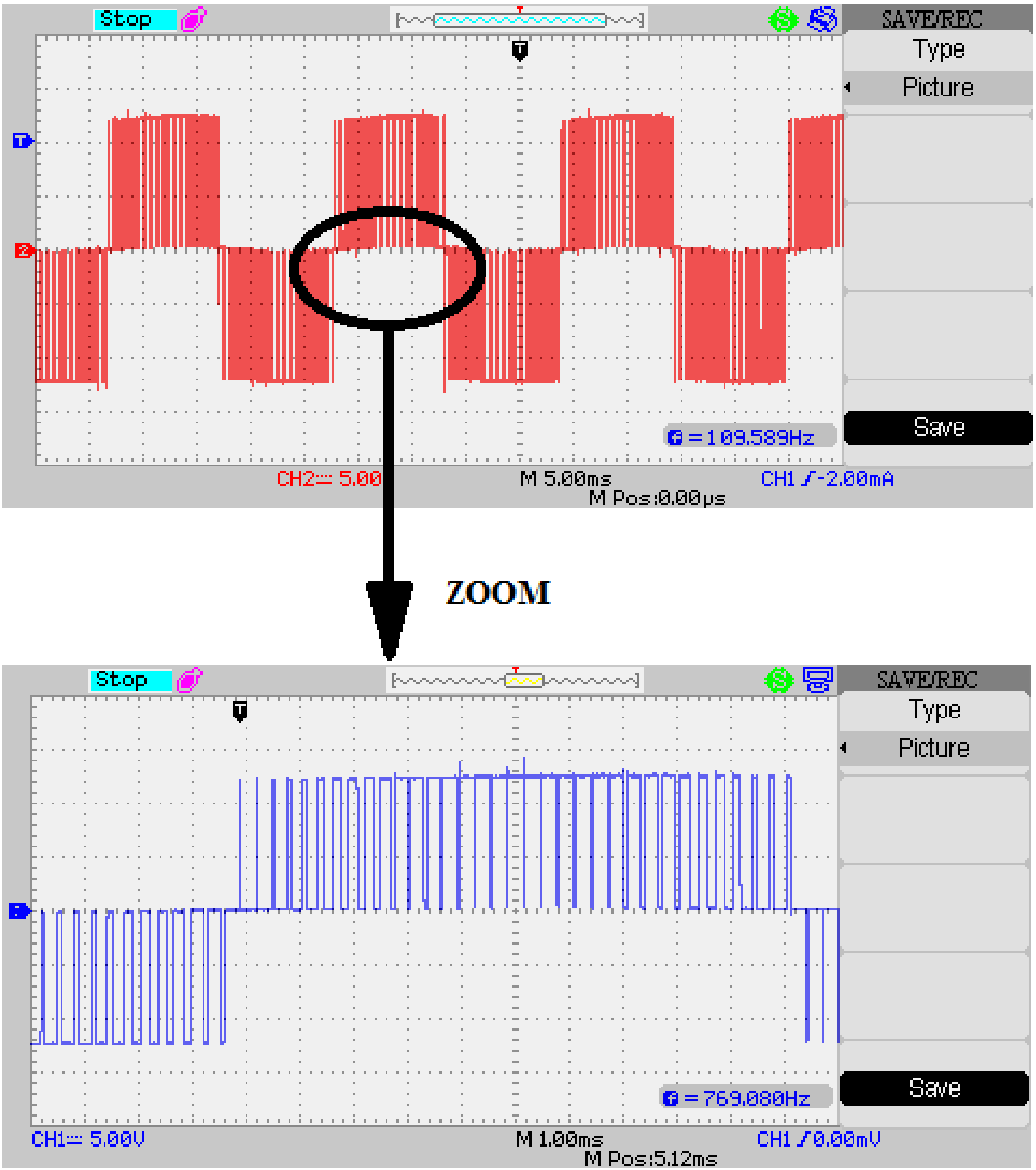


Figure 6.6: Output Voltage with R load Without filter

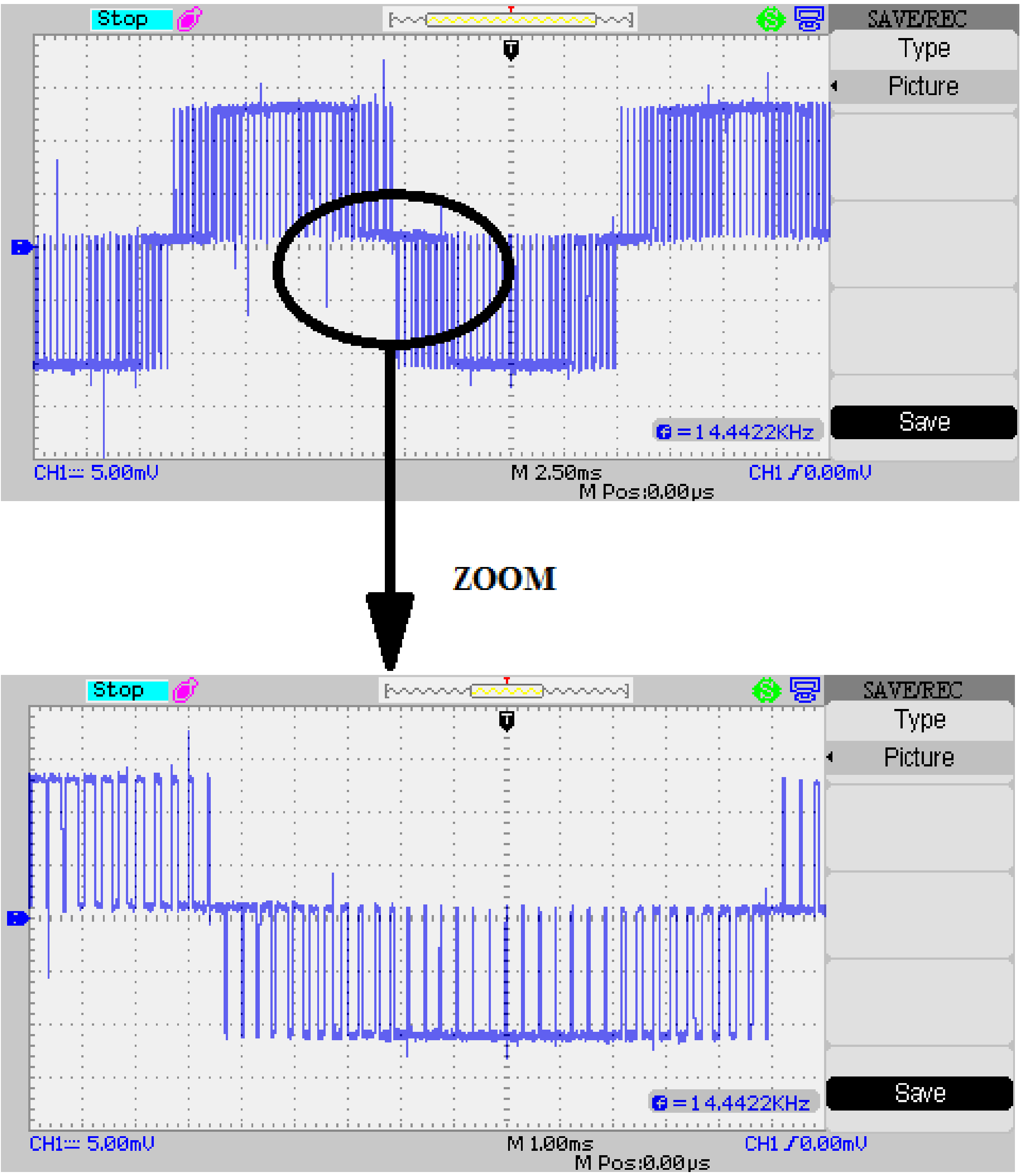


Figure 6.7: Output Current with R load without filter

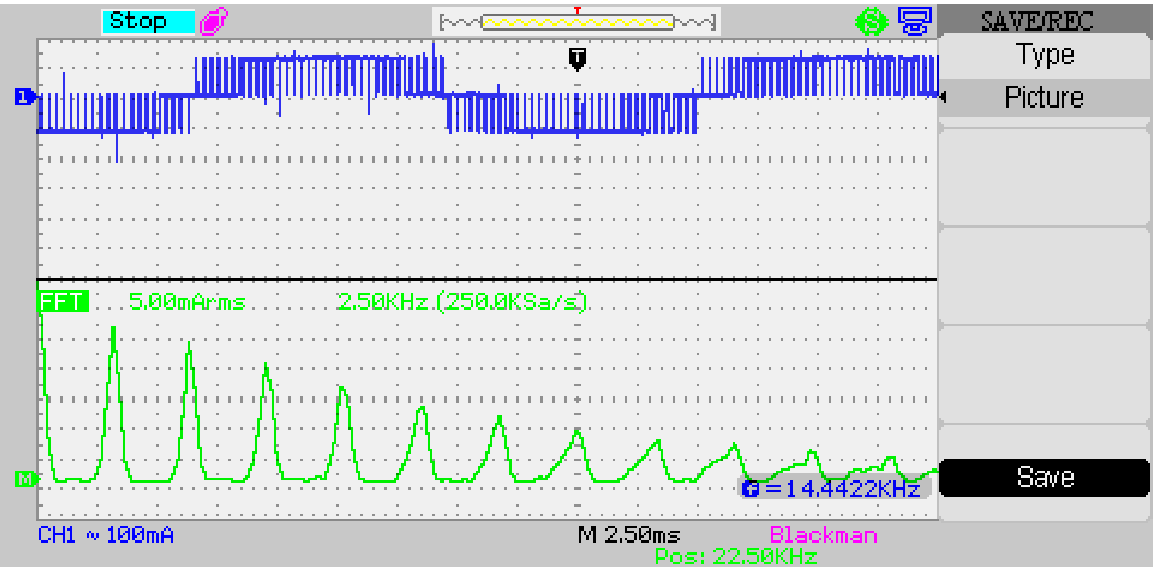


Figure 6.8: FFT Analysis of Output Current Without Filter

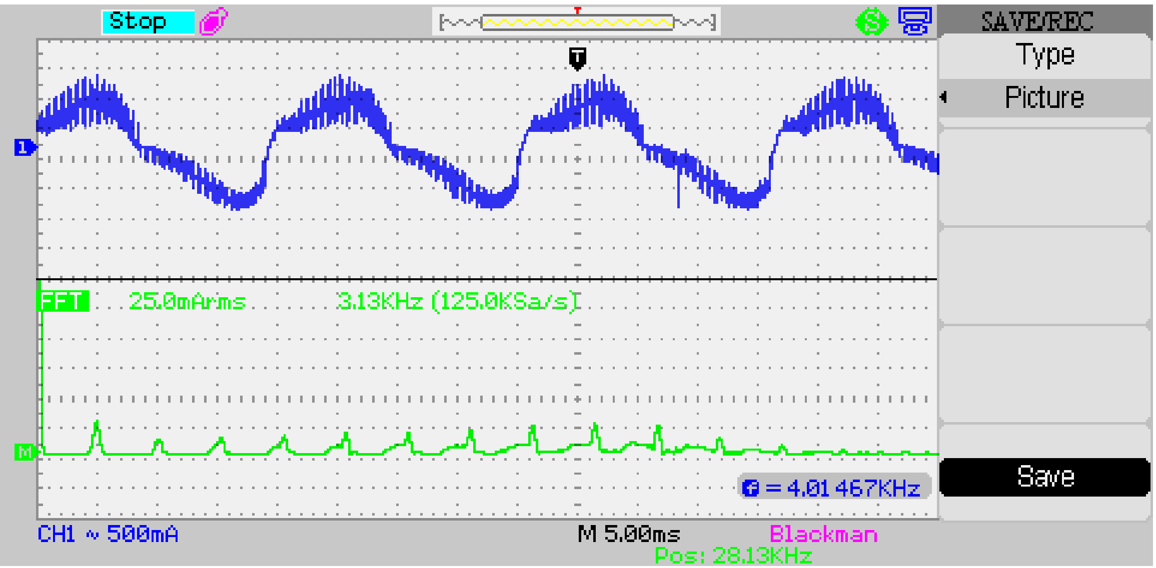


Figure 6.9: FFT Analysis with filter

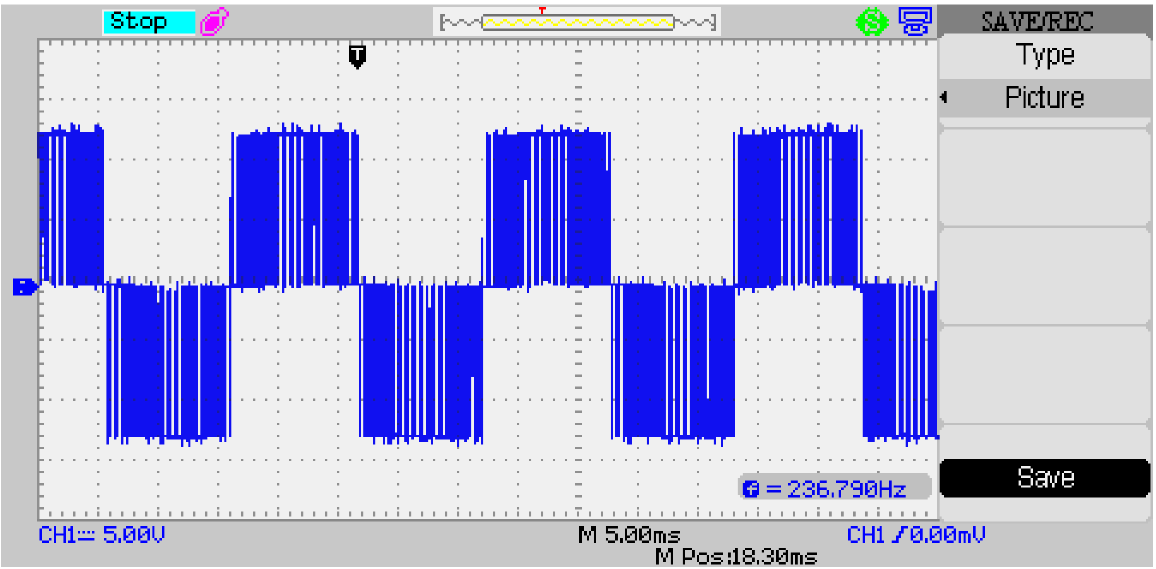


Figure 6.10: Output Voltage with RL load Without Filter

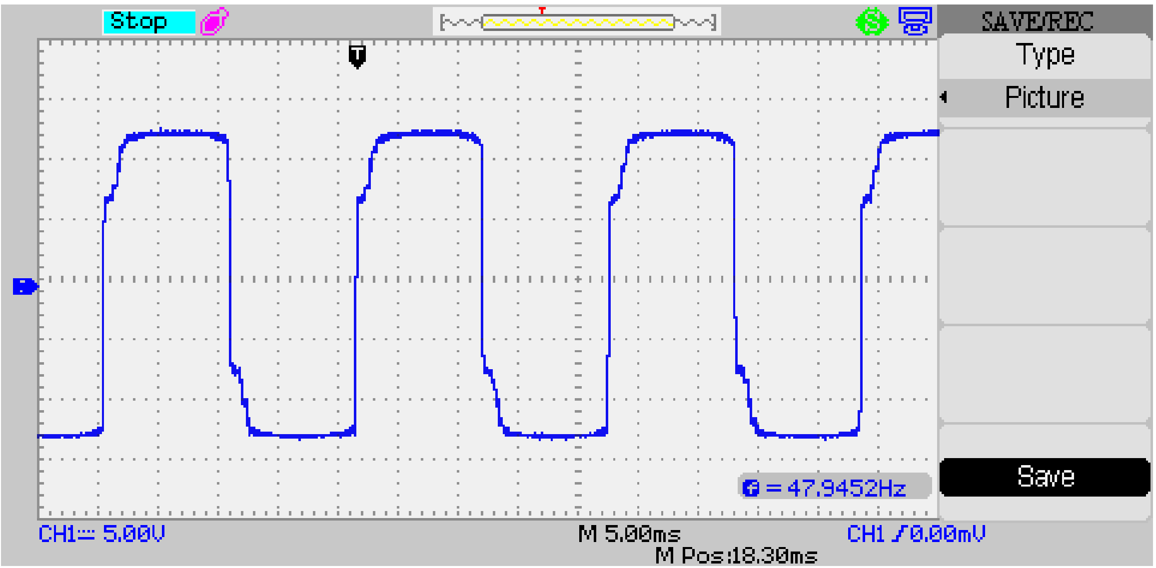


Figure 6.11: Output Voltage With RL Load With Filter

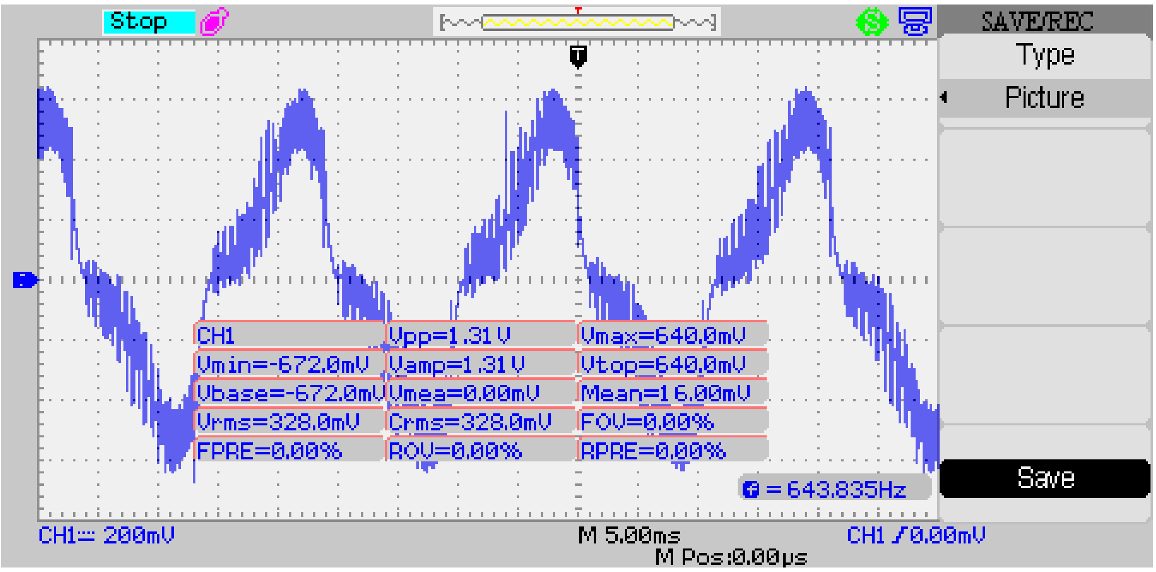


Figure 6.12: Output Current with Filter with RL Load

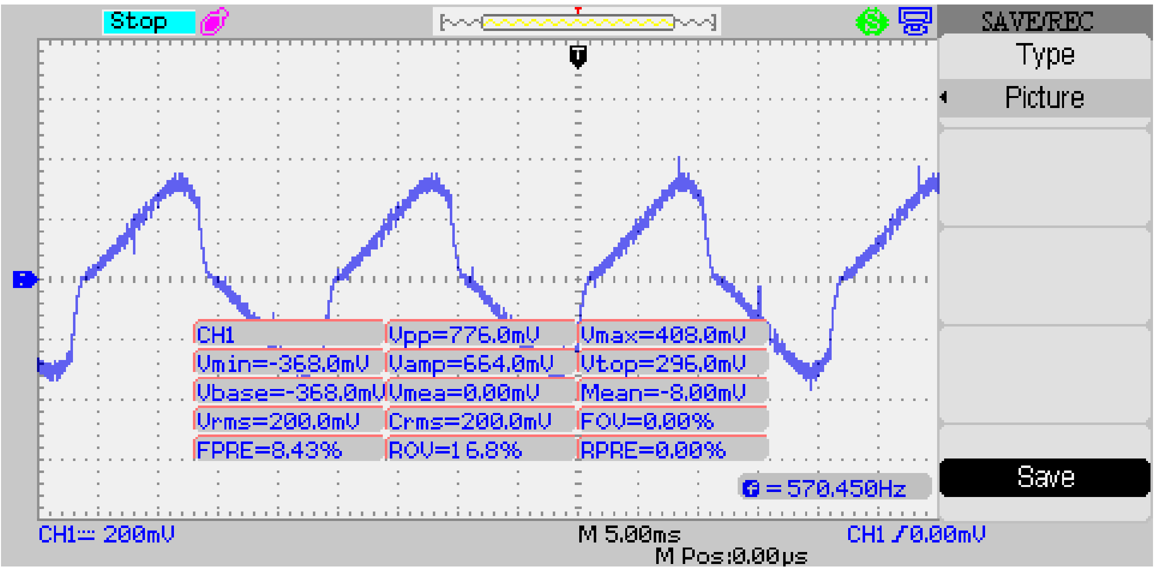


Figure 6.13: Output Current At a Load of 10mH

Chapter 7

Conclusion and Future Work

7.1 Conclusion

a. For single phase solar inverter design calculation of booster is done. The value of inductor and capacitor are calculated for the boost converter.

b. Simulation for HERIC inverter at different loads is done in which the output voltage remains constant at 220 Volt.

c. MPPT algorithm is done with a efficiency of 93%.

d. Hardware Implementation For Complete PV system is done for Open loop System.

7.2 Future Scope

a. To determine an MPPT algorithm with higher efficiency.

b. Hardware implementation of HERIC inverter higher efficiency.

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[14] Claude Morris, Dr. Martina calais. "Grid Connected Transformerless Single-Phase Photovoltaic inverter : An evaluation on DC current injection and PV array voltage fluctuation"

Chapter 8

List of Publications

[1] Payal Somani, Divyesh J. Vaghela, "HERIC Configuration Based Transformerless Topology for Grid Connected Single-phase Photovoltaic Inverter", in proc. IEEE Sponsored Fourth International Conference On Computation Of Power, Energy, Information And Communication (ICCPEIC 2015).