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GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

DESIGN OF A BUCK-BOOST CONVERTER AND ITS IMPLEMENTATION IN A REAL SYSTEM

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2016

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a dissertation for the degree of Master of Science.

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ABSTRACT

DESIGN OF A BUCK-BOOST CONVERTER AND ITS IMPLEMENTATION IN A REAL SYSTEM

RIZWAN UZ ZAMAN

MS in Electrical and Electronics Engineering

Advisor: Yrd. Doc. Dr. HACER ŞEKERCI

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A buck boost dc-dc converter is designed for the reason that it has a long range of input ac or dc voltage to provide regulated and undistorted dc output voltage. The purpose of the converter is to provide better efficiency with respect to the other converters and to overcome the problem of ripples in the output.

For the simulation and implementation of the buck boost dc-dc converter a photovoltaic panel Guang Yue, GY-Box-5c parameters studied, calculated and Simulink with the same corresponding available features in MATLAB Simscape Power System. The reason for the selection of the photovoltaic system is its variation and instability in the output power that helps to learn the different aspects of the converter.

The output of the PV panel feed to the input of converter for controlling and providing regulated dc with the help of Incremental Conductance Method for its better efficiency as compared to other algorithms.

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ÖZET

BUCK-BOOST DÖNÜŞTÜRÜCÜ TASARIMI VE GERÇEK SİSTEMİN ÜZERİNDEKİ UYGULAMASI

RIZWAN UZ ZAMAN

Elektrik ve Elektronik Mühendisliği Yüksek Lisans

Danışman: Yrd. Doc. Dr. HACER ŞEKERCI

Haziran 2016, 73 Sayfalar

Bu çalışmada sabit ve bozulmamış dc çıkış elde edebilmek için geniş bir değişken giriş voltajı aralığında çalışabilen bir voltaj düşürücü-yükseltici dc-dc çevirici tasarlanmıştır. Tasarlanan çevirici ile çıkış voltajındaki küçük değişimleri önlemek ve diğer çevirici tiplerine göre daha yüksek bir verime ulaşmak amaçlanmıştır.

Voltaj düşürücü-yükseltici dc-dc çeviricinin benzetimi ve gerçekleştirilmesi için Guang Yue, GY-Box-5c güneş paneli parametreleri MATLAB Simscape Power System programında tasarım için kullanılmış ve tasarım Simulink programında test edilmiştir. Güneş panelinin seçilmesinin nedeni değişken ve istikrarsız güç çıkışı vermesi nedeniyle çeviricinin farklı özelliklerinin öğrenilmesinde yardımcı olmasıdır.

PV panel çıkışı küçük adımlı iletkenlik yöntemi ile çevirici girişine verilmiş ve çıkış voltajının diğer algoritmalar ile karşılaştırılması sağlanmıştırr.

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Over the course of this thesis, many people and friends helped and contributed immeasurably on this ground.

First of all I would like to express the appreciation to my advisor Dr. Hacer Şekerci for her great assistance and scholarly explanation.

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Finally special thanks to my brother Ashraf uz Zaman who support me in all the manner and does not leave me in my hard times.

Rizwan uz Zaman

Izmir, April 2016

MOTIVATION

A punch line behind this thesis that made me force towards this topic.

"An energy is an ability to do work."

Certainly!! for every work there is some energy required either in any shape i.e. mechanical to electrical, chemical to electrical and so on. The most often energy used is electrical energy. It is a base energy for the production of all energy. In this technological world surviving without energy, especially electrical energy is impossible.

I belong from Pakistan's biggest city Karachi and the 2^{nd} biggest populated city in World. It is an industrial zone having international seaport and also a business hub of Pakistan. It generate up to 70% of the whole revenue for my country. There are 100th of industries working day and night. And obviously there are issues regarding electricity production and supply line. People get muddle and teasing due to the Shortage of electricity. And this makes me think to do something useful so that I can start or join projects for helping in energy production. As Pakistan also have advantages of its good climate and weather condition. The average yearly sun shine time is about 10 hours per day, which is enough for the production of the electricity through sunlight. This is a reason solar energy Projects are better to plant in Pakistan. In future, they will also helpful in the development of the economy of Pakistan.

DEDICATION

To my loving parents,

Muhammad Noor uz Zaman & Shadab Khatoon

my brothers & Hina Khan.

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NOMENCLATURE

LIST OF ABBREVIATIONS			
IEA	International Energy Agency	EPA	Environmental Protection Agencies
PV	Photovoltaic	US	United States
RAPS	Remote Area Power Supply	PCU	Power Conditioning Unit
DC	Direct Current	AC	Alternate Current
STC	Standard Test Conditions	MPPT	Maximum Power Point Tracking
FB	Full-Bridge	SEPIC	Single-End-Primary Inductor
PS-TEM	Phase-Shift-Control-Scheme-Based Two-edge-modulation		
GY	Guang Yue	POS	Point-Of-Sale
MPP	Maximum Power Point	PSIM	Power Simulation
PLECS	Piecewise Linear Electrical Circuit Simulation	PSpice	Personal Simulation Program with Integrated Circuit Emphasis
OrCAD	Oregon+Computer-Aided Design	Powergui	Power Graphical User Interface
LIST OF SYMBOLS			
W	Watt	P(V)	Power(Voltage)
I(V)	Current(Voltage)	P&O	Perturb and Observe
D	Diode	I	Equivalent Current
q	Charge Of An Electron	N	Ideality Factor Of Diode
k	Boltzmann Constant	T	PV Cell Temperature
V	Output Voltage Of Cell	A	Cell Area
Ƞ	Efficiency of Solar Cell	ΔI	Change in Current
ΔT	Change in Temperature	ΔV	Change in Voltage
Q1	MOSFET1	Q2	MOSFET2
D1	Diode1	D2	Diode2
L	Inductor	ΔQ	Change in Capacitor Charge
T	On-Time of Q1/Q2	R	Output Load of Converter
D	Duty Cycle	f	Switching Frequency
C	Capacitance of Output Capacitor		
LIST OF SUBSCRIPTS			
$\boldsymbol{V_{OC}}$	Open Circuit Voltage	I_{SC}	Short Circuit Current
$\boldsymbol{V_{MP}}$	Voltage At Maximum Power Point	I_{MP}	Current At Maximum Power Point
$\boldsymbol{I_L}$	Source Current	R_{sh}	Shunt Resistance
$\boldsymbol{R_s}$	Series Resistance	I_D	Diode Current
$\boldsymbol{I_{Sh}}$	Shunt Resistance Current	I_S	Saturation Current
$\boldsymbol{V_{max}}$	Maximum Power dissipating at this voltage	I_{max}	Maximum Power dissipating at this Current
$\boldsymbol{P_{in}}$	Incident Light Power	G_a	Ambient Irradiation

$\boldsymbol{P_{max}}$	Maximum Dissipating Power	$V_{MP,ref}$	Reference Voltage at Maximum Power Point
$\boldsymbol{I_{SC,ref}}$	Reference Short Circuit Current	$I_{MP,ref}$	Reference Current at Maximum Power Point
$\boldsymbol{V_{OC,ref}}$	Reference Open Circuit Voltage	$\propto_0$	Current Temperature Co-efficient
$\boldsymbol{C_1, C_2}$	Constants	β_0	Voltage Temperature Co-efficient
$\mathbf{IR}_{\boldsymbol{T}}$	Incident Irradiation	$\mathrm{IR}_{T,ref}$	Reference Irradiation
$\mathbf{T}_{\boldsymbol{Cell}}$	Cell Temperature	$\mathrm{T}_{Cell,ref}$	Reference Cell Temperature
$\Delta \boldsymbol{i}_{\boldsymbol{L}_{(CLOSED)}}$	Change in Inductor Current when Q1/Q2 is Closed	$\Delta i_{L_{(OPEN)}}$	Change in Inductor Current when Q1/Q2 is Open
$\boldsymbol{V_{in}}$	Input Voltage of Converter	V_{OUT}	Output Voltage of Converter
$\boldsymbol{I_{in}}$	Input Current of Converter	I_{OUT}	Output Current of Converter
$\boldsymbol{D_1}$	Duty Cycle for Q1	D_2	Duty Cycle for Q2
$\boldsymbol{\Delta V_{OUT}}$	Output Ripple Voltage	V_{PV}	Photovoltaic Voltage
$\boldsymbol{I_{PV}}$	Photovoltaic Current	P_{PV}	Photovoltaic Power
$\boldsymbol{I_b}$	Converter Output Current	V_b	Converter Output Voltage
$\boldsymbol{P_b}$	Converter Output Power		

CHAPTER-1

INTRODUCTION

1.1 INTRODUCTION TO RENEWABLE ENERGY

Today, there is a need to concentrate not only on fossil fuels for energy production, but also on renewable energy sources to satisfy energy demand. The fossil fuels (oil, gas and coal) produce about 80% of the current energy need in the world. The increase in energy demand at the rate of 25% per decade creates panic that energy assets are going to be used up, with obliterating outcomes for the world economy. The International Energy Agency (IEA) says the consumption of world's energy could increase by 50% until 2030.

Thomas Alva Edison (1931) stated that,

> "We are like tenant farmers chopping down the fence around our house for fuel when we should be using nature's inexhaustible sources of energy – sun, wind and tide. I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."

The Environmental Protection Agencies (EPA) enactment pushing worldwide investors towards the expanded utilization of renewable energy. In 2011, in America the fossil fuels industry cut 3,875 jobs and solar created 14,000 jobs in 2012 which is 36% more than 2010. The various forms of renewable energy and their production are shown in Table 1.1 [1-2].

Table 1.1 Renewable forms of energy

Energy	**Percent of renewable resources**	**Product**
Bio mass	Burning of plant materials and animal wastes	Heat and gas
Hydro power	Water flowing from higher to lower elevations through dams	Electricity
Wind	Capture of wind by turbines	Electricity
Geothermal	Tapping steam and hot water from the Earth's mantle	Heat and electricity
Solar	Absorbing and storing heat from the Sun	Heat and electricity
Emerging technologies		
Hydrogen fuels	Burning hydrogen gas	Power for movement

Nanotechnology	Using the unique properties of materials on the size scale of molecules or atoms	Electricity
Ancient technologies		
Wind	Water wheels, dams, weight	Power motion
Water	Windmills, sails	Power motion
Movement (kinetic energy)	Animals, human exertion	Power motion

1.2 ADVANTANGE OF SOLAR ENERGY OVER OTHER

Alexander Bacquerel (1839) discovered the Photovoltaic Effect and constructed vacuum photo cells [3]. According to him,

> "The supply of solar energy is both without limit and without cost and will continue to stream down on earth after we exhaust our supplies of fossil fuels."

Photovoltaic PV is renewable energy source premise on the healthy environment without disturbing social and economic standard life. Solar PV applications implemented previously in industries, but now they are available for the commercial and domestic use as well. The Solar PV module market are increasing rapidly at the rate of 30% per year, because of the reliable, cheap and immediate installation of PV systems for electricity production without burning expensive fuel. Table 1.2 point out the lead times for the different type of electrical energy resource [1].

Table 1.2 Different type of electrical energy resources

Type of facility	Lead time (Years from decision to start up)
Nuclear Plant	8-10
Coal or Oil Fired Power Plant	5-7
Hydroelectric Plant	20
Solar Energy Plant	0-2
Gas Turbine Power Plant	2
New Coal Mine	3-6
New Off-Shore Oil Field	2-4
Shale Oil Plant	5
Liquefaction Plant	5
Geothermal Power Plant	5

1.3 PHOTOVOLTAIC SOLAR SYSTEM

Charles Fritts (1883), an American inventor was the creator of the first Solar Photovoltaic Cell by putting a layer of selenium on a metal plate, coating it with gold leaf and placed in the sunlight to produce electricity but not enough. Later on the invention took place and even in 1958, US Navy sent PV cell-powered based radio transmitter Vanguard I satellite in orbit [3-4].

Over the past 20 years, the statistical average performance ratio of a new PV installation has improved from 0.65 to approximately 0.85, which makes a light explosive sound on people's homes and businesses. The recent projected capacity of the worldwide growth of Solar Photovoltaic is about 233GW in 2015. People want to get rid of conventional power sources and acquire alternative power sources by using the low cost sun to power electricity. Many researches consistently are looking for the development of the further down cost, increasing efficiency and eager to deliver better PV systems [1-2].

1.3.1 CLASSIFICATION OF SOLAR SYSTEMS

Generally, photovoltaic solar system consist of Grid-direct PV systems and Battery-based PV systems. The Battery-based PV systems can also be divided into two types as Standalone PV systems or Remote Area Power Supply (RAPS) that works independently from the grid and other is Utility-interactive PV systems that provide backup after utility outages [2].

1.3.2 GRID-DIRECT PV SOLAR SYSTEM

Grid-direct PV Solar system has an ability to produce power and send it back to the utility grid. The Power Conditioning Unit (PCU) as shown in figure 1.1, is the primary component after the panels that converts the DC power into AC power according to the requirement of the utility grid.

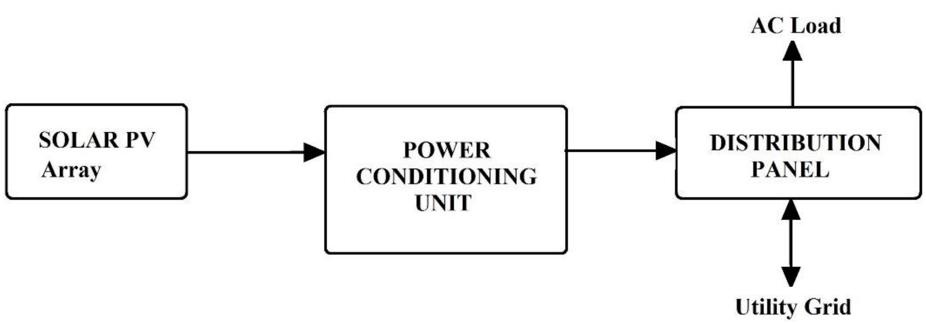

Figure 1.1 Block diagram of Grid-direct PV Solar System

A bi-directional interface on-site distribution panel maintain AC power between the load and back-feed to the utility grid as per requirement of the power by the load or the utility grid. With increased efficiency these type of PV systems are the most popular providing low cost and reduce maintenance as compared to their counterparts. The disadvantage of Grid-direct PV systems is that they cannot work during the outages of utility grid [1-2].

1.3.3 BATTERY BASED UTILITY-INTERACTIVE PV SOLAR SYSTEM

Battery-based Utility-interactive PV systems are the best replacement of the Grid-direct systems as shown in figure 1.2. An additional unit connected with the PCU termed Battery Bank to provide the backup for the load. And when the battery bank fully charged, the system operates like a grid-direct PV Solar system [1, 2, 5].

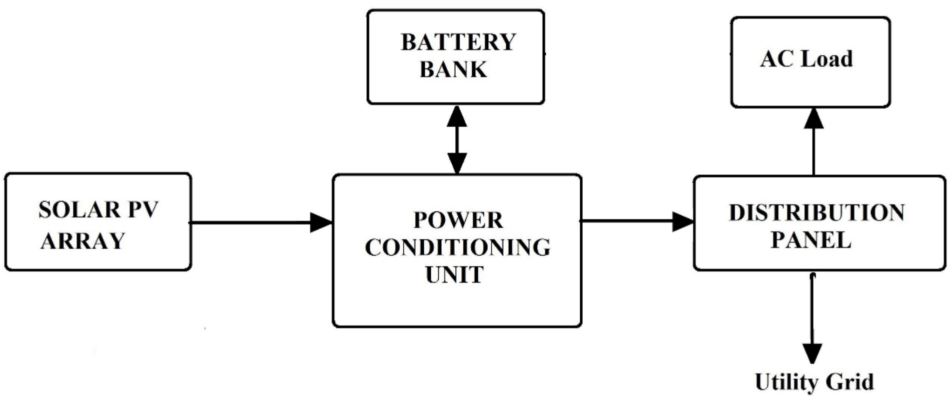

Figure 1.2 Block diagram of Utility-interactive PV Solar System

1.3.4 BATTERY BASED STANDALONE PV SOLAR SYSTEM

Battery-based Standalone systems provide electricity to the load placed in remote areas. For the installation, they require information regarding the energy consume by the load powered through the battery bank. The desired power help the estimation of other components i.e. charge controller, sizing of battery, etc. The charge controller in figure 1.3, keeps the battery safe in the nominal capacity and regulates output current and prevent voltage level from exceeding the maximum value. The DC power supply for charging the battery bank and for operation of the load. The DC power output should sufficient to retain the load while operating. The inverter used to convert the DC power into the AC power for the AC Load [1, 2, 5].

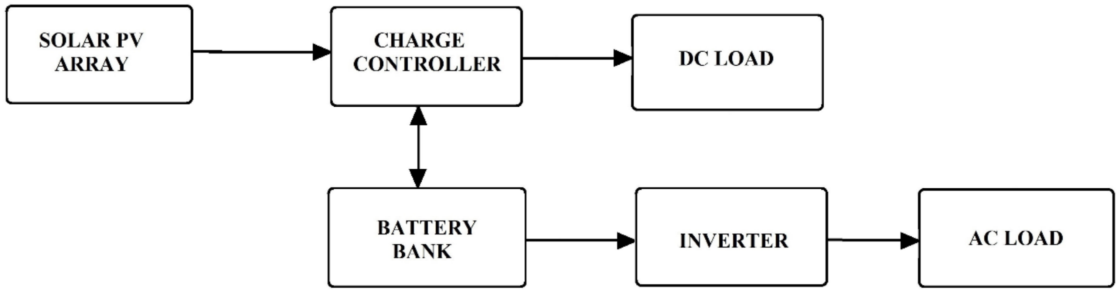

Figure 1.3 Block diagram of Standalone PV Solar System

1.3.5 DIRECT COUPLED PV SOLAR SYSTEM

Standalone PV system are used to directly supply DC / AC source to electrical loads. These are called direct coupled PV system because they provide DC output of the panel directly to the load without storing energy in the batteries. They can work during the presence of sunlight. A charge controller is used to maintain the output level as per requirements. A simple direct coupled PV solar system is shown in figure 1.4.

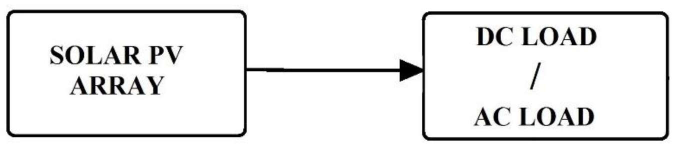

Figure 1.4 Block diagram of Direct Coupled PV Solar System

1.4 OTHER RESEARCHES

Many researches have taken place for the development of the simulation based PV module and buck boost converter. Kanchan Ghute and Vinay Kale [6], presented MATLAB script simulation model for a PV cell and the software that includes the models of the PV panel. The proposed MATLAB script file of the model has been verified with a PV cell and commercial modules for the representation of the PV cell, module and array.

Zekiye Erdem and M. Bilgehan Erdem [7], demonstrated in MATLAB/Simulink for a typical 60W solar panel to show the effect of insolation, temperature, ideality factor and series resistance based on mathematical equations. They developed a general model to simulate the electrical behavior of the PV systems in a grid connected application.

Habbati Bellia et al [8], implemented the most used software by researchers and engineers under Matlab/Simulink. It can be used to study all types of PV modules available in markets, especially, their behavior under different weather data of standard test conditions (STC) and help to determine I(V), P(V) characteristics under any new conditions of irradiance and temperature.

A. Pradeep Kumar Yadav et al [9], looks at the different type of converter which affects the output power of module and investigates the MPPT for the high efficiency. They found using simulation results that Incremental Conductance to be the best controller for MPPT for buck and boost converter.

Hairul Nissah Zainuddin and Saad Mekhilef [10], studied the two most popular algorithms techniques incremental conductance algorithm and perturb and observe algorithm with three different converters for comparison of parameters in terms of efficiency, voltage, current and power output. Applied multi changes in irradiance, temperature by keeping voltage and current main sensed parameter in simulation. They depicted the Incremental Conductance Controller as the best controller for the MPPT.

I. William Christopher and Dr. R. Ramesh [11], studied specifically perturb and observe and incremental conductance because of its low-cost and ease of realization and traced voltage, current and power output for different combination. They proved that Incremental conductance method has better performance than P&O algorithm. This algorithm not only improve dynamic and steady state performance of PV system but as well as efficiency of the dc-dc converter system.

Satish. Bandaru and R. Suresh [12], proposed an isolated buck-boost dc/dc converter for wide input-voltage range and also full-bridge (FB) boost converter analyzed. All the characteristics of the isolated buck-boost converters are same as the two switch buck-boost converter except for considering the turns ratio of the transformer when it is performed ideally. They experienced the operating principle of the FB-boost converter and three mode dual-frequency PS-TEM control in this paper and declared effective.

Haifeng Fan, System Engineer [13], presents an article for the operational principle, current stress and power loss analysis of single-end-primary inductor converter (SEPIC), ZETA converter and two switch buck-boost converters have positive or non-inverting outputs and presents design criteria for non-inverting buck boost converter.

1.5 CONTEXT OF THE THESIS

In this thesis the buck boost dc-dc converter is designed to implement in the photovoltaic system because of its non-steady state. It is the best way for finding the efficiency of converter within the non-stable state. Due to the environment the non-linear functionality of PV system produces fluctuation in its output. At this stage converter and controller force PV system to work in steady state and extract more power from it. The MATLAB SimPower system is used for simulation of PV panel, buck boost dc-dc converter and MPPT controller. The goals achieved in this thesis are as follow,

→ Calculating all parameters for the Guang Yue GY-box-5c photovoltaic panel.
→ Simulating the PV panel in SimPower system.
→ Finding parameters of panel i.e. V_{OC}, I_{sc}, V_{MP}, I_{MP} using simulation.
→ Simulation I-V and P-V characteristics curve in MATLAB SimPower System.
→ Calculating the values for the components of buck-boost converter.
→ Find the low output voltage ripple value.
→ Designing and simulating the values for buck boost dc-dc converter.
→ Simulation the Incremental Conductance Method.
→ Simulation of complete standalone system in SimPower System.
→ Compare the results of Output Voltages, Currents and Powers between panel and converter.
→ Compare the results for ripple values.

1.6 STRUCTURE OF THE THESIS

Chapter-1 begins with the background of the renewable energy, which point out the advantages of solar energy, leading towards the photovoltaic system, classification of the photovoltaic system and researches.

Chapter-2 explain theoretical background, which include formation of solar cell to PV system, mathematical modelling of the solar cell to find maximum current and voltage produce by the cell. It also includes the mathematical modelling of the PV module with its maximum power point. A buck boost dc-dc converter proposed in this chapter with its different mode of operation, selection of an inductor and determining the key role for finding the output voltage ripple. Finally an incremental conductance method for controlling and tracking maximum output power explained for its better efficiency.

Chapter-3 presents the simulation of the system discussed in previous chapters. The Simulink modelling of buck boost converter, photovoltaic panel GY-box-5c and incremental conductance explained in this chapter. All the blocks combined together to represents complete Photovoltaic Standalone Solar System (Remoter Area Power Supply).

Chapter-4 include all the results find during simulation of the standalone system. It contains the application of different kinds of irradiances and their response at the output of the Photovoltaic Panel and Buck Boost Dc-Dc Converter. The output results compare together for the voltages, currents and power. In this part the result due to the constant irradiance also produced and compare for the low ripples.

Chapter-5 contain the efforts for the implementation of the buck boost dc-dc converter using photovoltaic panel as an input source. The switching of the MOSFETs done by signal generator. The results of experiment setup compare between the output voltages and currents of panel and converter.

Chapter-6 is a summary of the thesis which gives conclusion to the purpose of the thesis and also future recommendation that can improve the implementation of the converter.

CHAPTER-2

THEORITICAL BACKGROUND

2.1 FROM A SOLAR CELL TO A PV SYSTEM

A Solar module also called PV module consist of several solar cells, which are made up of silicon doped with phosphorous or boron to increase the number of free electrons or holes within the semiconductor. Silicon is a component of sand and quartz that also makes much of Earth's crust. PV cells wired together, encased in plastic and glass within metal frame to create PV module and by increasing of PV module we can make PV array as shown in figure 2.1 that can also produce more voltage and current.

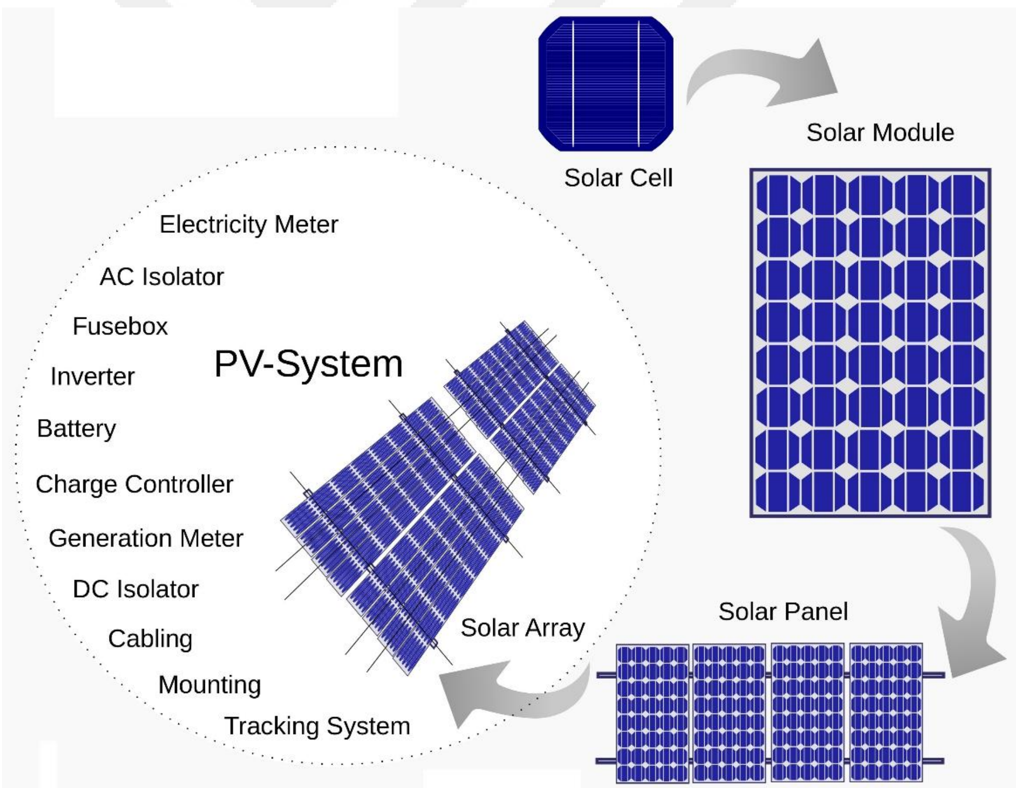

Figure 2.1 From a Solar Cell to a PV System

A Solar Array can efficiently operates with the maximum solar radiation of 1000 watt per meter square to converts the sunlight into direct-current. An output current of Solar Array change proportionally with respect to the incident sunlight. A Charge Controller regulates the output of Solar Array and either just charge the battery and/or provide it directly to the load. Battery Bank is form by connecting batteries individually together to retain charge in the load. Other components include mounting structure, cables, Protection devices also affect PV system efficiency, performance, maintenance cost, reliability and esthetic in future [1,2,14].

2.1.1 SOLAR PHOTOVOLTAIC CELL

An ideal solar cell can be modelled by a current source I_L in parallel with a diode D. In real time, no solar cell is ideal and hence a shunt resistance R_{sh} and a series resistance R_s are added to the model. The Shockley Diode current I_D and the shunt resistance current I_{sh} are shown in the figure 2.2. By applying Kirchhoff's Current Law in figure 2.2 for a single silicon solar cell [15, 16].

$$I = I_L - I_D - I_{sh} \tag{2.1}$$

$$I = I_L - I_s \{e^{\frac{q(V+I.R_S)}{n.k.T}} - 1\} - \frac{V+I.R_S}{R_{sh}} \tag{2.2}$$

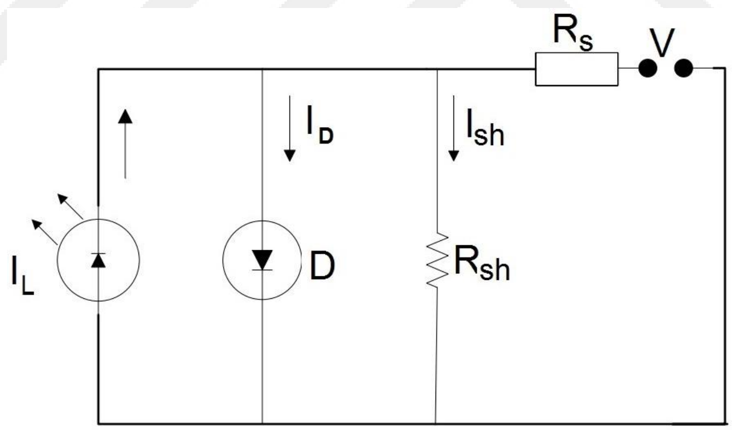

Figure 2.2 Equivalent circuit for a PV Cell

The diode current I_D of a p-n junction diode relates the diode voltage V by $I_s \{e^{\frac{q(V+I.R_S)}{n.k.T}} - 1\}$.

Where,

I_s = Saturation current or scale current of diode

q = Charge of an electron (1.6021766208(98) x10^{-19} coulombs)

n = Ideality factor of diode

k = Boltzmann constant (1.38064852 x 10^{-23} m^2Kg / s^2K)

T = PV cell temperature

2.1.2 I-V CURVE FOR SOLAR PHOTOVOLTAIC CELL

A typical I-V characteristics of a solar cell point out that the power delivered to the load depends on the resistance, if the load is small the cell operates in M-N region and if the load is large the cell operates in P-S region of the curve [17] as shown in figure 2.3. I_{sc} is the short circuit current at V=0. V_{oc} is the open circuit voltage at I=0. The point at which the maximum power dissipating in the load at point 'A' (V_{max}, I_{max}) [15]. With these factors maximum efficiency of a solar cell is given as,

$$\eta = \frac{P_{max}}{P_{in}} = \frac{V_{max} \text{ x } I_{max}}{A\ G_a} \quad (2.3)$$

Where $P_{in}$is the incident light power, $G_a$is ambient irradiation and A is cell area.

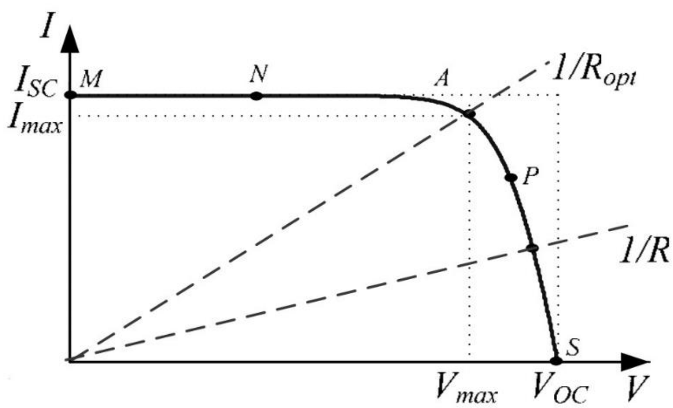

Figure 2.3 A typical I-V curve for Solar Cell

2.1.3 SOLAR PHOTOVOLTAIC MODULE

Kamaruzzaman Sopian et al [15], proposed a photovoltaic module in which they used interpolation model based on I_{sc}, V_{oc}, I_{MP} and V_{MP}.

$$C_1 = (1 - \frac{I_{MP,ref}}{I_{sc,ref}}) \exp(- \frac{V_{MP,ref}}{C_2 . V_{oc,ref}}) \quad (2.4)$$

$$C_2 = (\frac{V_{MP,ref}}{V_{oc,ref}} - 1) / \ln (1 - \frac{I_{MP,ref}}{I_{sc,ref}}) \quad (2.5)$$

The change in current with respect to the irradiance and temperature can be calculated as,

$$\Delta I = \propto_0(\frac{IR_T}{IR_{T,ref}})\ \Delta T + (\frac{IR_T}{IR_{T,ref}} -1)\ I_{sc,ref} \tag{2.6}$$

The two parameters ΔT and V_R for the temperature of PV and Solar irradiation can written as,

$$V_R - V = \Delta V = \beta\ \Delta T + R_S\ \Delta I \tag{2.7}$$

$$\Delta T = T_{Cell} - T_{Cell,ref} \tag{2.8}$$

By substituting all the values from equations (2.4 - 2.8), the output current for the Photovoltaic Solar Module can be computed as,

$$I = I_{sc,ref}[1\text{-}C_1\{\exp(\frac{V - \Delta V}{C_2 . V_{oc,ref}})\text{-}1\}] + \Delta I \tag{2.9}$$

Like a solar cell, PV module also operates at the maximum power point as depicted in figure 2.4 that the I-V curve and P-V curve correspond to the maximum power mentioned by the maximum are in the rectangle.

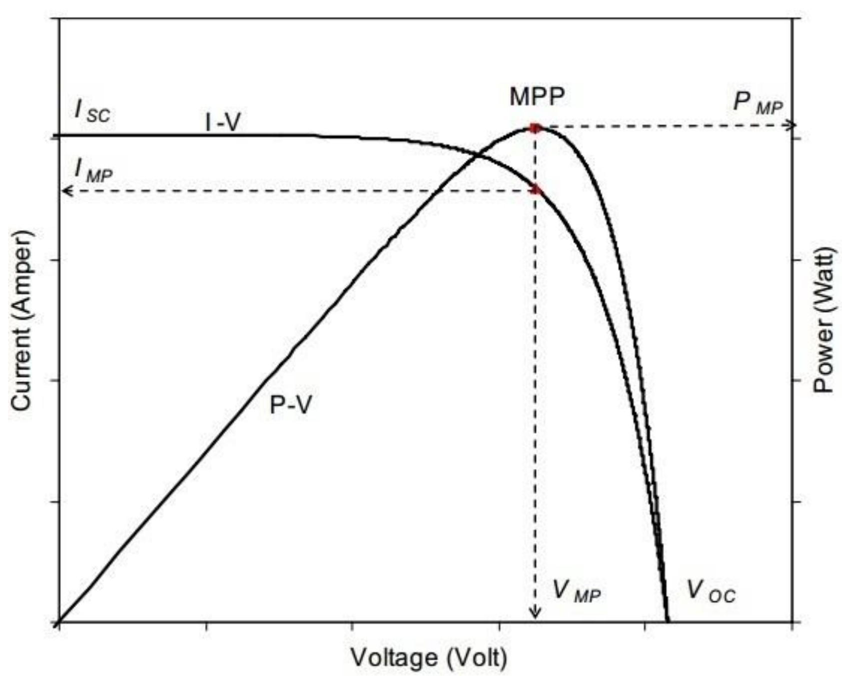

Figure 2.4 Typical I-V and P-V curve for PV module

The interpolation model used by Ai et al [19], evaluated equations of V and ΔV in maximum power conditions.

$$V_{MP} = V_{MP,\mathrm{ref}}\,[1 + 0.0539 \text{ x} \log(\frac{IR_T}{IR_{T,ref}}) + \beta_0 \Delta T] \tag{2.10}$$

$$I_{MP} = I_{SC,\mathrm{ref}}\,[1 - C_1\{\exp(\frac{V_{MP} - \Delta V}{C_2 . V_{oc,ref}}) - 1\}] + \Delta I \tag{2.11}$$

$$\Delta V = V - V_{MP,ref} \tag{2.12}$$

2.2 BUCK-BOOST CONVERTER

The widely use of the buck-boost converter are in those systems where the input voltage is lower or higher than the desired output voltage. In a buck mode it produce a DC output in a range from 0 Volt to just less than the input voltage. And in boost mode the DC output voltage ranging from the same voltage as input to the much higher level of the input [12]. Figure 2.5 represents a two switch dc-dc buck boost converter.

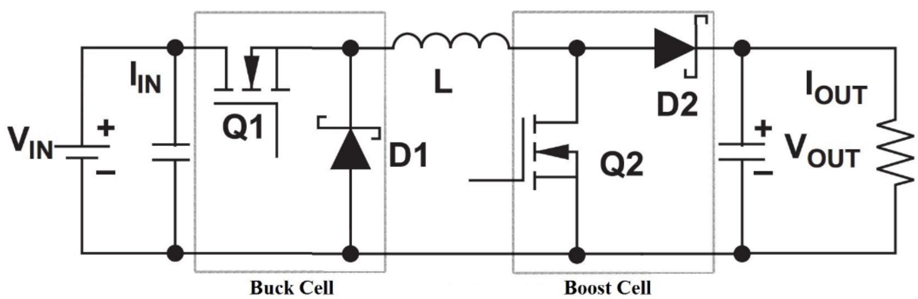

Figure 2.5 A two switch DC-DC Buck-Boost Converter

Mostly these (step-up and step-down) converters are used in industrial personal computers, point-of-sale (POS) systems and automotive start-stop systems [13]. The input of the buck boost converter fed by the output of PV panel. The incident light on the panel responsible for the working principle of the converter to either in step-up mode or step-down mode.

2.2.1 OPERATING MODE

The two-switch buck-boost converter is a cascaded combination of a buck converter followed by a boost converter. A two switch buck boost converter operates in either buck or boost mode and can also operate in buck-boost mode having same gate control signals but has low efficiency for step-up and step-down conversion.

2.2.1.1 BUCK MODE

Figure 2.6 represents buck mode switching of MOSFET Q1 to control the output voltage keeping MOSFET Q2 always off.

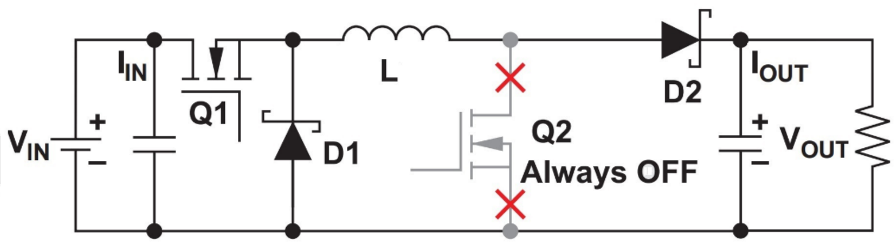

Figure 2.6 Buck mode operation of the two switch Buck Boost Converter

2.2.1.2 BOOST MODE

In the boost mode, MOSFET Q1 always on and the output voltage is controlled by MOSFET Q2. The Diode D1 is reverse biased allow the increase in an output voltage.

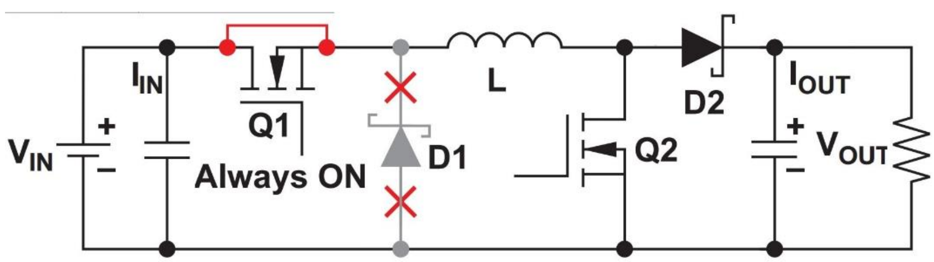

Figure 2.7 Boost mode operation of the two switch Buck Boost Converter

2.2.2 ANALYSIS OF OPERATIONAL MODES

2.2.2.1 BUCK OPERATION

When the gate of Q1 is high in the buck mode operation, the current flow through L, charging its magnetic field and force output capacitor to charge and supplying load. D1 is OFF due to the positive on its cathode as in figure 2.8 [20]. The change in current during Q1 is closed can be written as,

$$\Delta i_{L(CLOSED)} = \frac{(V_{IN} - V_{OUT})}{L} D_1 . T \tag{2.13}$$

Where, D_1 is the duty cycle and T is the time when Q1 is CLOSED.

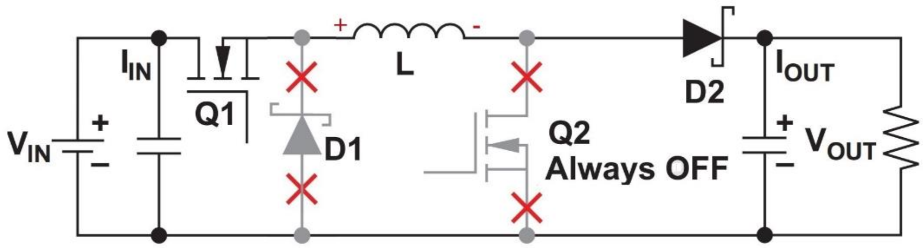

Figure 2.8 Buck mode operation when the gate of Q1 is high

In figure 2.9, the gate of Q1 is low or open allowing the L to collapse its field and reverse its polarity which turns ON D1 and current will flow through D2 to the load. The discharge voltage of L accumulated in the capacitor to retain its voltage almost constant [20]. And if the value of charging capacitor increases the exponential curve reduces significantly. And the inductor current decreases linearly and becomes,

$$\Delta i_{L(OPEN)} = -\left(\frac{V_{OUT}}{L}\right)(1 - D_1).T \tag{2.14}$$

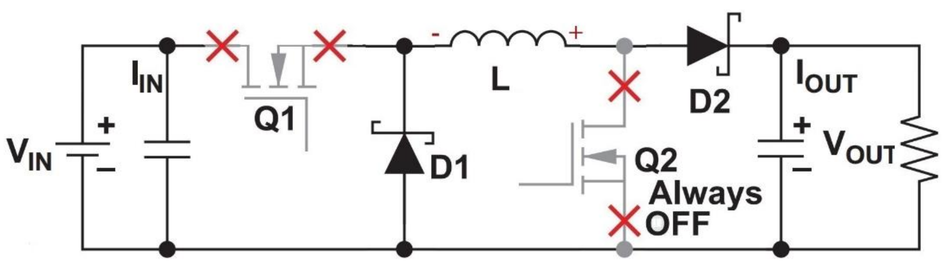

Figure 2.9 Buck mode operation when the gate of Q1 is low

In steady state the net change in inductor current over the complete period is zero i.e.

$$\Delta i_{L(CLOSED)} + \Delta i_{L(OPEN)} = 0 \tag{2.15}$$

Using (2.14) and (2.15) we can solve to find the ratio between V_{OUT} *and* V_{IN}as,

$$V_{OUT} = V_{IN} . D_1 \tag{2.16}$$

Hence, for the buck operational mode the output voltage depends on the duty cycle applied. Ideally, maximum duty cycle tends to produce output voltage which will equal the input voltage.

2.2.2.2 BOOST OPERATION

For the boost converter mode, Q1 is always ON allowing L to charge its magnetic field. In the mean time when Q2 becomes high, it held anode of D2 at ground potential and current pass through Q2 only to supply negative terminal. During this the charge on capacitor built by previous oscillation supply to the load. The total current across the inductor when Q2 is CLOSED,

$$\Delta i_{L(CLOSED)} = \frac{V_{IN}}{L} D_2 . T \tag{2.17}$$

Where, D_2 is the duty cycle and T is the time when Q2 is CLOSED.

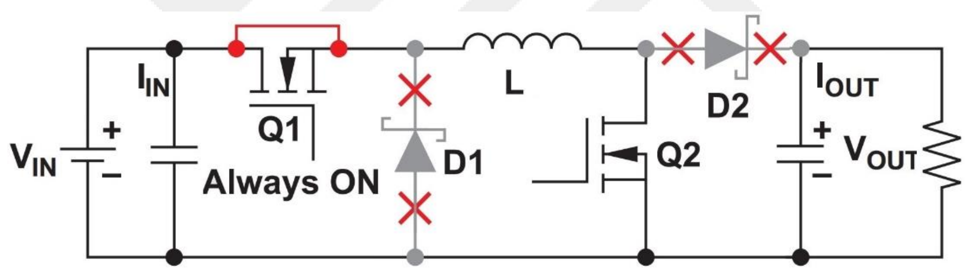

Figure 2.10 Boost mode operation when the gate of Q2 is high

Now the Q2 is forcing to OFF as in figure 2.11. L possess magnetic field and capacitor discharged partially. The magnetic field of the L begins to collapse with the reverse polarity. Forward biasing D2 and adding up its voltage to the input voltage giving an output voltage equal or greater than the input [20].

$$\Delta i_{L(OPEN)} = \frac{(V_{IN} - V_{OUT})}{L} (1 - D_2) . T \tag{2.18}$$

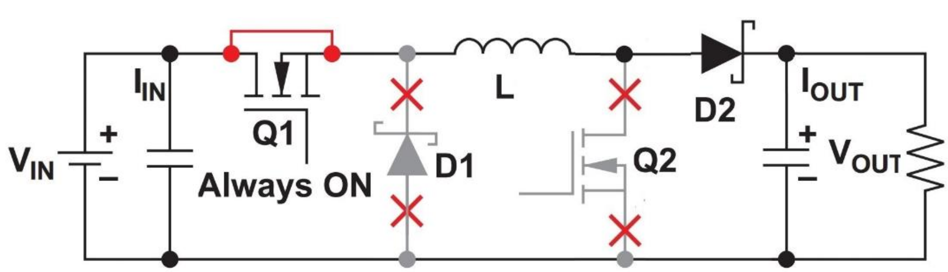

Figure 2.11 Boost mode operation when the gate of Q2 is low

By substituting the values from (2.17) and (2.18) in (2.15) the ratio between V_{IN} and V_{OUT} calculated as,

$$V_{OUT} = V_{IN}. (\frac{1}{1-D_2}) \tag{2.19}$$

By examining the equation (2.19) it can be stated that the output voltage of the boot operational mode increases with the increase in the duty cycle of Q2, keeping the Q1 always ON.

2.2.2.3 BUCK-BOOST OPERATION

The two switch buck boost converter operate in the following condition mode as shown in Table 2.1. There is no conduction in 1st condition when both Q1 and Q2 OPEN. While the converter perform the same operation in condition 2 and 4 with the same inductor current as previously discussed.

Table 2.1 Switching of buck boost converter

CONDITIONS	1	2	3	4
MOSFET Q1	ON	OFF	ON	OFF
MOSFET Q2	ON	ON	OFF	OFF

In 3rd condition, Q1 OPEN and Q2 is CLOSED as in figure 2.12. The charged inductor possess magnetic will collapse through the Q2. The change in inductor current during this period is,

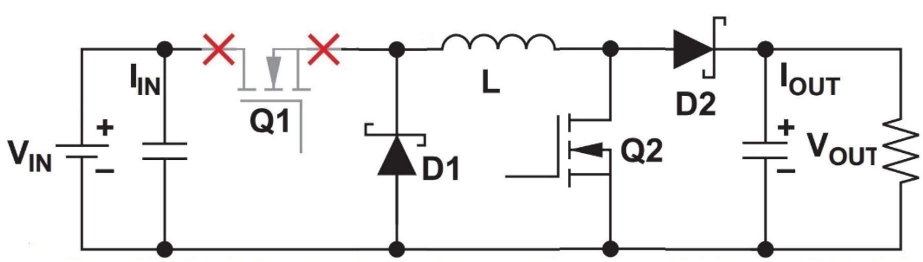

Figure 2.12 Buck-Boost mode operation when the gate of Q1 is low and Q2 is high

$$\Delta i_{L(CLOSED)} = \frac{(V_{OUT}-V_{IN})}{L} D_2.T \tag{2.20}$$

Using equations (2.13), (2.14), (2.17) and (2.20) the V_{IN} and V_{OUT} ratio computed as,

$$V_{OUT} = V_{IN}.\left(\frac{D_1}{1-D_2}\right) \quad (2.21)$$

In the buck boost operational mode both the switch set to keep the voltage at certain level. As in equation (2.21) output voltage depends on the duty cycles D_1 and D_2. In this mode wide range of voltage fluctuation can be controlled for the regulated dc output. It is better to calculate the values to keep control the duty cycle of D_2 allow to turn Q2 not more than ninety percent for the conduction. In other case the output may vary anonymously.

2.2.3 INDUCTOR SELECTION

For the determination of inductor value ideally the averaged input power must be the same as the averaged output power at load i.e.

$$P_{in} = P_{OUT} \text{ or } I_{in}V_{in} = I_L V_{in} = V_{OUT}I_{out} \quad (2.22)$$

The expression for maximum and minimum current calculated as under,

$$I_{max} = \frac{V_{IN}}{R}.\left(\frac{D_1}{1-D_2}\right)^2 + \left(\frac{V_{IN}D_2}{2Lf}\right) \quad (2.23)$$

$$I_{min} = \frac{V_{IN}}{R}.\left(\frac{D_1}{1-D_2}\right)^2 - \left(\frac{V_{IN}D_2}{2Lf}\right) \quad (2.24)$$

The minimum inductor current lies between continuous and discontinuous mode can be calculated if I_{min}=0,

$$0 = \frac{V_{IN}}{R}.\left(\frac{D_1}{1-D_2}\right)^2 - \left(\frac{V_{IN}D_2}{2Lf}\right) \quad (2.25)$$

$$L = \left(\frac{1-D_2}{D_1}\right)^2 \left(\frac{RD_2}{2f}\right) \quad (2.26)$$

Inductor values take part in the output power of the converter. It should have to design with a low resistance for the better efficiency. As efficiency of the inductor is equal to the ratio between output power and sum of output power and its losses. The losses increases with the increasing amount of the inductor resistance.

2.2.4 OUTPUT VOLTAGE RIPPLE

An infinite capacitance implying the output voltage of the buck boost converter constant. But in practice, a finite capacitance produce some fluctuation or ripple in output voltage. The peak-to-peak output voltage ripple can be calculated from the capacitor current waveform calculating the change in capacitor charge of figure 2.13.

$$|\Delta Q| = \left(\frac{V_{OUT}}{R}\right) DT = C\Delta V_{OUT} \tag{2.27}$$

An expression for the ripple voltage is then,

$$\Delta V_{OUT} = \frac{V_{OUT}\,DT}{RC} = \frac{V_{OUT}D}{RCf} \tag{2.28}$$

Where f is the switching frequency. Alternatively, capacitance in terms of output voltage ripple can written as,

$$C = \frac{D}{R(\Delta V_{OUT}/V_{OUT})f} \tag{2.29}$$

Equation (2.29) helps to reduce the output voltage ripple of the buck boost converter by selecting the appropriate capacitance value. The ratio between $\Delta V_{OUT}/V_{OUT}$ select properly for the low output ripple value.

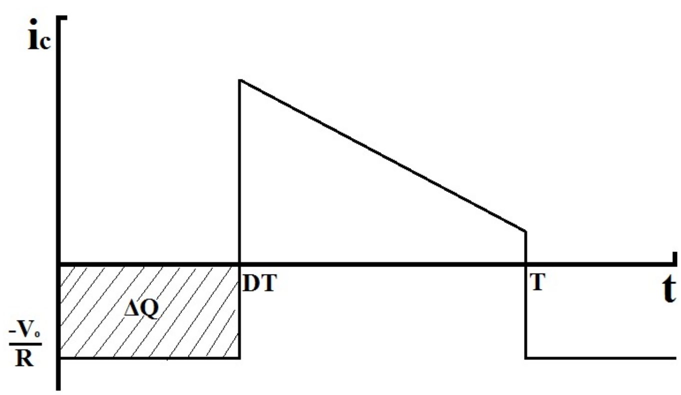

Figure 2.13 Capacitor Current

2.3 CHARGE CONTROLLER

Photovoltaic module is an unstable power system without charge controller as it depends on the temperature and intensity of solar irradiance. Charge controller helps regulate the output power of the solar panel and extract maximum power. Without controller the loss in power may result in premature battery failure or capacity loss, higher installation cost and eventually low efficient.

2.3.1 INCREMENTAL CONDUCTANCE CONTROLLER

The purpose for selecting the incremental conductance method for controlling the output power of the photovoltaic panel is for its better performance. Many researches have been taking place for the comparison of the charge controller and found that the incremental conductance method provides better result in terms of dynamic response, efficiency and implementation [9-11]. In this method the slope of PV array power curve is zero at MPP, positive for output power smaller than MPP and negative for output power greater than MPP as shown in figure 2.14.

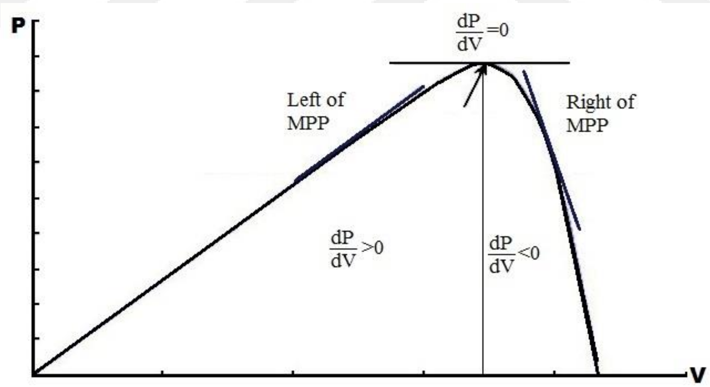

Figure 2.14 Basic concept of InC on a PV curve

Since the output power P of panel is the product of panel voltage V and the current I. And by differentiating the P with respect to V and setting the result to 0 as,

$$dP/dV = I + V\, dI/dV = 0 \tag{2.30}$$

This leads to:

$$dI/dV \approx \Delta I/\Delta V = -\, I_{MP}/V_{MP} \tag{2.31}$$

The main idea is to compare the incremental conductance ($\Delta I/\Delta V$) to the instantaneous conductance (I_{MP}/V_{MP}) as shown in flowchart given in figure 2.15. The PV array force to operate at V_{MP} and once it reached PV array maintained to operate at this condition unless a change in current occurs. The algorithm then tracks MPP by increasing or decreasing the voltage. Therefore by evaluating the derivative,

$$\begin{aligned} &dP/dV = 0 \quad => \quad \Delta I/\Delta V = -\,I_{MP}/V_{MP} \quad \text{at MPP} \\ &dP/dV > 0 \quad => \quad \Delta I/\Delta V > -\,I_{MP}/V_{MP} \quad \text{left of MPP} \\ &dP/dV < 0 \quad => \quad \Delta I/\Delta V < -\,I_{MP}/V_{MP} \quad \text{right of MPP} \end{aligned} \tag{2.32}$$

On the basis of result, the operating voltage either increased or decreased to reach MPP and stops modifying the operating voltage when correct value is reached. A change in PV current will restart the MPP tracking. Depending on the conditions, the same function may be achieved by using equation dP/dV.

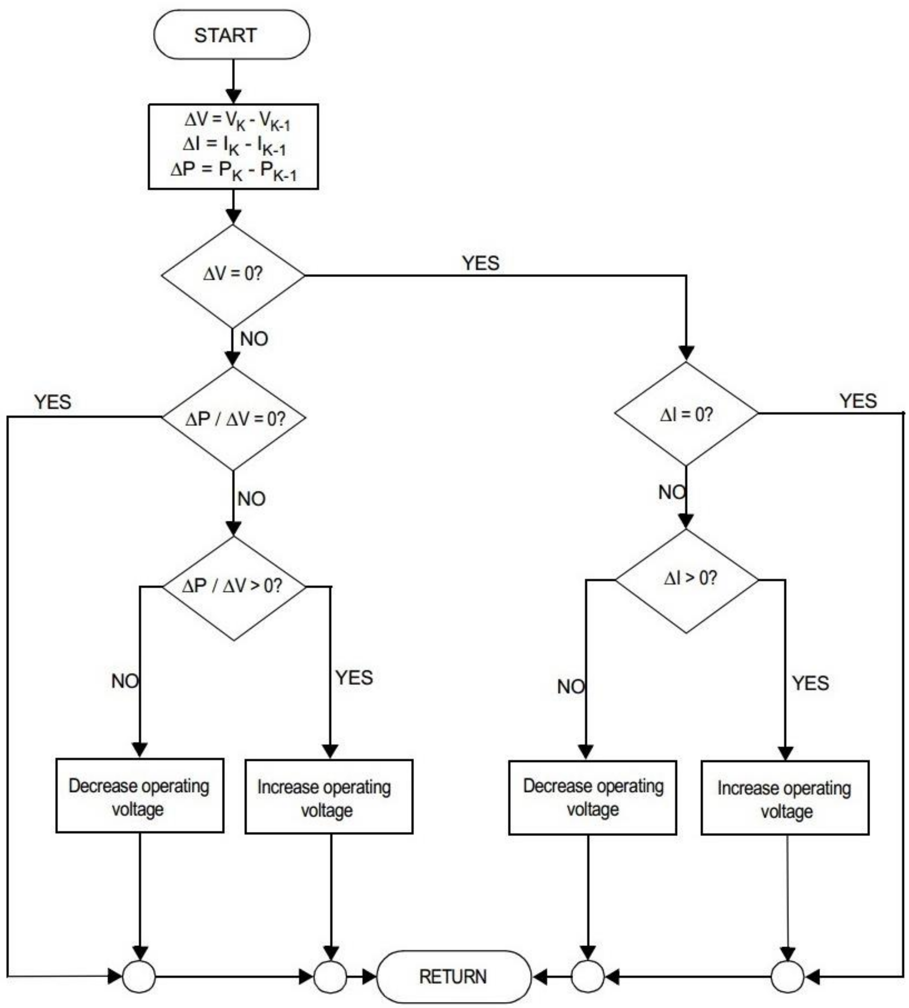

Figure 2.15 Flow chart of MPPT Incremental Conductance

CHAPTER-3

MODELLING

3.1 MATLAB SIMPOWER SYSTEM

A bunch of software like PSIM, PLECS, OrCAD, PSpice, MATLAB SimPower System, MATLAB SimElectronics System etc. available for the simulation of electrical and electronics projects. In all of the above MATLAB Simulink is reliable and widely used software for easy handling. It can also analyze power system with additional feature of simple programming of .m file environment. It satisfies load flow in many applications of power system.

3.2 SIMULATION OF BUCK-BOOST CONVERTER

As per the name of two switch buck-boost dc-dc converter, it consists of two MOSFETs (Q1, Q2) turning on and off according to the duty cycles D1 and D2, input capacitor C1 (with its equivalent series resistance), an inductor L, diodes diode1 and diode2 to prevent the circuit from reverse current, output capacitor Co and a load resistance Ro as show in figure 3.1.

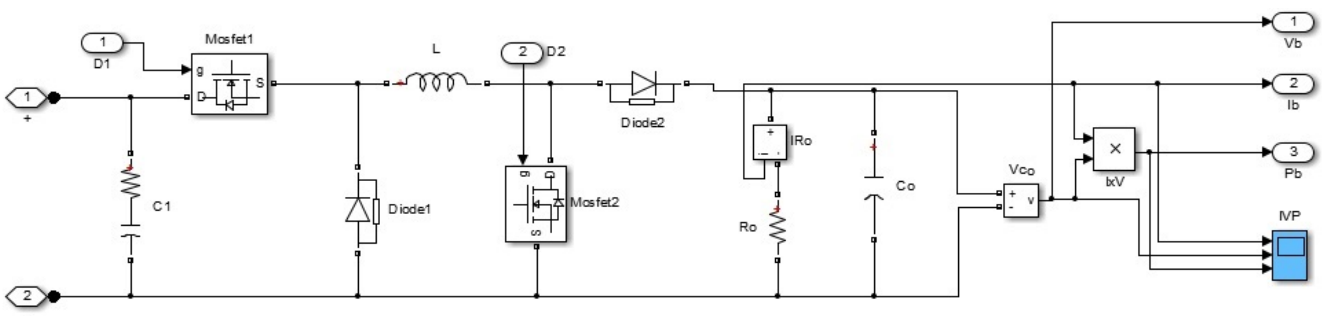

Figure 3.1 Simulation Model of Buck-Boost Dc-Dc Converter

Tables 3.1 signifies the values of the components involved in the Simulink of buck-boost dc-dc converter. The output voltage ripple of the converter controlled by the output capacitor.

Table 3.1 Buck boost converter components

Component	Value
Capacitor C1	25.8 uF
ESR of C1	0.01

Diode1 / Diode2	0.8 fwd voltage
Inductor L	135 uH
Load Resistor Ro	58 Ohm
Output Capacitor Co	25.8 uF

All the components in above table calculated to produce output voltage with respect to the applied input as in table 3.2 and after simulation in Matlab Simulink SimPower system the results are much identical. The comparison between the results signify the losses in Simulink because of the MOSFET features and diode forward voltage.

Table 3.2 Buck boost converter output's comparison

Calculated Result		Simulink Result		Error
Input Voltage	17.6V	Input Voltage	17.6V	0
Output Voltage	70V	Output Voltage	67.1V	4.14%

The buck boost dc-dc converter's input fed with the output of the photovoltaic panel. The input capacitor C1 of the converter plays an important role as it reduces the fluctuations and distortions produced by the photovoltaic panel. A large value of C1 can remove the ripples in the output voltage of panel. The capacitor C1 charged and force Q1 to allow current through it. The duty cycle D1 control the switching of Q1. The diodes D1 and D2 prevent the circuit from reverse current and also help to provide stable output. Inductor L stores energy when the Q1 switch on. Switching of Q2 by duty cycle D2 also take part in controlling output voltage. The more the duty cycles D1 and D2 high, the output voltage will also high. The simple resistive load Ro used to measure the voltage across it. As previously discussed Co keeps the output voltage constant. The bigger the Co results lower ripple value. By using equation 2.29, $\Delta V_{OUT}/V_{OUT}$ selected to produce 5% of output ripple i.e. 3.5V peak to peak.

3.3 SIMULATION OF PHOTOVOLTAIC PANEL

The simulation of the system begins with the calculations of the values for the panels paramteres. After the calculating paramteric values the proposed model [15] used to simulink the equations in the SimPower system. The steps involved in the derivation of the photovoltaice panel and also its characterisation will discuss in next.

3.3.1 CALCULATION OF PHOTOVOLTAIC PANEL

The simulation of photovoltaic panel has done after considering the paramteres of Guang Yue GY-Box-5c. All the conditions for the simulation of the panel set accordingly. The parametric values for the panel shown in table 3.2.

Table 3.3 Parameters of PV panel

Component	Value
Test Conditions AM1.5	1000W/m^2, 25C
Maximum Power (P_{MP})	85.008W
Open Circuit Voltage (V_{OC})	21.8V
Short Circuit Current (I_{SC})	5.18A
Maximum Voltage (V_{MP})	17.6V
Maximum Current (I_{MP})	4.83A
Max System Voltage	1000V

The result for the values depicted in above table for the Open Circuit Voltage (V_{OC}), Short Circuit Current (I_{SC}), Maximum Voltage (V_{MP}), Maximum Current (I_{MP}) and Maximum Power (P_{MP}) simulated in Matlab Simpower system are shown in figure 3.2 and figure 3.3. As in figure the $V_{OC}$and $I_{SC}$are same as the theoretical value.

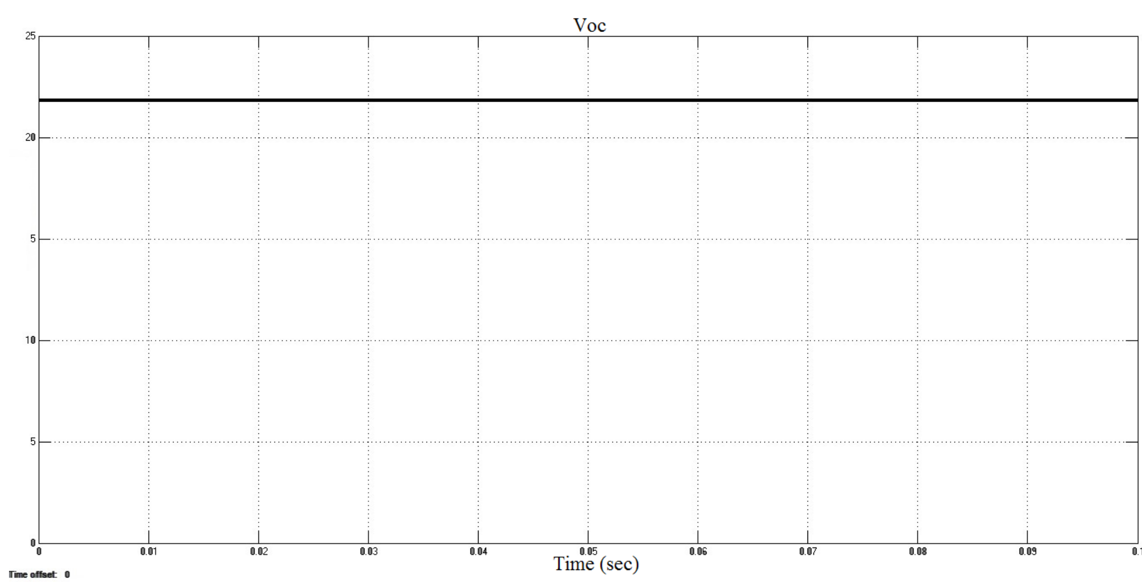

Figure 3.2 (a) Open Circuit Voltage (V_{OC})

For V_{OC} the output of the PV panel connected to a maximum load. The open circuit voltage produced by this simulation has the same result of about 21.8V. Similarly for I_{SC} a very minute resistance placed at the output of the panel. And the same result of about 5.18A produced for I_{SC}.

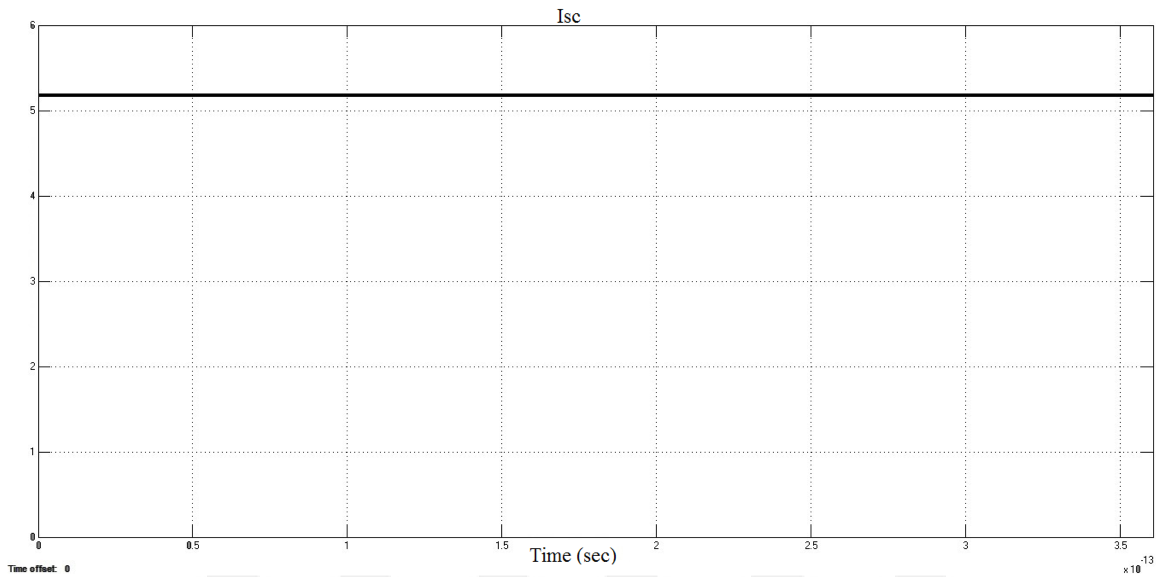

Figure 3.2 (b) Short Circuit Current (I_{SC})

For obtaining the values for V_{MP}, I_{MP} and P_{MP} the photovoltaic panel is connected with the converter and a constant duty cycle applied through the Pulse Generator. The duty cycle of Q1 is kept constant to turn it always on allowing the current to pass through it. The switching frequency selected to be 10kHz and On-time for Q2 is 75%.

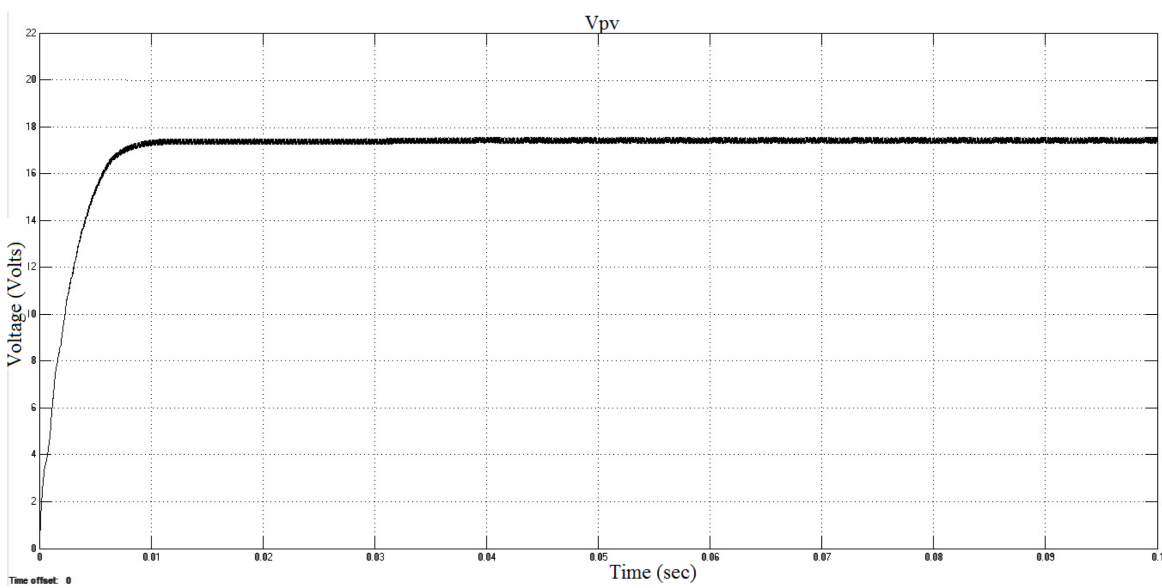

Figure 3.3 (a) Voltage at Maximum Power Point (V_{MP})

In figure 3.3 (a) the voltage initially zero. As long as when the simulation running and photovoltaic panel experiencing a resistive load at the output of converter, the amount of voltage increases. At last the voltage reached a point where it becomes constant.

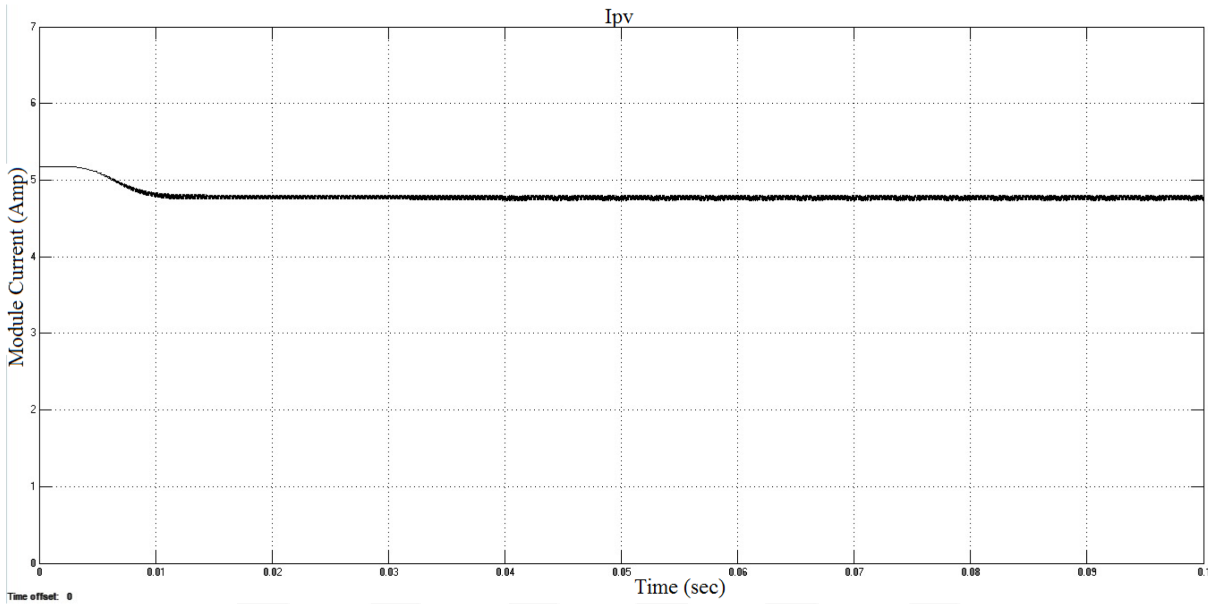

Figure 3.3 (b) Current at Maximum Power Point (I_{MP})

Initially the simulation starts at short circuit current as shown in figure 3.3 (b). The amount of current reduces as the voltage increases and in the meantime panel current charge the capacitor at the input of converter. So that after a few seconds capacitor fully charged and the current maintain at a constant level of maximum power point.

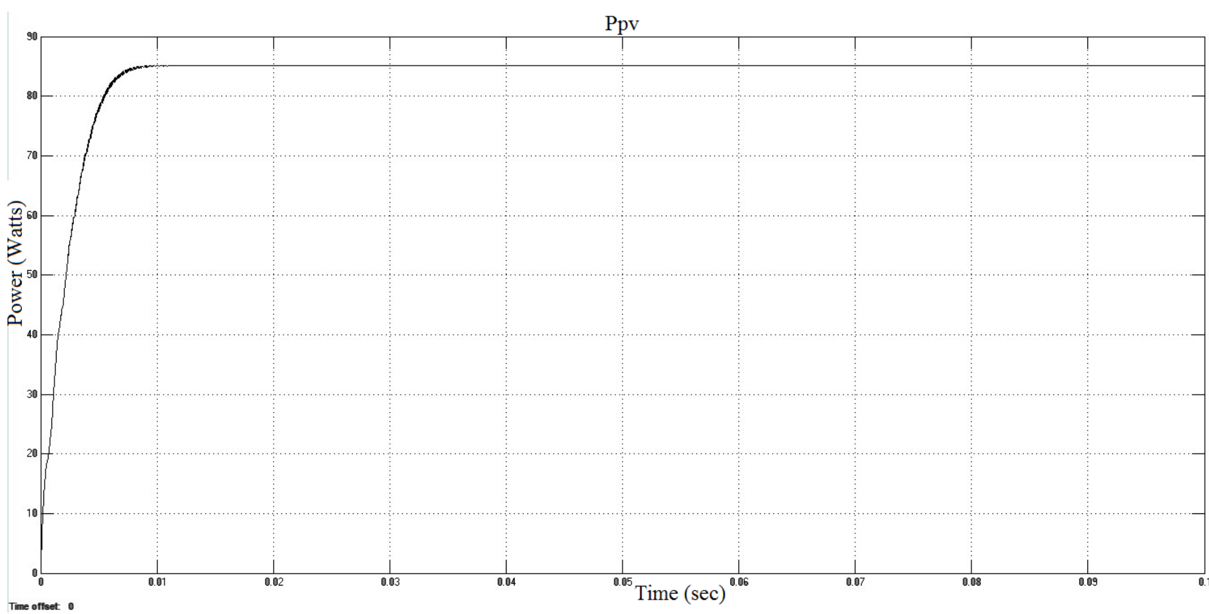

Figure 3.3 (c) Power at Maximum Power Point (P_{MP})

The power is the product of current and voltage. It started from zero value because of the voltage. The output power of panel linearly increases and becomes constant due to current and voltage effect.

3.3.2 SIMULINK BASED SIMPOWER SYSTEM MODEL

The photovoltaic model Simulink in Matlab SimPower System is shown in figure 3.4. In figure the photovoltaic panel is connected with the tag sources which correspond to the panel output voltage V_{PV}, current I_{PV}, power P_{PV} and the remaining positive and negative terminals are directed towards the input of converter. The irradiance and temperature of the panel set ideally to produce maximum available power.

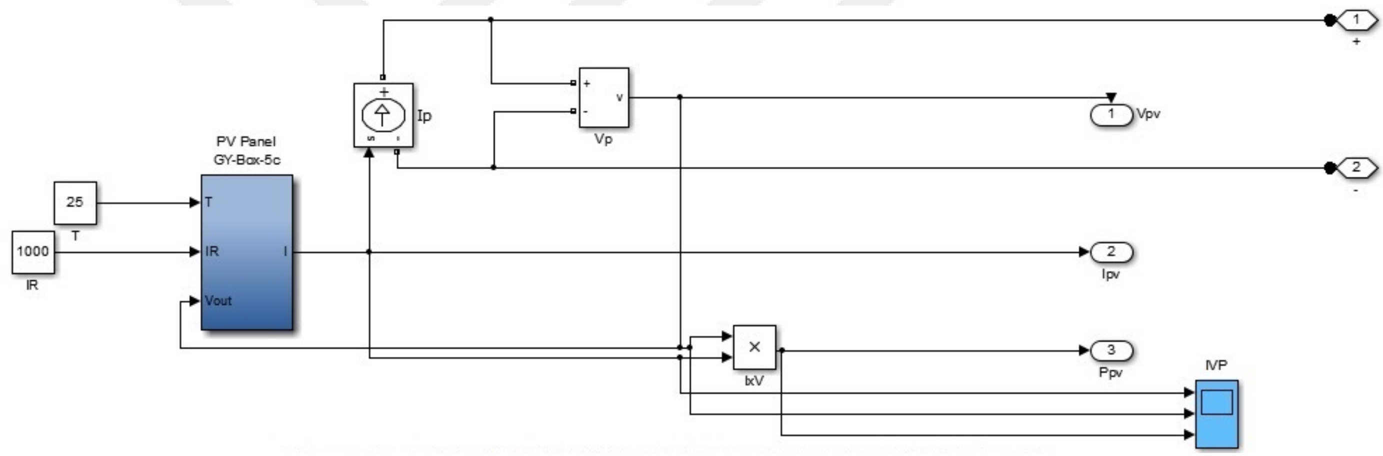

Figure 3.4 Simulink Model of Photovoltaic Panel GY-Box-5c

The photovoltaic panel model as in above figure further expand for better evaluation to understand the equations 2.4 through 2.9 involved in simulating. The expanded photovoltaic panels is shown in figure 3.5. The reference temperature and irradiance set according to the ideal situation of the panel's test conditions. The value of 'a' current temperature co-efficient ($\propto_0$=0.015) and 'b' voltage temperature co-efficient (β_0=-0.1) are kept constant.

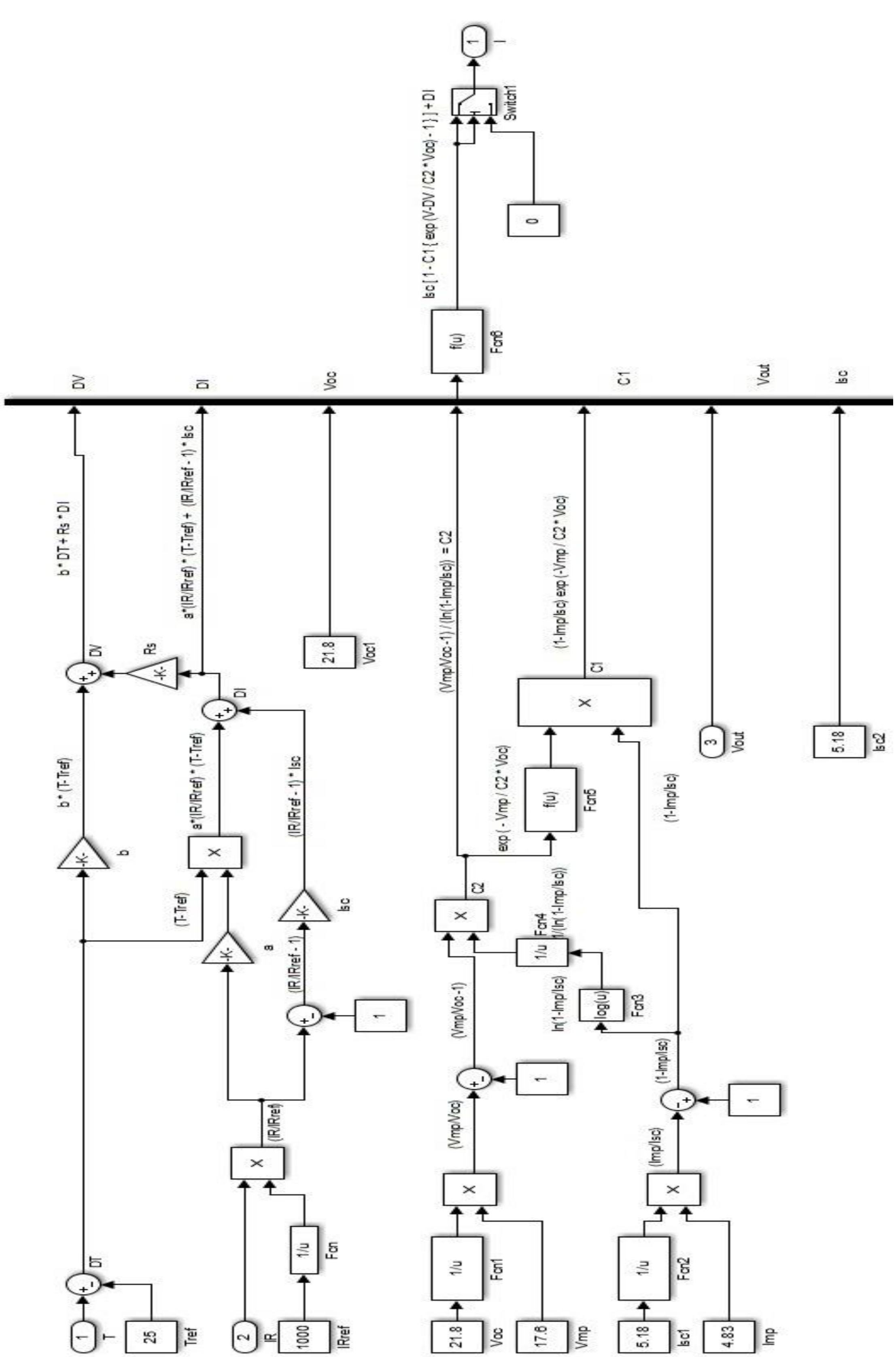

Figure 3.5 Simulink expanded model of Photovoltaic Panel GY-Box-5c

3.3.3 CHARACTERISTICS OF PHOTOVOLTAIC PANEL

The single solar cell produced less power, but when they combine in series or parallel combination for the attaining required amount of voltage and current then the effectiveness of output power of the module also increases. This amount of power useful and able to provide backup for home appliances, grid station feedback or other system etc. More number of cells in series result more output voltage but same current and similarly more number of cells in parallel increases the output current with the same output voltage. For better understanding the characteristics of photovoltaic panel in figure 3.6 represents the IV (Current vs Voltage) curve and PV (Power vs Voltage) curve at irradiance of about 900 W/m^2.

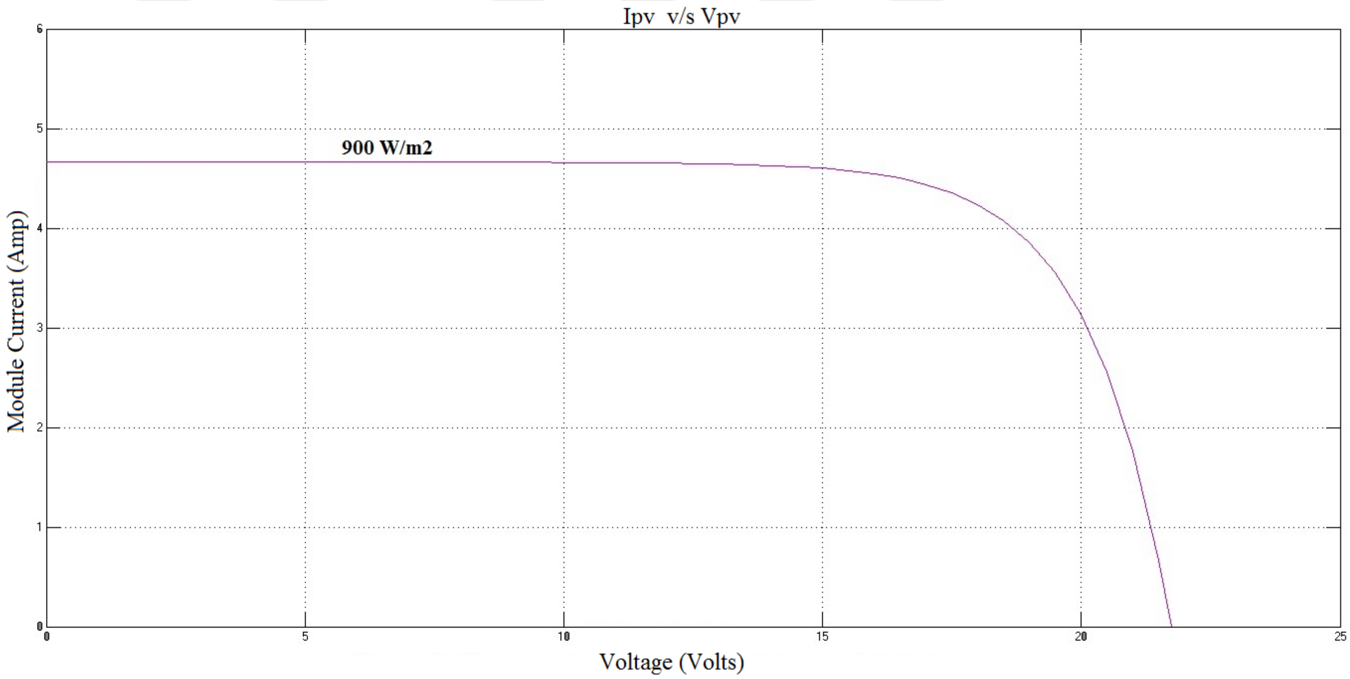

Figure 3.6 (a) IV characteristics of PV Solar System for 900 W/m^2

Initially the current is zero experiencing no load at the output of the panel. By the change in the interval of time the current going to reduce and reached at a position along voltage axis where the current of the panel becomes zero. At this point voltage is open circuit voltage as in figure 3.6 (a).

Figure 3.6 (b) represents the PV characteristics curve for the photovoltaic panel obtained at 900W/m^2.

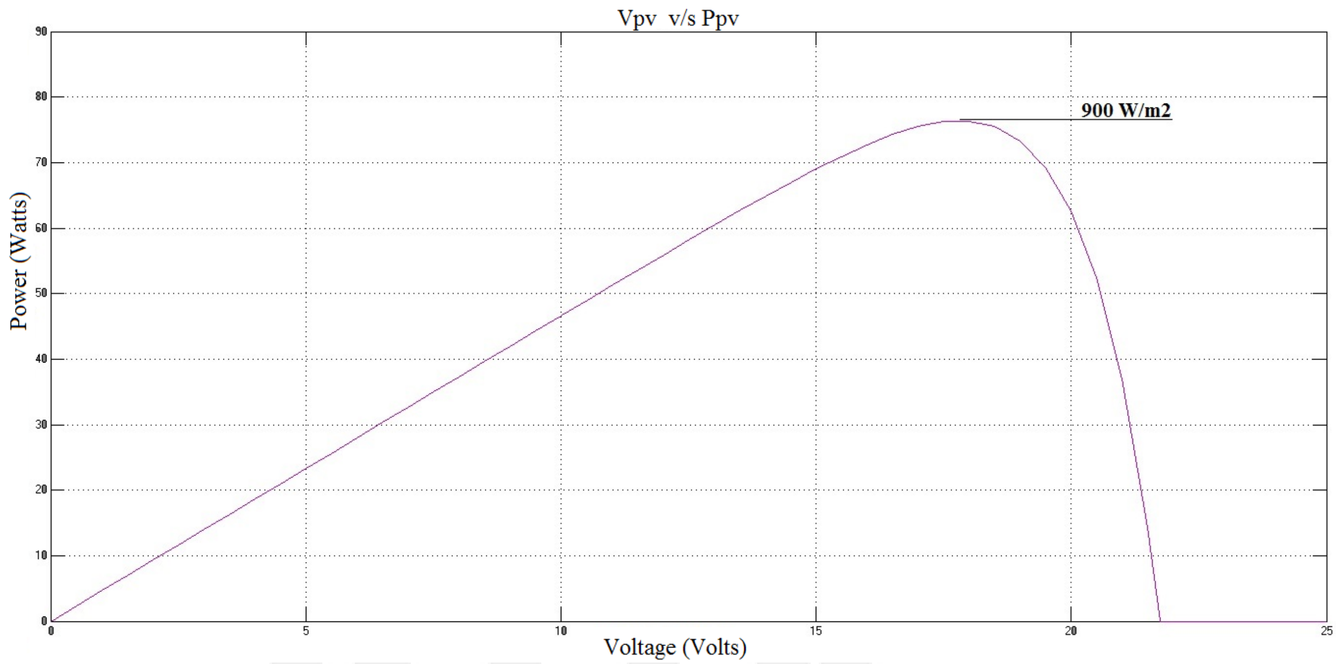

Figure 3.6 (b) PV characteristics of PV Solar System for 900 W/m^2

The voltage and power was zero initially but the amount of current was maximum. As long as the current going to reduced voltage increase and in the response of this power also increase. A moment where power reached at its maximum point of about 76.3W is the maximum power produced by the panel at 900 W/m^2. After this point, increase in voltage results decrease in current and finally a point is reached where voltage become open circuit voltage.

The variable irradiance levels between (500-1000 W/m^2) can obtained solar PV output power with fixed solar cell temperature of 25℃ as shown in table 3.4. The solar PV voltage and current varied corresponding to the solar irradiance as shown in figure 3.7.

Table 3.4 Output power for different operating conditions

#	Irradiance (W/m^2)	Output Power (W)
1	500	41.2
2	600	49.98
3	700	58.75
4	800	67.5
5	900	76.3
6	1000	85.1

The corresponding points in figure 3.7 (a) on voltage axis represent open circuit voltages at different irradiances where the current are zero and therefore this is the condition where PV panel operating at its open circuit voltage. Similarly on y-axis all the values when the current maximum and voltage become zero are the short circuit current values of the PV panel as discussed before.

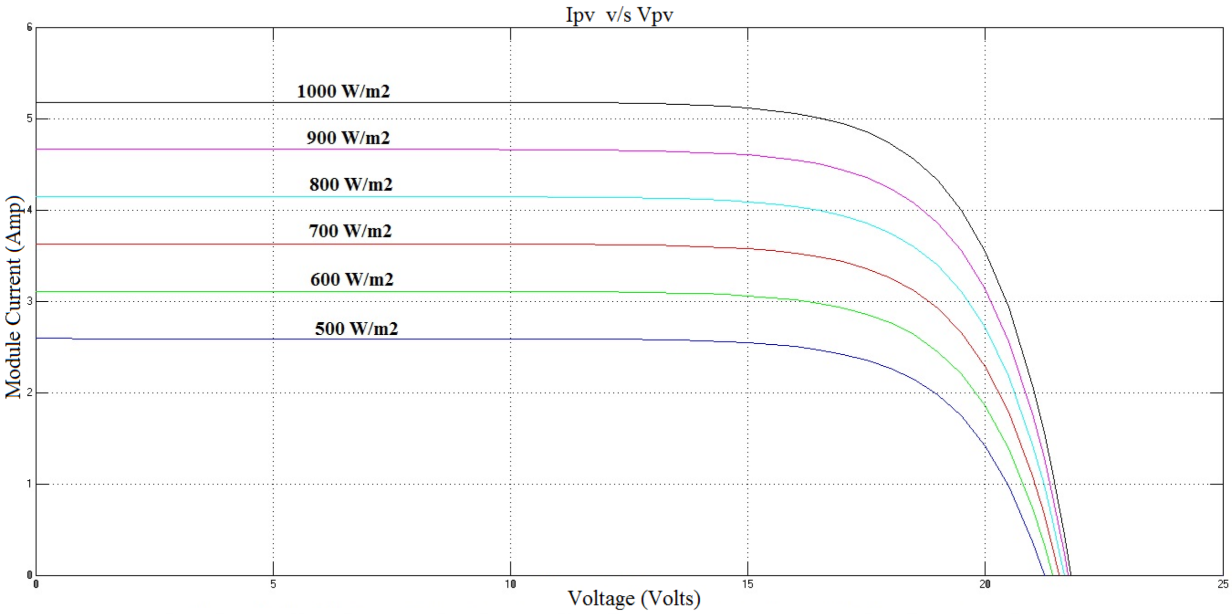

Figure 3.7 (a) IV characteristics of PV module-Multiple Irradiance-Fixed Temperature

The PV characteristics curves are obtained in the Matlab SimPower System is shown in figure 3.7 (b). Which signifies the maximum operating power for multiple irradiance.

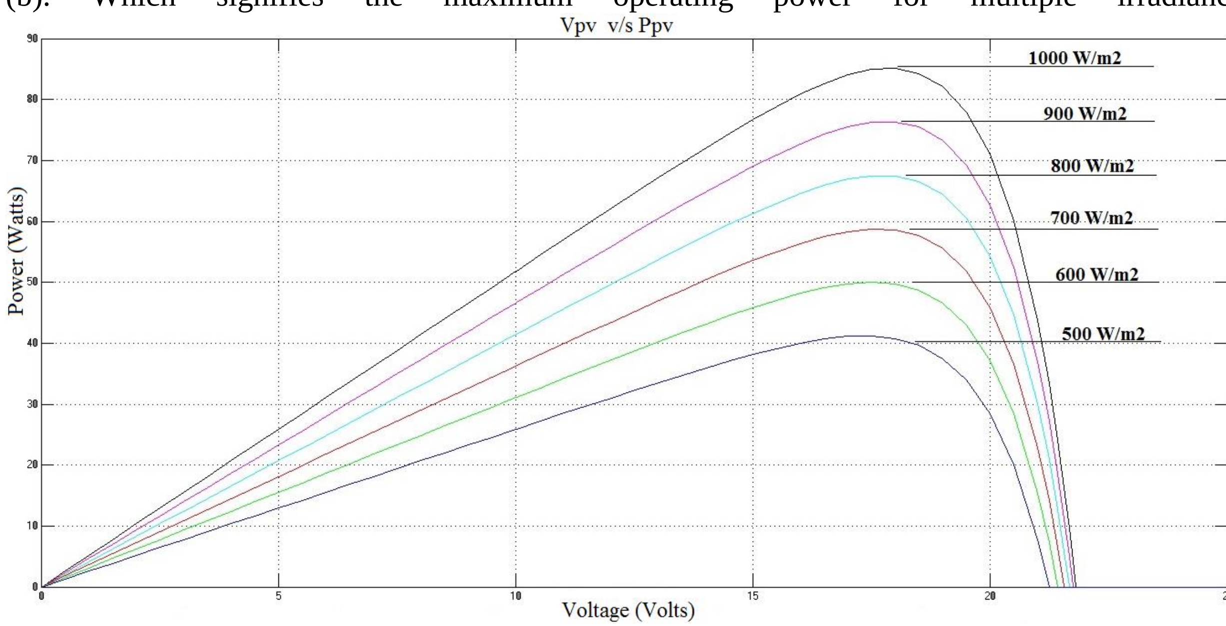

Figure 3.7 (b) PV characteristics of PV module-Multiple Irradiance-Fixed Temperature

3.4 SIMULATION OF INCREMENTAL CONDUCTANCE

The solar output voltage and current are measured and fed to the Incremental Conductance Method based MPPT controller for controlling and tracking maximum power. The Simulink model on incremental conductance used for this purpose is shown in figure 3.8.

Based on the change of power with respect to the change of voltage dP/dV and ΔdP/dV, incremental conductance determines the reference voltage from solar output system by modulating the duty cycle in buck boost converter. The size of increment or decrement detect how fast MPP is tracked. The fast tracking cause oscillations and also system may not operate at MPP. That is the reason it selected to be 0.001. The low pass filter are also used for the attenuation of the higher frequencies from the PV panel.

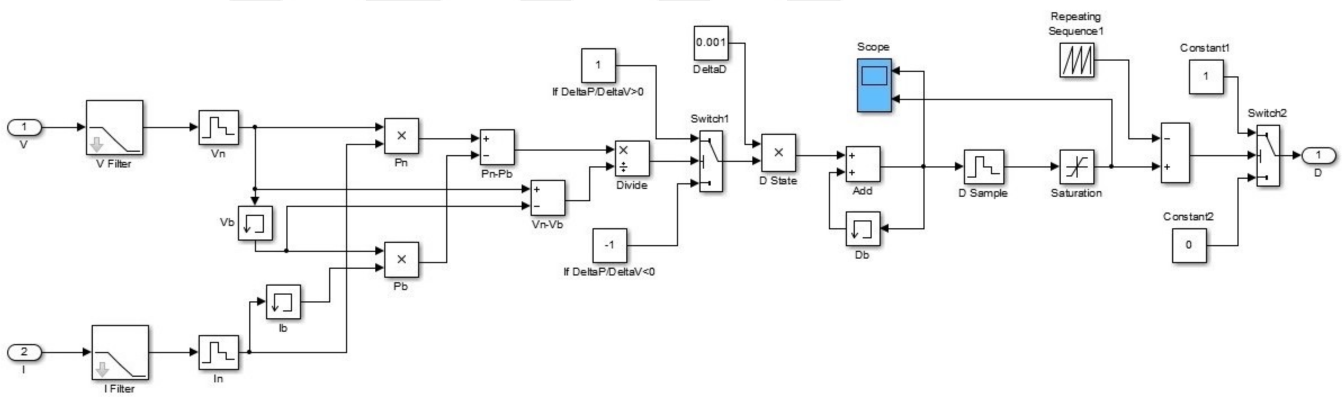

Figure 3.8 Simulink Model of Incremental Conductance

3.5 SIMULATION OF COMPLETE SYSTEM

The following figure 3.9 represents a complete Simulink system of PV Solar System. The Powergui block is graphical user interface for the analysis of currents and voltages of circuits or systems. For the accuracy of the result continuous simulation is selected. The integration algorithm estimate the step size and then calculate the result.

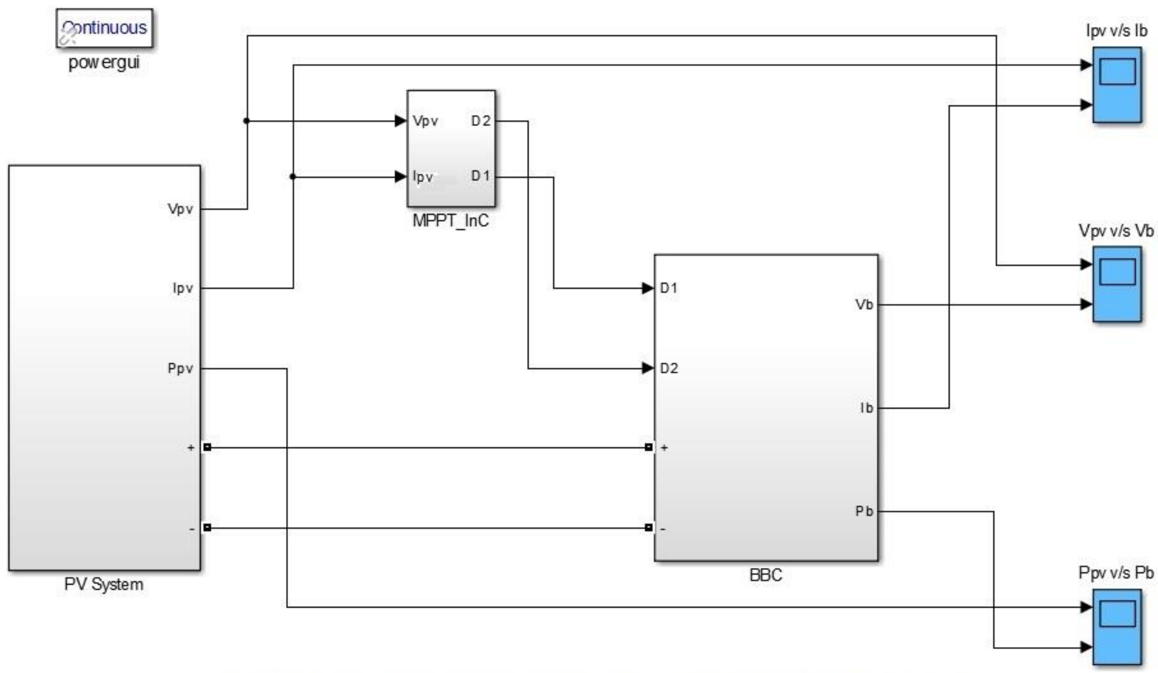

Figure 3.9 Simulink Model of Complete Photovoltaic Solar System

The complete system consist of the above main three parts. The PV System includes PV panel and the output voltage and current from the PV panel directed to MPPT_InC block to calculate and obtained duty cycle for switching of MOSFETs turn on and off. The PV panel also provide voltage to the input of the converter. The comparison between PV panel and buck boost converter can evaluate with the help of currents, voltages and powers through oscilloscope.

CHAPTER-4

SIMULATION RESULTS

In this chapter simulation results will present for better understanding. The complete system makes it possible to implement these parameters for experiment and also production of electricity. Three types of solar irradiance applied at the input of the PV panel. These irradiance placed with the corresponding outputs of the panel and converter to illustrate the differences. Also the output ripple from the converter controlled and it will compare with the uncontrolled output ripple in this section. The values for the irradiance set up to the time of 0.01 second. While the whole system simulate for 0.05 seconds.

4.1 RESULTS WITH CONSTANT IRRADIANCE

A constant irradiance of 1000 W/m^2applied to find the output parameters from the PV solar panel and buck boost dc-dc converter for comparing.

4.1.1 OUTPUT VOLTAGE WITH CONSTANT IRRADIANCE

Figure 4.1 (a) represents the output voltages of the PV panel V_{pv} and buck boost dc-dc converter V_b. As in figure V_{pv} has a distortion and then it linearly stable after about 5ms with ripple voltage of 4V. While the converter efficiently limit the initial distortion and also decreases the range of ripple voltage of V_b.

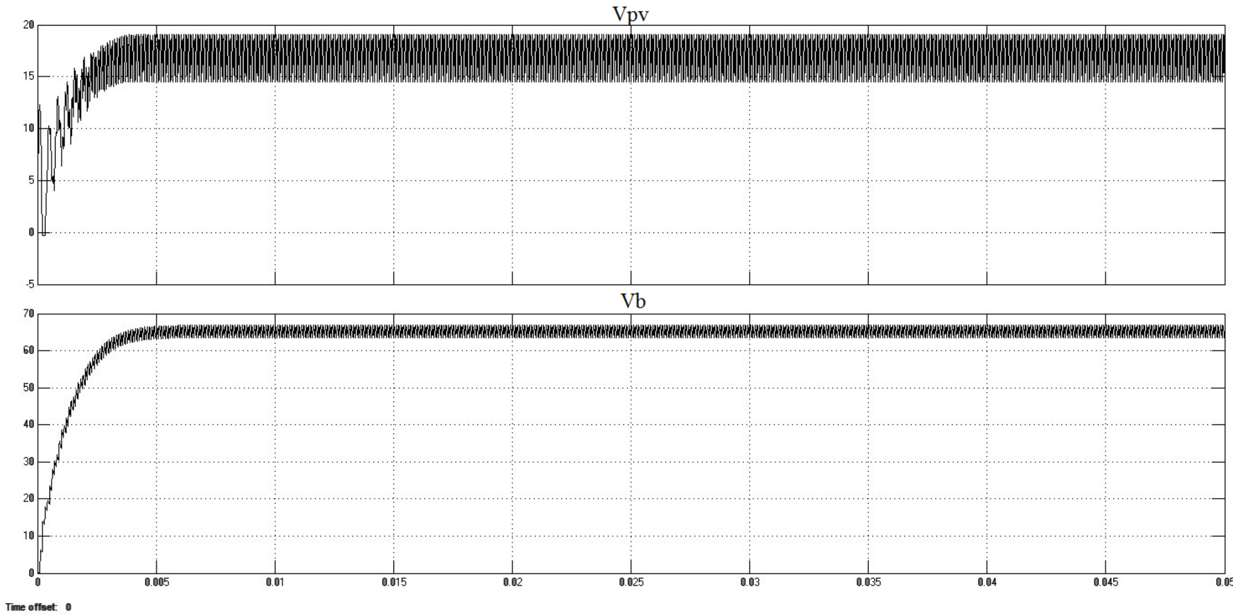

Figure 4.1 (a) Comparison between the Output Voltages with Constant Irradiance

4.1.2 OUTPUT CURRENT WITH CONSTANT IRRADIANCE

The panel current begins with the I_{sc} and as long as the voltage increases the current I_{pv} reduces between 4.27A to 5.1A. In the mean while the current I_b of buck boost converter linearly increases with some ripples and stable after the same time of 5ms at about 1.1A as depicted in figure 4.1 (b).

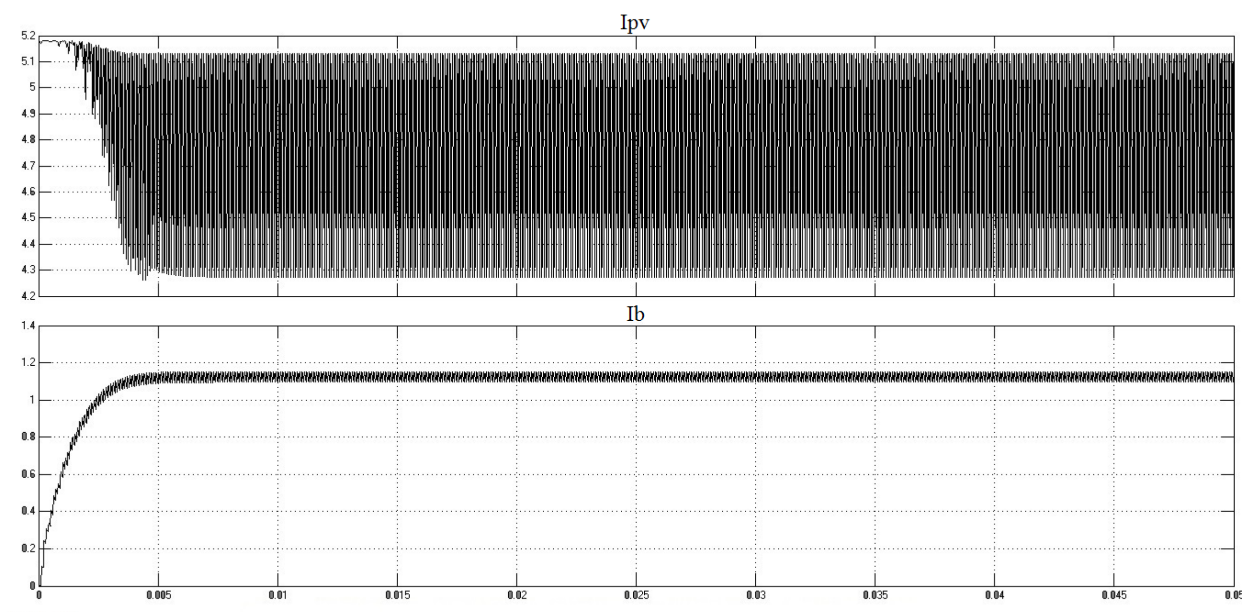

Figure 4.1 (b) Comparison between the Output Currents with Constant Irradiance

4.1.3 OUTPUT POWER WITH CONSTANT IRRADIANCE

The output power depends on the output voltage and current, so output power P_b of converter also affected by the product of I_b and V_b. The resultant $P_b$is noise less and also become constant after about 5ms. The maximum power produce by converter is shown in figure 4.1 (c).

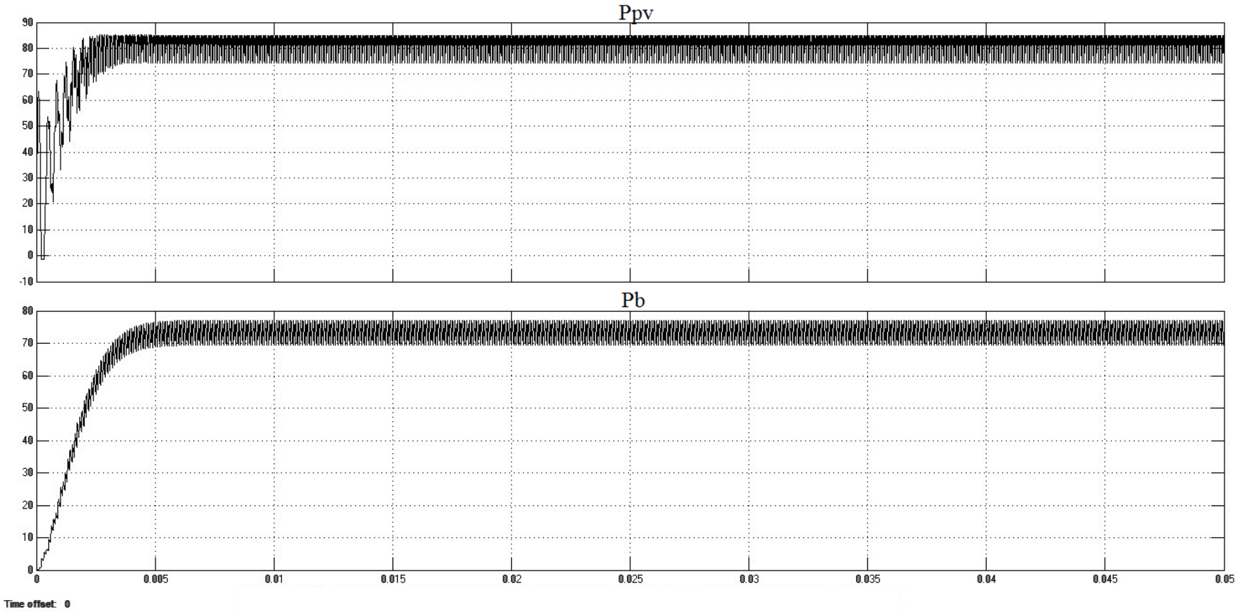

Figure 4.1 (c) Comparison between the Output Powers with Constant Irradiance

4.2 RESULTS WITH VARIABLE IRRADIANCE

The variable irradiance signal variates between 750 W/m^2 to 1000 W/m^2. Initially it starts from the 900 W/m^2 for 3ms and then decreasing linearly within 1ms to 750 W/m^2. After running for 2ms it deviates to 1000 W/m^2 as shown in figure 4.2 (a).

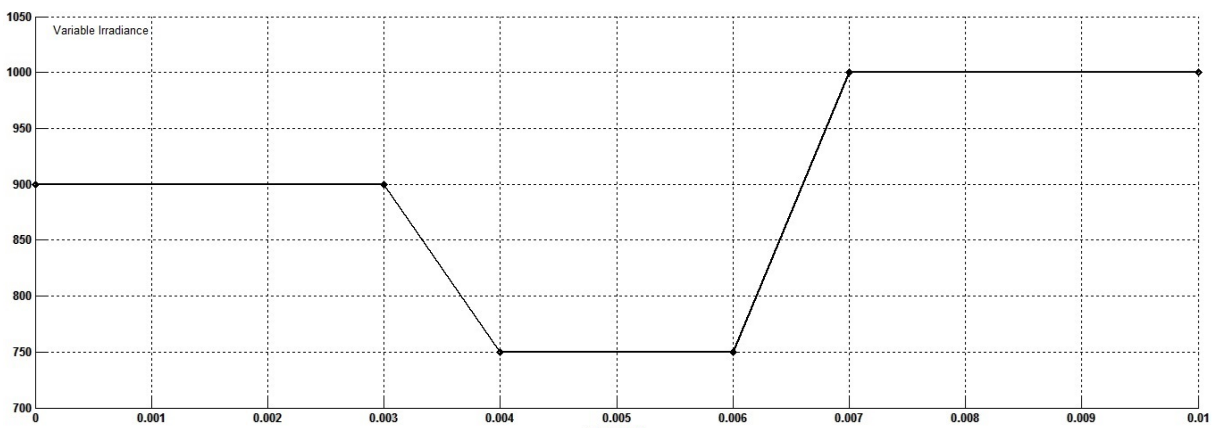

Figure 4.2 (a) Variable Irradiance

4.2.1 OUTPUT VOLTAGE WITH VARIABLE IRRADIANCE

As the duration of variable irradiance is 0.01s, then it is better to consider the duration of output voltages before 0.01s. Because after this interval voltages becomes constant due to irradiance. In figure 4.2 (b) output voltages increase with the amount of irradiance applied. At 3ms V_{pv} and $V_b$starting decrease. V_{pv} becomes completely horizontal between the duration of 4ms to 6ms, but the $V_b$reduces slowly. And just after the switching of irradiance towards 1000 W/m^2at 6ms voltages increasing and retain its position.

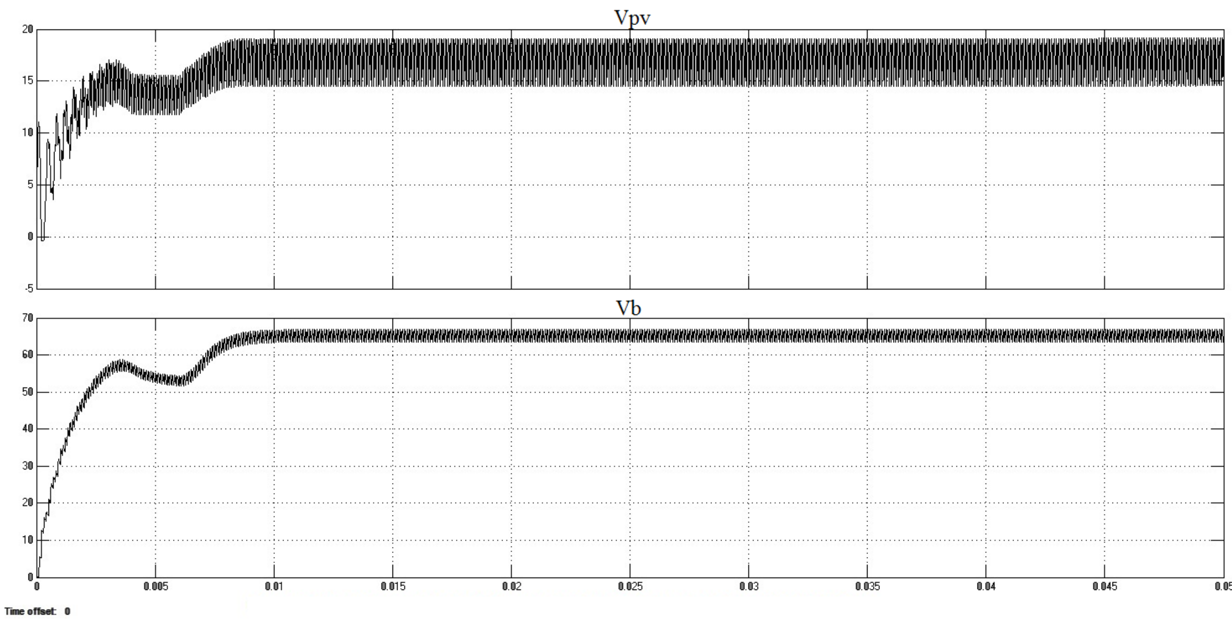

Figure 4.2 (b) Comparison between the Output Voltages with Variable Irradiance

4.2.2 OUTPUT CURRENT WITH VARIABLE IRRADIANCE

I_{pv} has a wide range of variation similar to the applied irradiance. While I_b reaches maximum current at 3ms and decreases to some extent during 3 to 6ms as shown in figure 4.2 (c). Then irradiance becomes 1000 W/m^2 after 7ms and also the goes constant at about 1.1A with low ripples.

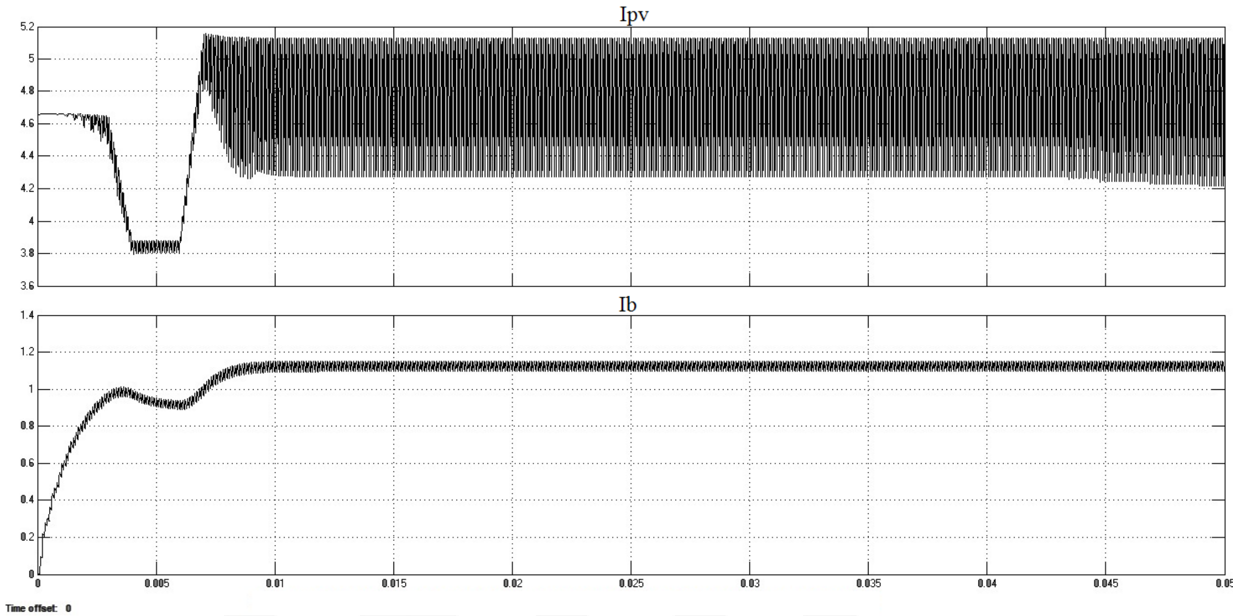

Figure 4.2 (c) Comparison between the Output Currents with Variable Irradiance

4.2.3 OUTPUT POWER WITH VARIABLE IRRADIANCE

The efficiency of the converter can easily understand here, when the panel power decreases and becomes constant at that moment P_b also decreases but linearly and did not go constant during the interval 4ms to 6ms. And it suddenly reacts when P_{pv} increases with the increase in irradiance as in figure 4.2 (d).

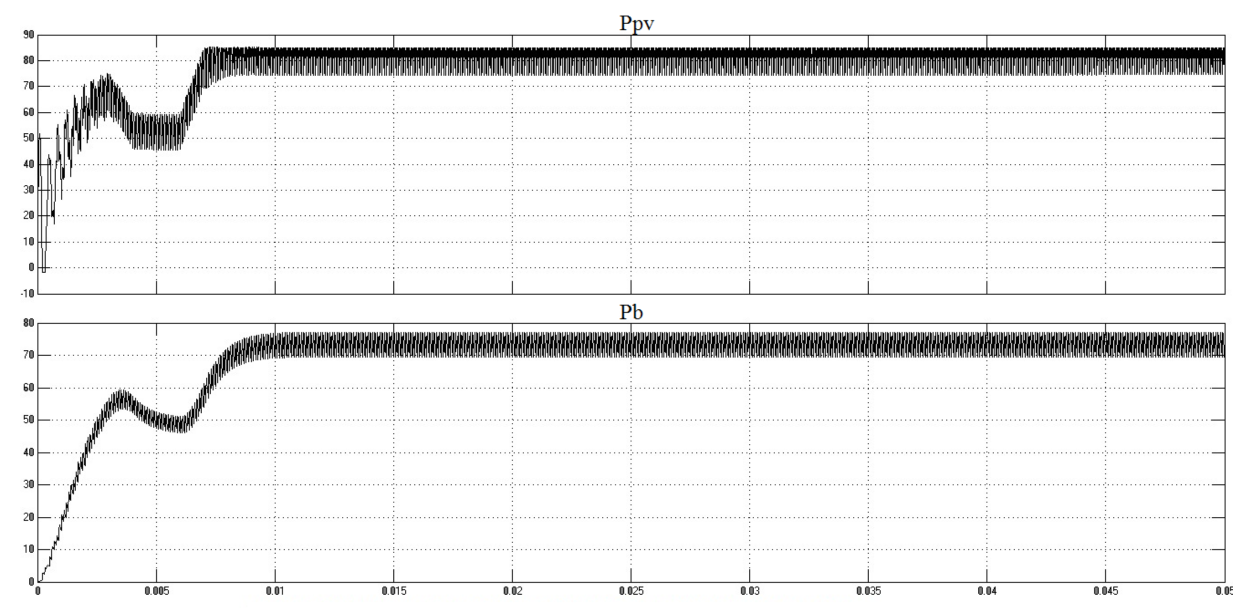

Figure 4.2 (d) Comparison between the Output Powers with Variable Irradiance

4.3 RESULTS WITH STEP VARIABLE IRRADIANCE

The step variable irradiance introduced to get the more specific results. The reason for this irradiance is to examine the effect of sudden change in P_{pv}. The signal vary between 700 W/m^2 to 1000 W/m^2. Initially it starts from the 900 W/m^2 for 2ms and then decreasing immediately to 800 W/m^2. After running for 2ms it again goes down to 700 W/m^2 and then deviates to 1000 W/m^2 as shown in figure 4.3 (a).

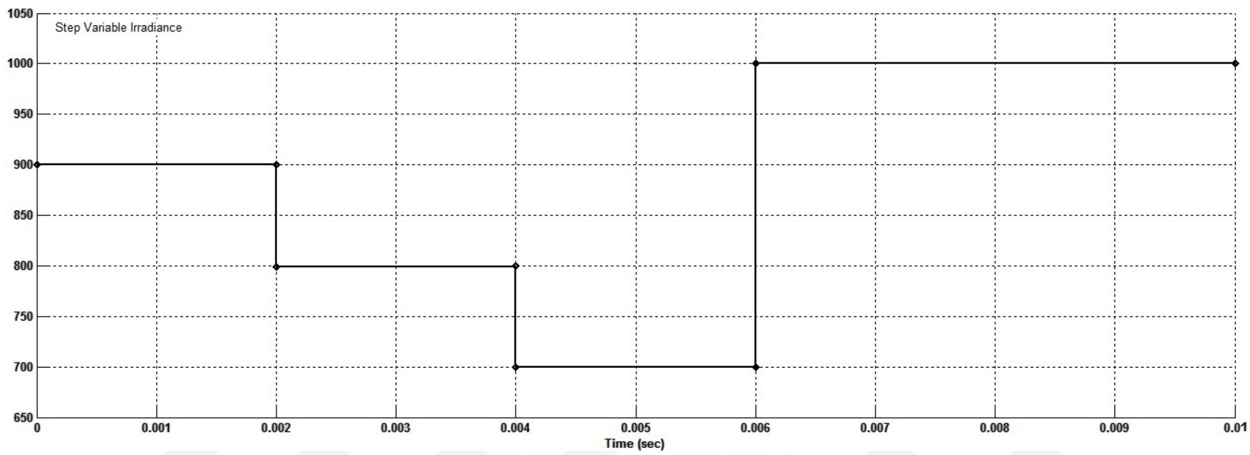

Figure 4.3 (a) Step Variable Irradiance

4.3.1 OUTPUT VOLTAGE WITH STEP VARIABLE IRRADIANCE

The change in V_{pv} corresponds to the change in V_b. There are 3 points which are important for consideration. Initially at 900 W/m^2 V_b increases linearly and reach up to 50V. At the time of 2ms when the irradiation decreases to 800 W/m^2, V_b maintain to increase. After a point at 4ms there is decrement of about 2ms and V_b goes below 50V. Finally an increase in irradiance again put the converter voltage constant as shown in figure 4.3 (b).

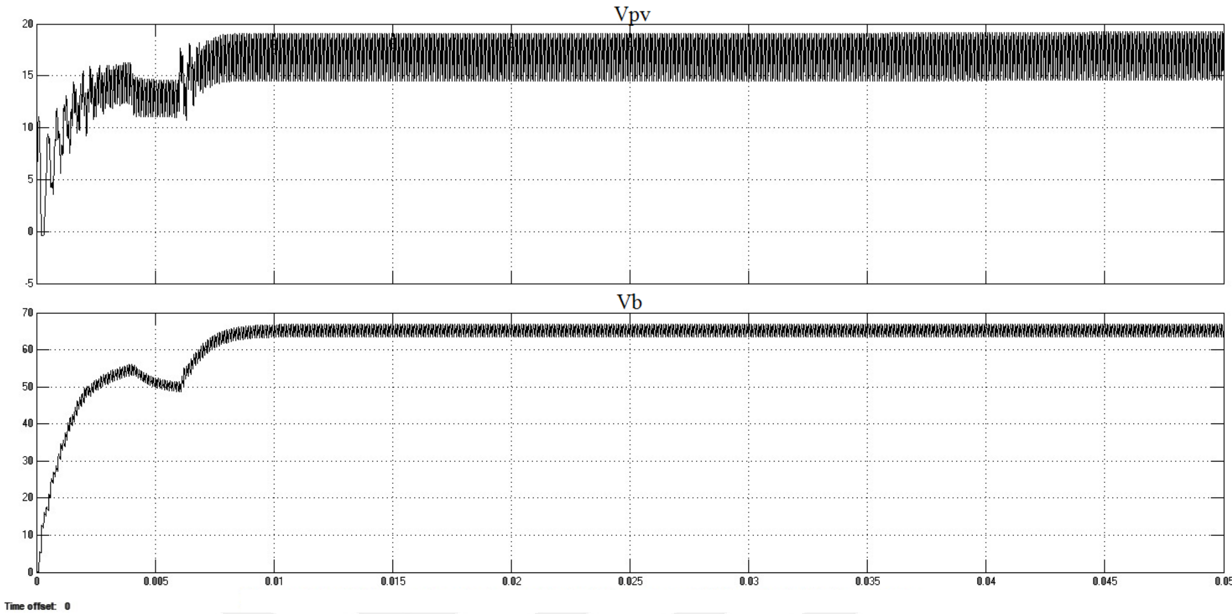

Figure 4.3 (b) Comparison between the Output Voltages with Step Variable Irradiance

4.3.2 OUTPUT CURRENT WITH STEP VARIABLE IRRADIANCE

The comparison between I_{pv} and I_b can easily understand by considering the following figure. I_b looks like the same as V_b in shape and not suddenly increase or decrease due to the input current of panel.

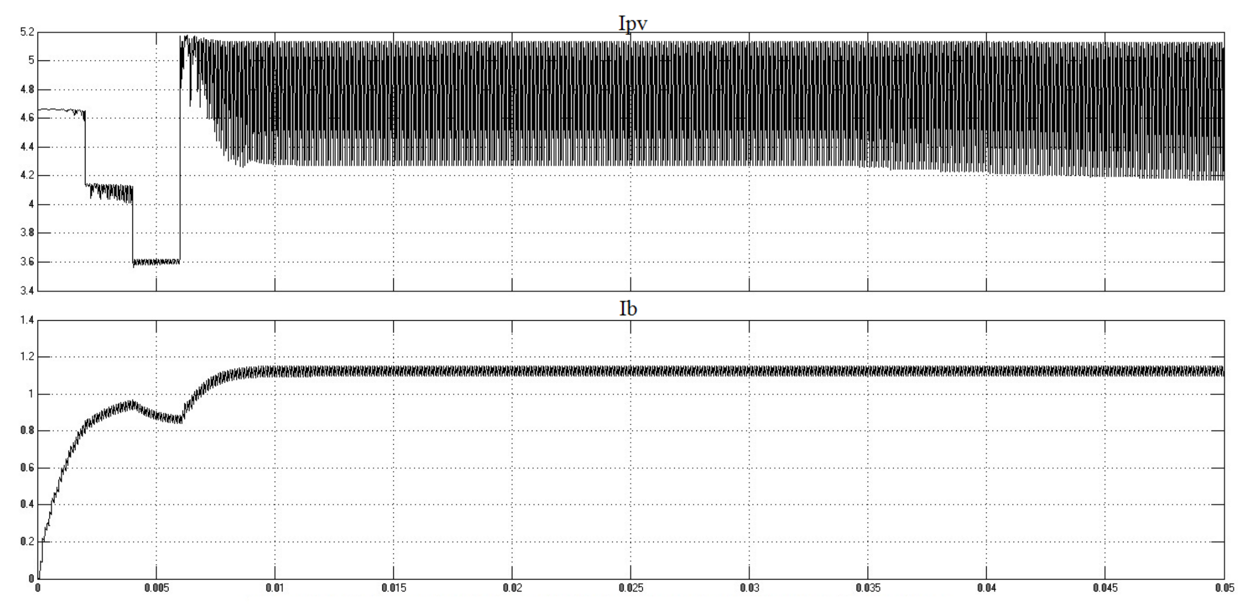

Figure 4.3 (c) Comparison between the Output Currents with Step Variable Irradiance

4.3.3 OUTPUT POWER WITH STEP VARIABLE IRRADIANCE

The power is the resultant product of current and voltage. So P_b also has the same response with respect to the $V_b$and I_b, but the sudden effect of step irradiance has not the same effect on P_b and converter maintain to overcome P_b decrease linearly as in figure 4.3 (d).

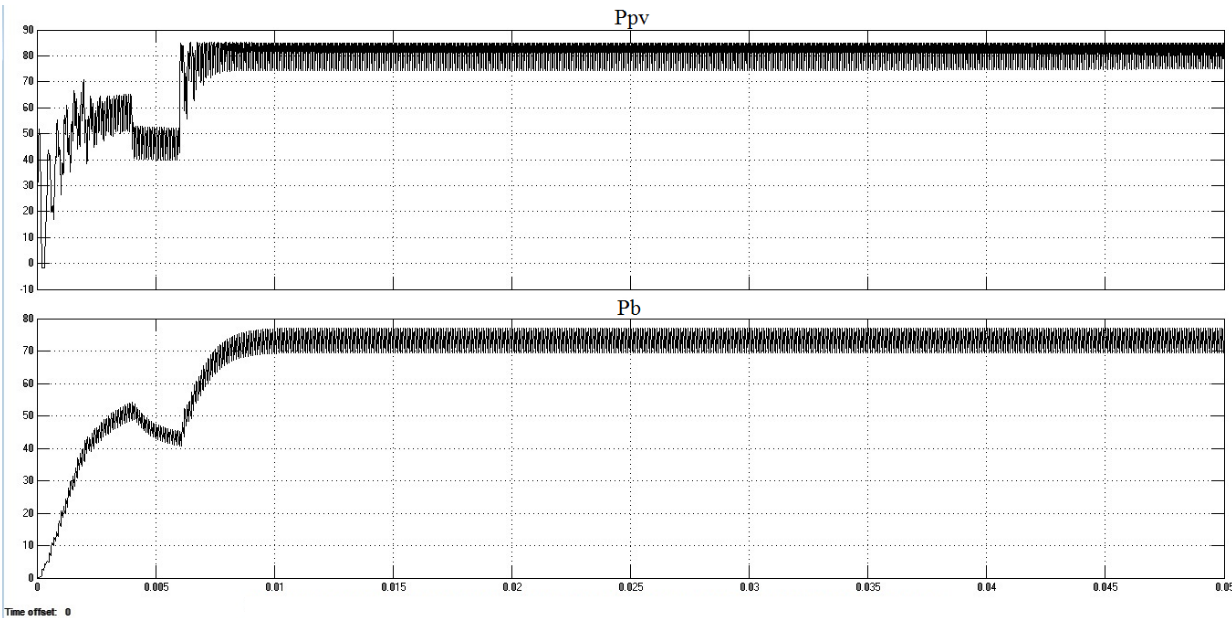

Figure 4.3 (d) Comparison between the Output Powers with Step Variable Irradiance

4.4 RESULTS FOR COMPARISON OF RIPPLE WITH CONSTANT IRRADIANCE

A constant irradiance of figure 4.1 (a) applied at the input of PV panel with different capacitor value for controlling the peak-to-peak output ripple voltage. Previously used value for the results produce of figure 4.1 (b) was at 5% of $\Delta V_{OUT}/V_{OUT}$. In this section to overcome ripple voltage, 1% of $\Delta V_{OUT}/V_{OUT}$ used as in table 4.1.

Table 4.1 Comparison between Output Ripple Voltage

ΔV_{OUT} $/V_{OUT}$	Capacitor uF	Calculated Result (peak-to-peak)	Simulink Result (peak-to-peak)	Error %
5%	25.8e-6	3.50V	3.39V	3.14
1%	1.30e-4	0.696V	0.685V	1.58

The output voltage, current and power obtained after the implementation of 1% of ripple voltage are shown in figure 4.4 (a-c). In the following V_{pv} and $V_b$took more time to reach a point where they become constant at about 25ms. The voltages produced by panel and converter are shown in figure 4.4 (a).

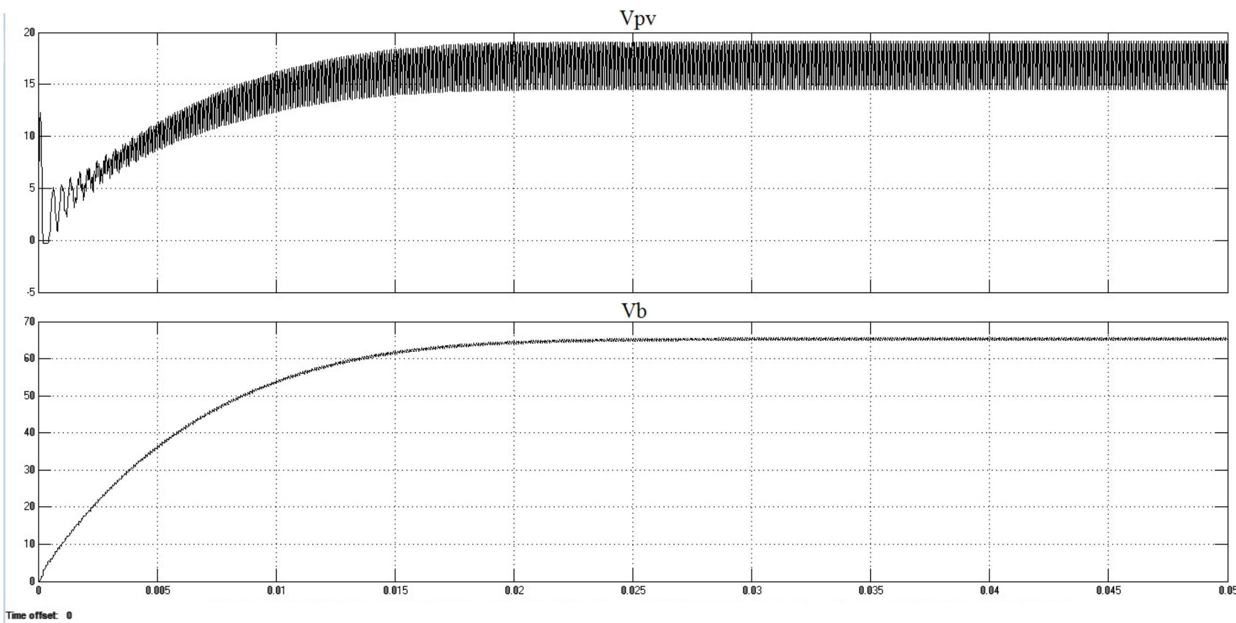

Figure 4.4 (a) Comparison between the Output Voltages with low ripple output voltage at Constant Irradiance

There is a same effect on I_{pv} and I_b as well. Initially the as the capacitor of the converter took more time for charging and limiting the ripples at output, in the meantime I_{pv} acts as a $I_{sc}$for about 7.5ms. Gradually the capacitor charged and provide voltage to the load. And at that time 25ms, I_{pv} and I_b become constant.

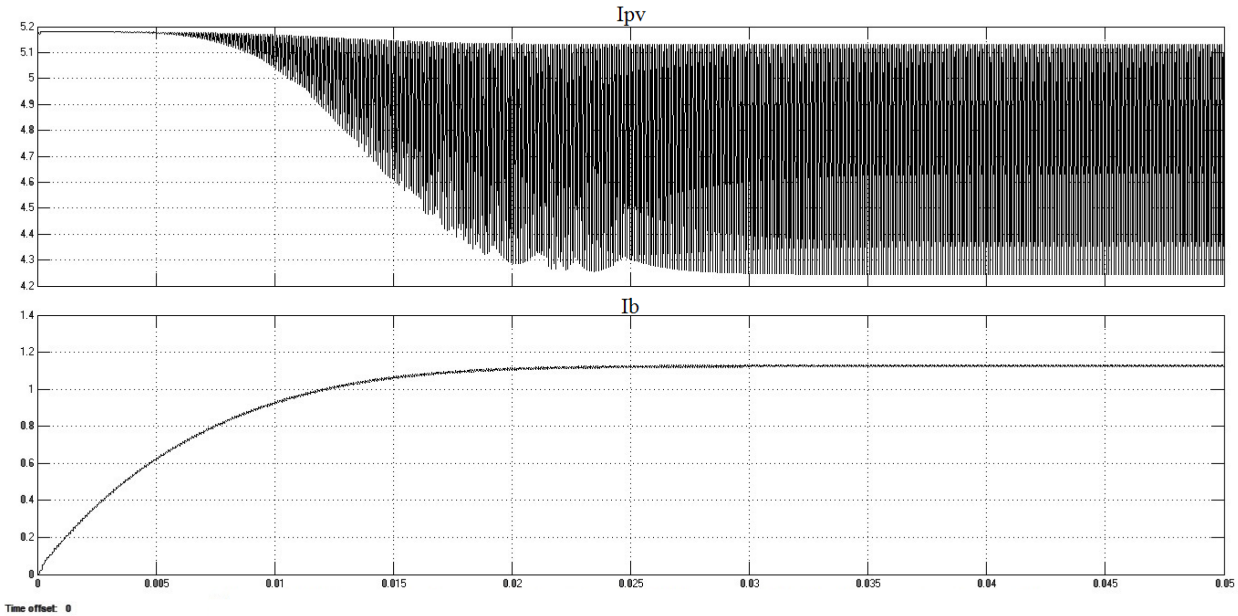

Figure 4.4 (b) Comparison between the Output Currents with low ripple output voltage at Constant Irradiance

As previously discussed power is the resultant product of current and voltage. And hence buck boost dc-dc converter provide power with low ripple value and without any distortion. Also figure 4.1 (d) and figure 4.4 (c) can compare for better understanding for the output powers with constant irradiance.

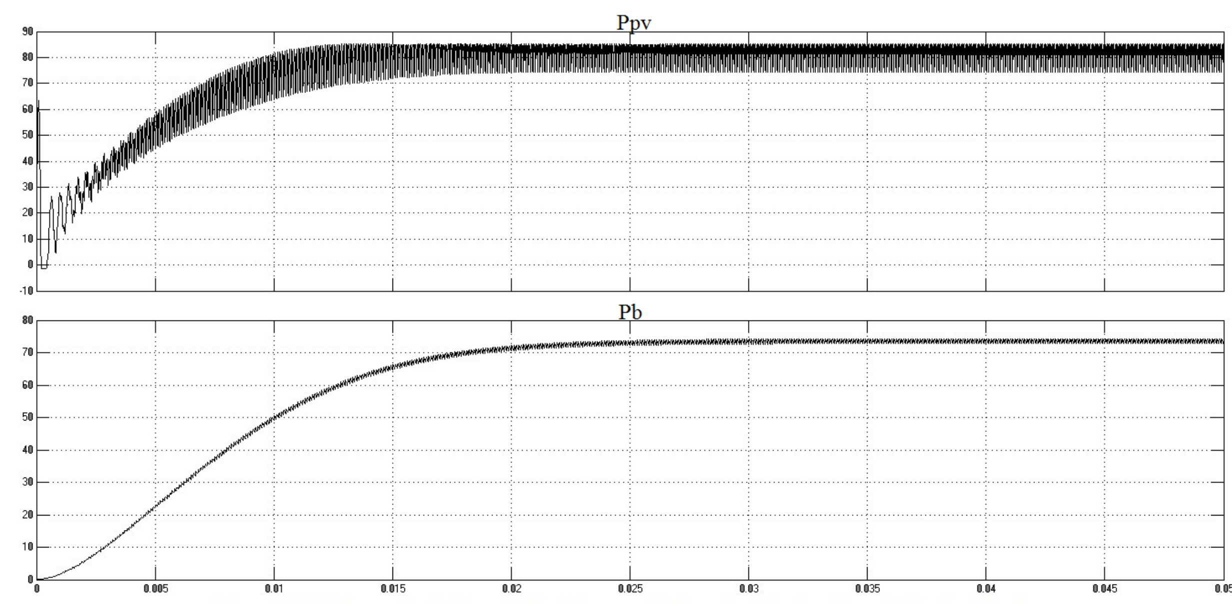

Figure 4.4 (c) Comparison between the Output Powers with low ripple output voltage at Constant Irradiance

CHAPTER-5

EXPERIMENTAL SETUP

The setup for the implementation of the buck boost converter consist of a

- Solar Photovoltaic Panel
- Transformer (as an inductor)
- Buck Boost dc-dc Converter with a resistive load

5.1 SOLAR PHOTOVOLTAIC PANEL

The practical of the buck boost dc-dc converter did by using several components. The main component involved in experimental process is solar panel GY-Box-5c available in the laboratory with the same specifications which was discussed briefly before and is shown in the figure 5.1. The panel placed at an angle of 35^o against the ground. Two wires from the solar panel connected directly at the input of the buck boost converter.

Maximum Power (Pmax)	85 Wp
Voltage at Maximum Power (Vmpp)	17.6 V
Current at Maximum Power (Impp)	4.83 A
Open Circuit Voltage (Voc)	21.8 V
Short Circuit Current (Isc)	5.18 A
Panel Efficiency	13 %
Panel Dimension (H/W/D)	1210x540x28 mm
Weight	8.2 Kg
Glass Type	High Transmittance, Low Iron
Glass Thickness	3 mm
Frame Type	Anodized Aluminium Alloy

Figure 5.1 Representation of Solar Panel with its characteristics

5.2 TRANSFORMER AS AN INDUCTOR

The function of buck boost converter base on the configuration of the inductor. In the development of the converter, winding of the transformer used as an inductor. The setup for finding the inductance of a transformer is show in figure 5.2.

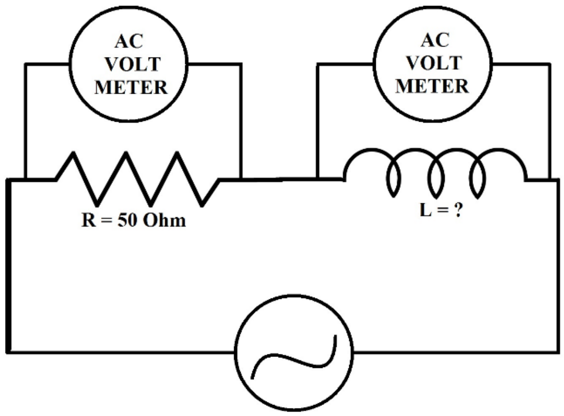

Figure 5.2 Arrangement for finding the inductance of transformer

The inductance of the primary winding of the available transformer calculated first by connecting the transformer in series with the resistor of about 56 Ohm similar with the signal generator output resistance of 50 Ohm as in figure 5.3. The ac volt meter connected across both the components. The applied sine wave frequency varied so that the voltage across both components become identical. This frequency is referred to as cutoff frequency. After reaching cutoff frequency the following equation used to find inductance of transformer's winding.

$$2 * \text{pi} * f * L = X_L \quad (6.1)$$

Where, f = cutoff frequency where voltage becomes same

L = inductance of the transformer

X_L = inductive reactance

The variation in the output current depends on the inductor value. Larger the value of inductor results low ripple value of current at the output.

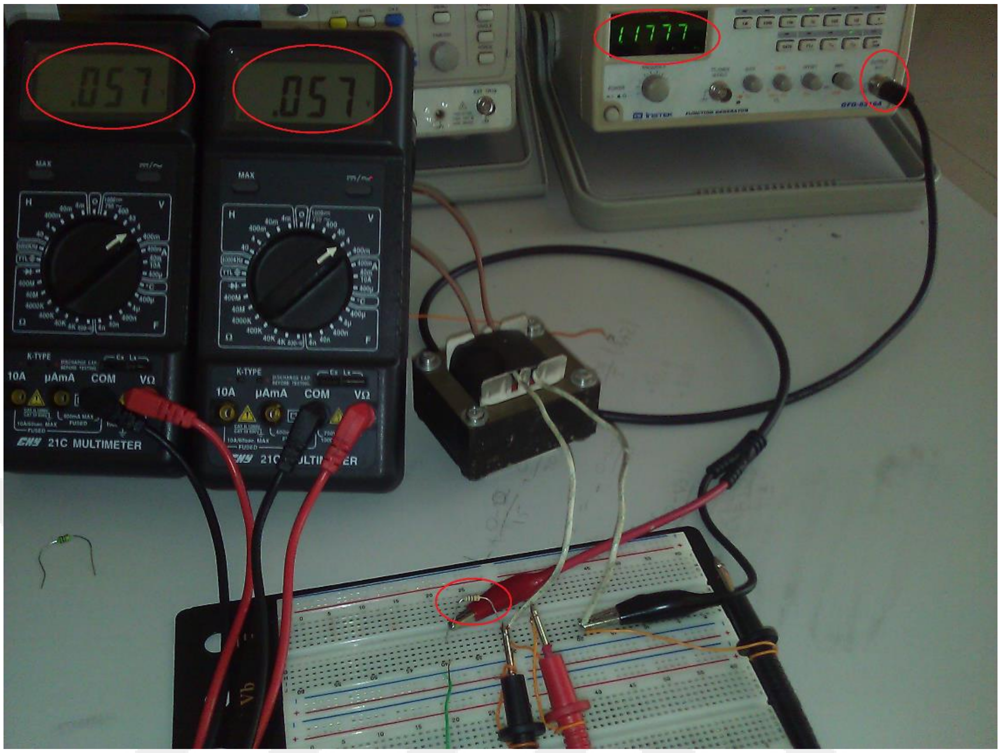

Figure 5.3 For finding the inductance of transformer https://youtu.be/HBpkXmHJC4I

5.3 BUCK BOOST DC-DC CONVERTER CIRCUIT

The interfacing between the solar panel and the resistive load carried out with the help of converter. The converter tends to protect the load at the output. The brief description of the converter explained in chapter 2. For the safe side and reliable operation MOSFET irf540n used for switching which has rating of minimal on resistance $R_{DS(on)}$ 44mOhm, V_{DSS} 100V and I_D 33A (http://www.irf.com/product-info/datasheets/data/irf540n.pdf). At the input of the converter a capacitor of 22uF/63V used which provide also filtering for the output of the solar panel. While at the output two capacitors of 47uF/63V (C_{eq}=94uF) connected in parallel with each other. These two capacitors help to reduce the amount of ripple to 0.03%. A low resistive load selected to obtain few tenth of current in milliamps. The transformer used in place of an inductor after the calculation of its inductance of about 7.29mH as shown in figure5.4. The function generator used for the switching of MOSFETs. The switching of transistors done synchronously with a frequency of 10kHz and duty cycle of 70%. Two diodes 1N4001 having forward voltage of 1.0 Volt also used to prevent from the inductor and output reverse current.

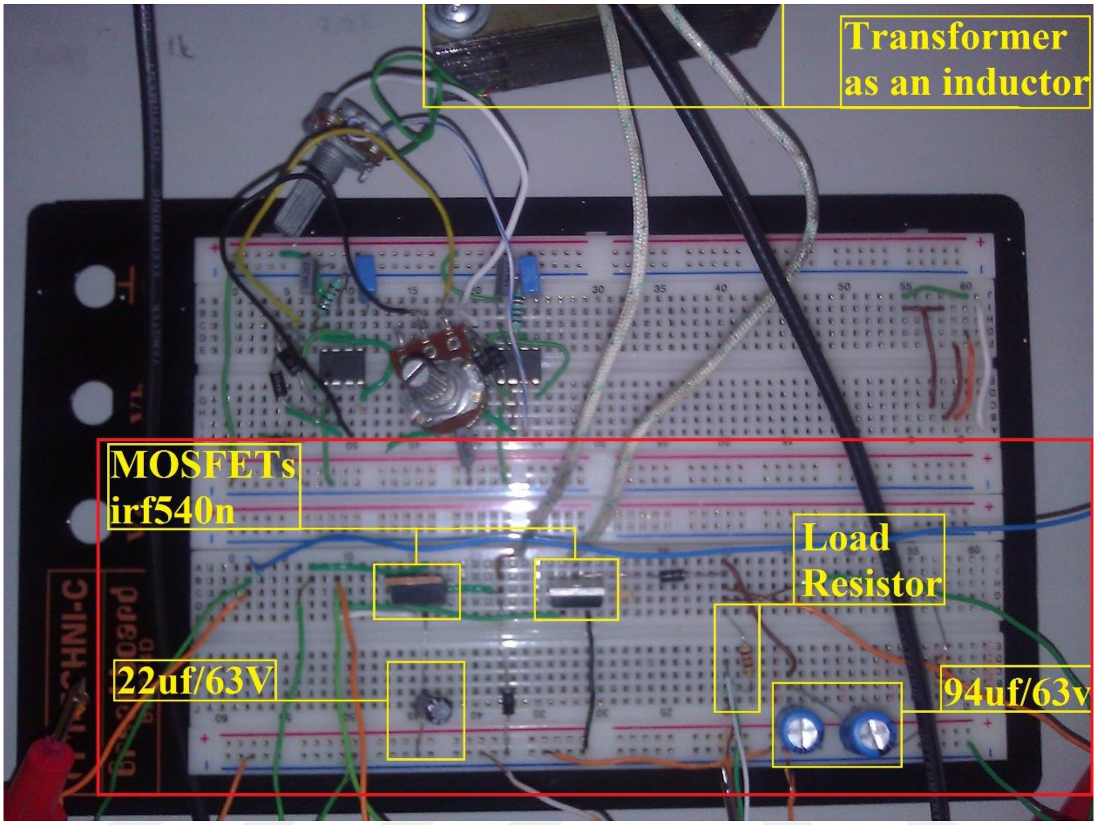

Figure 5.4 Buck-Boost Dc-Dc Converter Circuit

5.4 LABORATORY SETUP AND RESULTS

The photovoltaic solar placed at the same position as depicted in the first figure of this chapter. Two wires from the solar panel directed towards the input of the buck boost converter as shown in figure 5.5. The oscilloscope used to measure the output voltage and the applied frequency with its duty cycle. The square wave of about 10kHz with duty cycle began from 28% to 72% applied. The TTL CMOS output of the signal generator consider for the application at the gate of the MOSFETs. The output from the solar panel and buck boost dc-dc converter also measured by using multimeter. The voltages and current from the solar panel and converter are shown in the following figure.

At the time of implementation there was a variation in the incident sunlight and its intensity. The voltage measured from the solar panel is about 19.06 V and the current goes to the minimum range of 236.1 mA without mppt controller tracking. Similarly the set duty cycle allow the output of the converter to boost up to 38.24 V with a current of about 0.593 mA. The inductor is also responsible for the low current values. As long as the inductance value is larger the current value become lower.

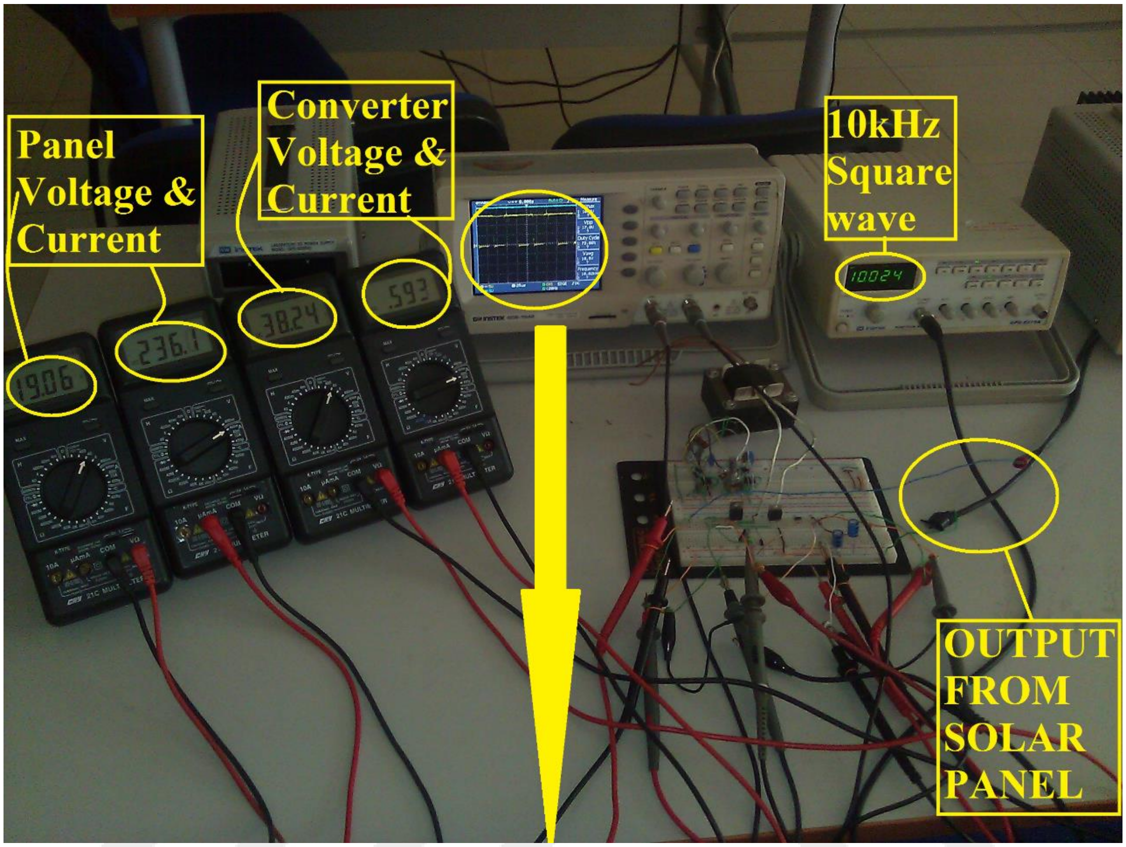

Figure 5.5 Complete Experimental Setup

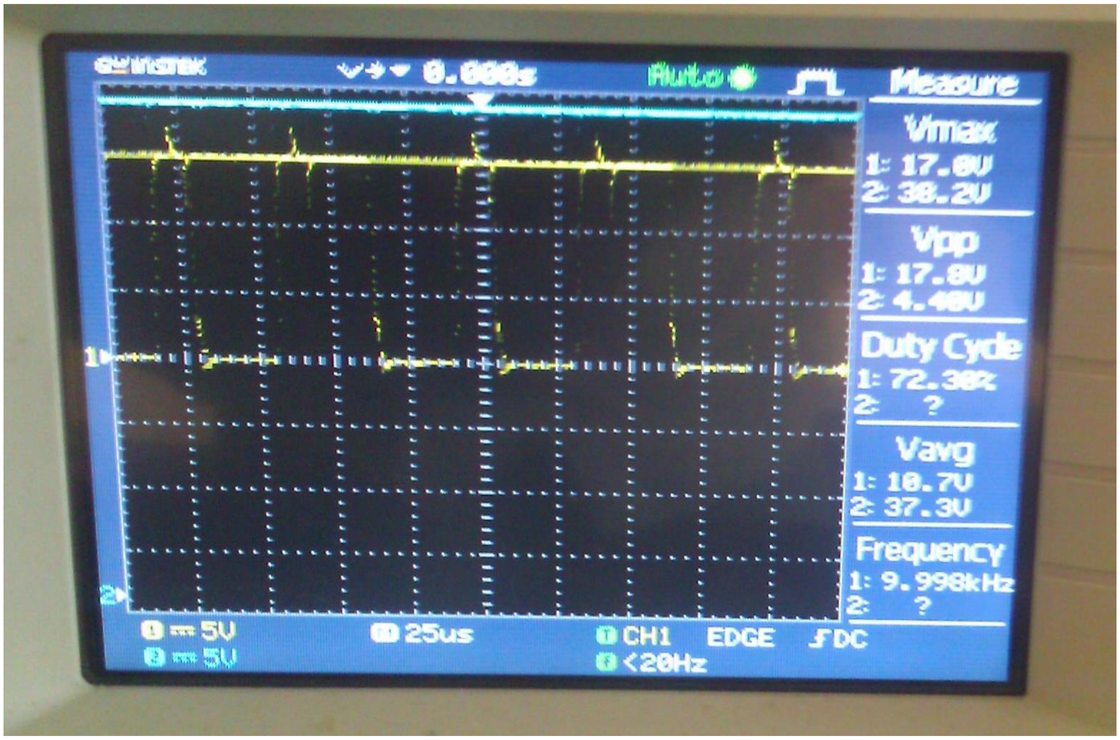

Figure 5.6 Switching frequency with duty cycle and Output Voltage

The graphical representation of the applied frequency and the output voltage are also shown in figure 5.6 for better understanding. The peak-to-peak gate pulse voltage sets to is maximum point on the signal generator using CMOS amplitude for better switching.

Figure 5.7 represents the effect of irradiation on the output of the solar panel. As the output voltage of panel reduced from 19.06 V to 15.84 V which results in the decrease of the output voltage of the converter from 38.24 V to 37.70 V. The percentage in variation of the output of panel voltage reached to 16% while this wide change affected the output of the converter by 1.4%.

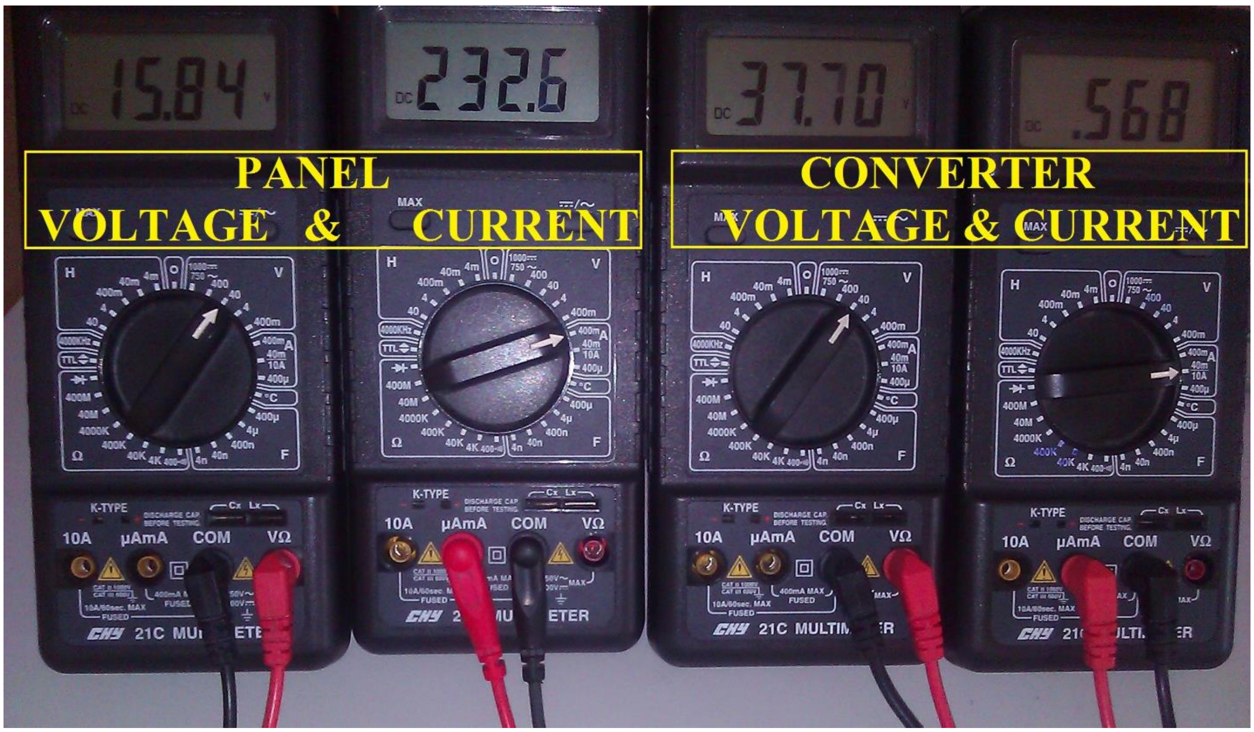

Figure 5.7 Variation in output due to irradiance

On the other hand the change in current produced by the panel was 3.5 mA and the change in converter current was 25 uA. As said before the small amount of current is due to the use of high inductance value.

In other case when the switching frequency of about 10kHz applied with a duty cycle of 50% as in figure 5.8 and the graphical representation in figure 5.9. The gate of the MOSFETs not open for the maximum period of time and hence the conduction time became less. The inductor store an amount of energy received at output was low corresponding to the previous case. Here the converter worked as a buck converter by producing an output less than the applied input.

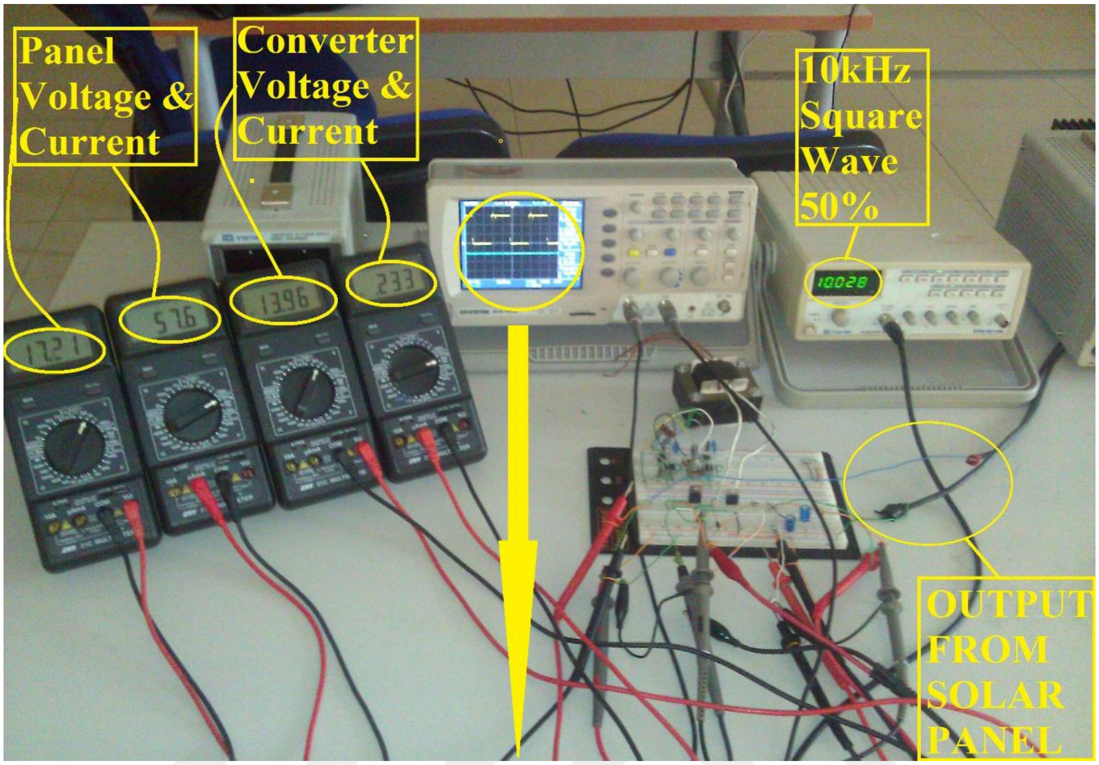

Figure 5.8 Output Voltage and Current with 50% duty cycle

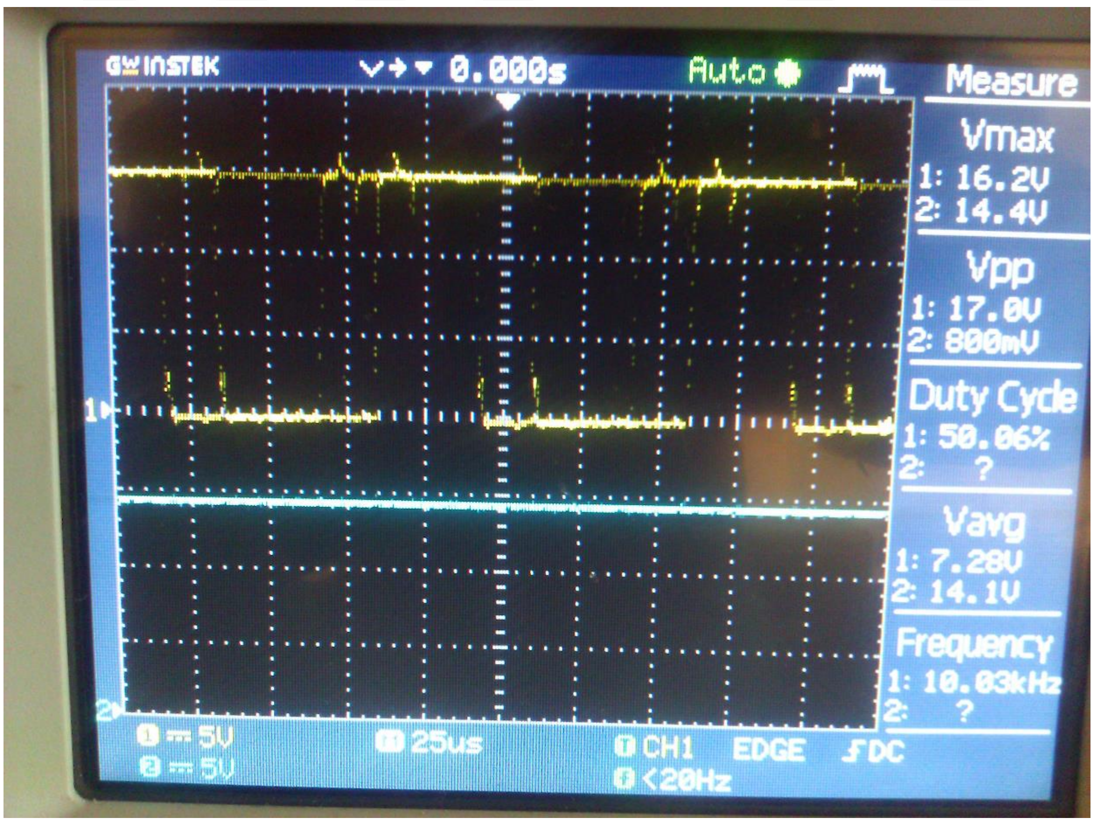

Figure 5.9 Graphical representation with 50% duty cycle

For the measurement of the current and voltage through transformer coil which performed a work in place of an inductor the voltmeter connected as shown in figure 5.10. The voltage across the winding of transformer found to be 0.16 V and the current through it about 1.986 mA. By means of it the resistance of the transformer can be calculated about 80 Ohm. This amount of resistance can vary with the applied input conditions. The results for the Simulink and Implementation without control algorithm with the same specification used in implementation are represent in table 5.1 with. In implementation the input voltage of the converter depends on the incident sunlight, while the transformer which worked as an inductor possess an ability to change the output current.

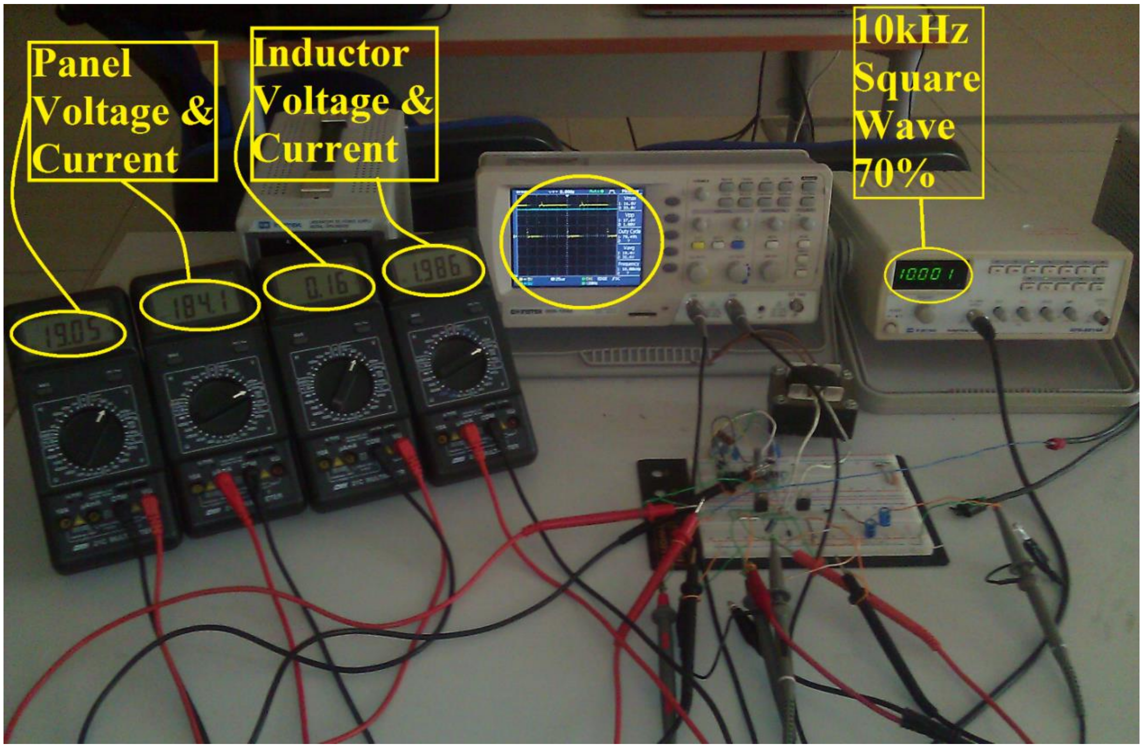

Figure 5.10 Voltage and Current of Solar Panel and Transformer

Table 5.1 Comparison between Simulink and Implementation			
Simulink Result		**Implementation Result**	
Input Voltage	21.7V	Input Voltage	19.06V
Output Voltage	45.8V	Output Voltage	38.24V
Input Current	0.221A	Input Current	0.236A
Output Current	20mA	Output Current	0.59mA
Average Inductor Current	0.13	Average Inductor Current	1.98mA

CHAPTER-6

SUMMARY OF THE THESIS

CONCLUSION

The world is surrounded by the bunch of technologies which require energy in the form of electricity. In this respect all the countries start working to make their future in the developing of the renewable energy resources. They are establishing wind energy and solar energy projects. In spite of wind energy project development, solar energy projects are easy to install and are not cost effective. In this thesis, a buck boost dc-dc converter is designed to implement with the photovoltaic panel using incremental conductance for controlling and tracking maximum power. The key aspects in designing of the converter is to make it more efficient. And allowing to work for a large bandwidth of different kinds of input signals.

For the simulation of the converter with a variety of input signals, a study of photovoltaic panel Guang Yue GY-Box-5c and its features was considered. The research papers examined for designing of a photovoltaic panels in MATLAB SimPower System. The simulation of the converter used with photovoltaic panel to find the maximum operating voltage, current and power under load condition for ideal condition. The IV and PV characteristics curve for single and multiple irradiance found using repeating sequence with controlled voltage source in SimPower System.

The comparative study of maximum power point tracking algorithm helps to find the Incremental Conductance Method as the best method for the controlling and tracking of the output power of the panel. This method also simulate using SimPower Blocks.

The results of simulation for the comparison between the panel output and converter output discussed to clarify the efficiency and response time of converter with its stability. The resultant output produced by the converter has some ripple values which were calculated and simulated. Then later, the idea for controlling the ripple value at the output of the converter with an error of 1.58 percent also presented and compared.

Finally the experiment of buck boost converter with the solar panel setup to scrutinize the effects of the solar panel output on the converter by applying pulses at the gate of the mosfet using signal generator. It has determined that the converter can work efficiently for a wide input range to produce distortion less output.

RECOMMENDATION FOR FUTURE WORKS

In many application there is a need of constant voltage and current produced with the help of an auto-regulated device. In case of photovoltaic systems the output voltage vary as per the incident radiant of sunlight, shading and temperature mainly. The lack of shading will result low output power causes the appliances to either damage or stop working. There should be a point in between a range of a bandwidth where the converter works and produces constant power at the output. No matter either the input current of the photovoltaic system fall down or raise, the converter able to work in steady state with the increment and decrement in duty cycle to provide constant output.

This may be done by using PID controller or to find the solution using advanced incremental conductance algorithm for its better efficiency and response time. In case of PID controller the output voltage of the converter feed backs to the to the controller section which can compare the output and then after computing generate duty cycle to either increase or decrease the ON-time of the switch. For advanced incremental conductance algorithm method there is a need to work in future.

On the other hand the practical implementation of the two switch buck boost dc-dc converter open a way to control it using different techniques. There are several different microcontrollers most likely to be pic16f87x series and Atmega168 because of their high clock frequencies which can provide control using incremental conductance method. As there is a need to control both the switches synchronously, other than the chances will increase for the variation in the result.

REFERENCES

[1] "Solar PV and Wind Energy Conversion System", An Introduction to Theory, Modelling with MATLAB / SIMULINK, and the Role of Soft Computing Techniques book by S. Sumathi, L. Ashok Kumar, P. Surekha, Springer.

[2] "Photovoltaic Design and Installation for Dummies" book by Ryan Mayfield, President. Renewable Energy Association.

[3] Solar timeline 1940's to present, Maryland Solar Solution Inc. http://www.marylandsolarsolutions.com/why-solar/what-is-solar.php

[4] A short history of Photovoltaic (PV) Cells, Schoolgen. http://www.schoolgen.co.nz/pdf/D2%20solar%20factsheet.pdf

[5] Standalone Solar System Senior Design Project, Research Thesis, Basel Dahleh, Fraz Ajmal, Hasnain Sarfraz, Mohammad Hassouna, American University in Dubai.

[6] A simplified Matlab based simulation of PV module with effect of temperature and irradiation, Kanchan Ghute and Vinay Kale, Research Paper, International Journal of Engineering and Technical Research (IJETR), ISSN: 2321-0869, Volume-2. Issue-4, April 2014.

[7] A proposed model of photovoltaic module in Matlab/Simulink for distance education, Zekiye Erdem and M. Bilgehan Erdem, Research Article, Procedia – Social and Behavioral Science 103 (2013) 55-62, ScienceDirect.

[8] A detailed modeling of photovoltaic module using MATLAB, Habbati Bellia, Ramdani Youcef and Moulay Fatima, Research Paper, National Research Institute of Astronomy and Geophysics, Algeria, April 2014.

[9] Comparison of MPPT Algorithms for the dc-dc converters based PV systems, A. Pradeep Kumar Yadav, S. Thirumaliah, G. Haritha, Research Paper, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 1, Issue 1, July 2012.

[10] Comparison study of maximum power point tracker techniques for PV systems, Hairul Nissah Zainuddin, Saad Mekhilef, Research Article, Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, December 19-21, 2010, Paper ID 278.

[11] Comparative study of P&O and InC MPPT Algorithms, I. William Christopher and Dr. R. Ramesh, Research Paper, American Journal of Engineering Research (AJER), e-ISSN: 2320-0847 p-ISSN : 2320-0936, Volume-02, Issue-12, pp-402-408, 2013.

[12] The isolated buck boost dc to dc converter with high efficiency for higher input voltages, Satish. Bandaru, R. Suresh, Research Paper, IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), Nov.-Dec. 2013.

[13] Design tips for an efficient non-inverting buck-boost converter, Haifeng Fan, System Engineer, Power Management, Article, Texas Instrument, Analog Application Journal.

[14] Chapter 2, Power Converter for Small-to-Large Photovoltaic Power Plants book by Md. Rabiul Islam, Youguang Gou, Jianguo Zhu, Springer.

[15] Mathematical Model for Determining the Performance Characteristics of Multi-Crystalline Photovoltaic Modules, Tjukup Marnoto, Kamaruzzaman Sopian, Wan Ramli Wan Daud, Mohamad Algoul and Azami Zaharim, Solar Energy Research Institute, Universiti Kebangsaan, Malaysia, Proc. Of the 9th WSEAS Int. Conf. on Mathematical and Computational Methods in Science Engineering, Trinidad and Tobago, November 5-7, 2007.

[16] Photovoltaic Charge Controller, Noor Juwaina Ayuni BT. Muhammad, Bachelors Thesis, Faculty of Electrical and Electronics Engineering, Universiti Malaysia Pahang, May 2009.

[17] Model of Photovoltaic Module in MATLAB, Francisco M. Gonzalez-Longatt, PhD Student, Universidad Central de Venezeula, Research Article, 2DO Congreso Iberoamricano De Estudiantes De Ingenieria Electrica, Electronic Y Computacion (II Cibelec 2005).

[18] Monitoring of Photovoltaic Systems: Good Practices and Systematic Analysis, Research Paper, Achim Woyte, Mauricio Richter, David Moser, Stefan Mau, Nils Reich, Ulrike Jahn presented at the 28th European PV Solar Energy Conference and Exhibition, 30 September-4 October, 2013, Paris, France.

[19] Computer-aided design of PV/wind hybrid system, Renewable Energy, B. Ai, H. Yang, H Shen, X. Liao, Science Direct, Research Article, August-2003.

[20] Pulse-width Modulated DC-DC Power Converters book by Marian K. Kazimierczuk, Wright State University, Dayton, Ohio, USA.