Design of a Charge Controller Circuit with Maximum Power Point Tracker (MPPT) for Photovoltaic System

A Thesis submitted to the
Dept. of Electrical & Electronic Engineering, BRAC University in
partial fulfillment of the requirements for the Bachelor of Science
degree in Electrical & Electronic Engineering

Shusmita Rahman	10321065
Nadia Sultana Oni	10321060
Quazi Abdullah Ibn Masud	10221074

December 15, 2012

Declaration

We do hereby declare that the thesis titled "Design of A battery charge controller with maximum power point tracker (MPPT) for solar home system" submitted to the Department of Electrical and Electronics Engineering of BRAC University in partial fulfillment of the Bachelor of Science in Electrical and Electronics Engineering. This is our original work and was not submitted elsewhere for the award of any other degree or any other publication.

Date: 15.12.2012

Supervisor

Dr. Mossaddekur Rahman

Shusmita Rahman
10321065

Nadia Sultana Oni
10321060

Quazi Abdullah Ibn Masud
10221074

Acknowledgement

We would firstly like to acknowledge our supervisor, Dr. Mossaddequr Rahman. We are grateful to him for his guidance and kind advice. He helped us by giving various ideas and taught many basics about solar cells and power electronics. Without his help we would not have been possible for us to implement and present this project.

We are indebted to Mrs. Amina Abedin for her guidance in preparing the simulations. Also, we would like to thank Jonayet Hossain for his support in software development. We are also grateful to faculty memebrs Rachaen Mahfuz Haque and Syed Sakib. We are thankful to Marzuq Rahman, Asad Bhai of CARG and Raktim Kumar Mondol for their patience and understanding.

Finally, we would like to thank our respective families for their constant encouragement and support.

Abstract

This thesis, aim to design and simulation of a simple but effective charge controller with maximum power point tracker for photovoltaic system. It provides theoretical studies of photovoltaic systems and modeling techniques using equivalent electric circuits. As, the system employs the maximum power point tracker (MPPT), it is consists of various MPPT algorithms and control methods. P-Spice and MATLAB simulations verify the DC-DC converter design and hardware implementation. The results validate that MPPT can significantly increase the efficiency and the performance of PV.

Table of Contents

6. CONCLUSION

Table List

Figure List

CHAPTER 1

INTRODUCTION

Solar energy is one of the most important renewable energy sources that have been gaining increased attention in recent years. Solar energy is plentiful; it has the greatest availability compared to other energy sources. The amount of energy supplied to the earth in one day by the sun is sufficient to power the total energy needs of the earth for one year. Solar energy is clean and free of emissions, since it does not produce pollutants or by-products harmful to nature. The conversion of solar energy into electrical energy has many application fields.

Solar to electrical energy conversion can be done in two ways: solar thermal and solar photovoltaic. Solar thermal is similar to conventional AC electricity generation by steam turbine excepting that instead of fossil fuel; heat extracted from concentrated solar ray is used to produce steam and apart is stored in thermally insulated tanks for using during intermittency of sunshine or night time. Solar photovoltaic use cells made of silicon or certain types of semiconductor materials which convert the light energy absorbed from incident sunshine into DC electricity. To make up for intermittency and night time storage of the generated electricity into battery is needed.

Recently, research and development of low cost flat-panel solar panels, thin-film devices, concentrator systems, and many innovative concepts have increased. In the near future, the costs of small solar-power modular units and solar-power plants will be economically feasible for large-scale production and use of solar energy.

In this paper we have presented the photovoltaic solar panel's operation. The foremost way to increase the efficiency of a solar panel is to use a Maximum Power point Tracker (MPPT), a power electronic device that significantly increases the system efficiency. By using it the system operates at the Maximum Power Point (MPP) and produces its maximum power output. Thus, an MPPT maximizes the array efficiency, thereby reducing the overall system cost.

In addition, we attempt to design the MPPT by using the algorithm of a selected MPPT method which is “Perturb and Observe” and implement it by using a DC- DC Converter. We have found various types of DC-DC converter. Among them we have selected the most suitable converter which is “CUK” converter, for our design.

PV generation systems generally use a microcontroller based charge controller connected to a battery and the load. A charge controller is used to maintain the proper charging voltage on the batteries. As the input voltage from the solar array, the charge controller regulates the charge to the batteries preventing any overcharging. So a good, solid and reliable PV charge controller is a key component of any PV battery charging system to achieve systems maximum efficiency. Whereas microcontroller based designs are able to provide more intelligent control and thus increases the efficiency of the system.

1.1 System Description

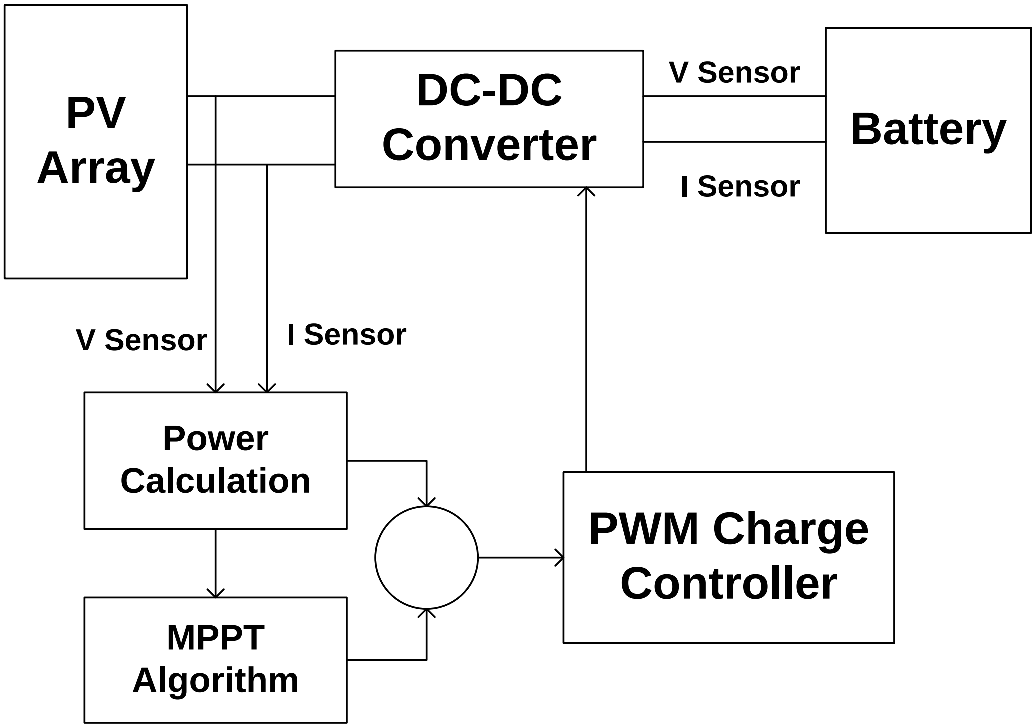


Figure: 1.1 Block Diagram of the System

A detailed block diagram of the system is shown in Figure: 1.1 which consists of following major components:

a) Solar panel
b) Battery
c) Charge Controller
d) Maximum Power Point Tracker
e) DC-DC converter

A brief description of each of the system components is given below,

a) Solar Panel

A solar panel is a packaged connected assembly of photovoltaic cells. The solar panel can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications.

Solar panels use light energy photon from the sun to generate electricity through the photovoltaic effect. The majority of modules use wafer based cells or thin film cells based on non-magnetic conductive transition metals, telluride or silicon. Electrical connections are made in series to achieve a desired output voltage and or in parallel to provide a desired current capability. The conducting wires that take the current off the panels may contain silver, copper or other non-magnetic conductive transition metals. The cells must be connected electrically to one another and to the rest of the system. Each panel is rated by its DC output power under standard test conditions, and typically ranges from 100 to 320 watts.

Depending on construction, photovoltaic panels can produce electricity from a range of light frequencies, but usually cannot cover the entire solar range (specifically, ultraviolet and low or diffused light). Hence, much of the incident sun light energy is wasted by solar panels, and they can give far higher efficiencies if illuminated with monochromatic light.

The advantages of solar panels are,

- They are the most readily available solar technology.
- They can last a lifetime.

- They are required little maintenance.
- They operate best on bright days with little or no obstruction to incident sunlight.

b) Battery

In stand-alone photovoltaic system, the electrical energy produced by the PV array cannot always be used when it is produced because the demand for energy does not always coincide with its production. Electrical storage batteries are commonly used in PV system. The primary functions of a storage battery in a PV system are:

1) Energy Storage Capacity and Autonomy: to store electrical energy when it is produced by the PV array and to supply energy to electrical loads as needed or on demand.
2) Voltage and Current Stabilization: to supply power to electrical loads at stable voltages and currents, by suppressing or smoothing out transients that may occur in PV system.
3) Supply Surge Currents: to supply surge or high peak operating currents to electrical loads or appliances.

c) Charge Controller

A charge controller or charge regulator limits the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging and may prevent against overvoltage, which can reduce battery performance or lifespan, and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life.

In simple words, Solar Charge controller is a device, which controls the battery charging from solar cell and also controls the battery drain by load. The simple Solar Charge controller checks the battery whether it requires charging and if yes it checks the availability of solar power and starts charging the battery. Whenever controller found that the battery has reached the full charging voltage levels, it then stops the charging from solar cell. On the other hand, when it found no solar power available then it assumes that it is night time and switch on the load. It keeps on the load until the battery reached to its minimum voltage levels to prevent the battery dip-discharge. Simultaneously Charge controller also gives the indications like battery dip-discharge, load on, charging on etc.

In this thesis we are using microcontroller based charge controller. Microcontroller is a kind of miniature computer containing a processor core, memory, and programmable input/output peripherals. The Functions of a microcontroller in charge controller are:

- Measures Solar Cell Voltage.
- Measures Battery Voltage.
- Decides when to start battery charging.
- Decides when to stop battery charging.
- Decides when to switch on the load.
- Decides when to switch odd the load.

Most importantly in this thesis, microcontroller also tracks the MPP of the output power.

d) Maximum Power Point Tracker

The maximum power point tracker (MPPT) is now prevalent in grid-tied PV power system and is becoming more popular in stand-alone systems. MPPT is a power electronic device interconnecting a PV power source and a load, maximizes the power output from a PV module or array with varying operating conditions, and therefore maximizes the system efficiency. MPPT is made up with a switch-mode DC-DC converter and a controller. For grid-tied systems, a switch-mode inverter sometimes fills the role of MPPT. Otherwise, it is combined with a DC-DC converter that performs the MPPT function.

This thesis, therefore, chooses a method Perturb and Observe algorithm for digital control for MPPT. The design and simulations of MPPT will be done on the premise that is going to be built with a microcontroller.

e) DC-DC Converter

DC-DC converters are power electronic circuits that convert a dc voltage to a different dc voltage level, often providing a regulated output.

The key ingredient of MPPT hardware is a switch-mode DC-DC converter. It is widely used in DC power supplies and DC motor drives for the purpose of converting unregulated DC input into a controlled DC output at a desired voltage level. MPPT uses the same converter for a different purpose, regulating the input voltage at the PV MPP and providing load matching for the maximum power transfer.

There are a number of different topologies for DC-DC converters. In this thesis we are using CUK dc-dc converter as it is obtained by using the duality principle on the circuit of a buck-boost converter.

MPPT is one of many applications of power electronics, and it is a relatively new area. This thesis investigates it in detail and provides better explanations. In order to understand and design MPPT, it is necessary to have a good understanding of the behaviors of PV. The thesis facilitates it using MATLAB models of PV cell and module. The other things such as DC-DC converter, microcontroller based charge controller are also explained elaborately.

1.2 Thesis Organization:

The thesis is organized in an order such as to provide the readers with a general understanding of the different components present in the photovoltaic battery charging system with maximum power point tracker, before moving on to the details specific to the project. The following chapter discusses the basic theory of PV cells using simple diode model, I-V characteristics, the concept of maximum power point (MPP) and how the MPP varies under different illumination and temperature conditions. This chapter also explains how maximum power transfer can be realized with buck-boost converter along with a maximum power point tracker. These general discussions are followed by the chapter (chapter 3) which details the comparison of different methods, namely the constant voltage, constant current, incremental conductance and perturb and observe, to determine and track the MPP. Chapter 4 provides a detailed description, design and implementation of a buck-boost (Cuk) converter with complete simulation and experimental results. Chapter 5 gives a detailed explanation of how the charge controller with MPPT can be implemented. It includes the circuit diagrams and explanation to build the system. The thesis ends with the concluding chapter that discusses future aspects of this project.

CHAPTER 2

SOLAR CELLS AND THEIR CHARACTERISTICS

2.1 Introduction

Photovoltaic or solar cells, at the present time, furnish one of the most-important long-duration power supplies. This cell is considered a major candidate for obtaining energy from the sun, since it can convert sunlight directly to electricity with high conversion efficiency. It can provide nearly permanent power at low operating cost, and is virtually free of pollution. Since a typical photovoltaic cell produces less than 3 watts at approximately 0.5 volt dc, cells must be connected in series-parallel configurations to produce enough power for high-power applications. Cells are configured into module and modules are connected as arrays. Modules may have peak output powers ranging from a few watts, depending upon the intended application, to more than 300 watts. Typical array output power is in the 100-watt-kilowatt range, although megawatt arrays do exist.

Photovoltaic cells, like batteries, generate direct current (DC), which is generally used for small loads (electronic equipment). When DC from photovoltaic cells is used for commercial applications or sold to electric utilities using the electric grid, it must be converted to alternating current (AC) using grid inverters, solid-state devices that convert DC power to AC.

2.2 Structure of Photovoltaic Cells

A photovoltaic (PV) cell converts sunlight into electricity, which is the physical process known as photoelectric effect. Light which shines on a PV cell, may be reflected, absorbed, or passed through; however, only absorbed light generates electricity. The energy of absorbed light is transferred to electrons in the atoms of the PV cell. With their newfound energy, these electrons escape from their normal positions in the atoms of semiconductor PV material and become part of the electrical flow, or current, in an electrical circuit. A special electrical property of the PV cell, called "built-in electric field," provides the force or voltage required to drive the current through an external "load" such as a light bulb.

To induce the built-in electric field within a PV cell, two layers of different semiconductor materials are placed in contact with each other. One layer is an "n-type" semiconductor with an abundance of electrons, which have a negative electrical charge. The other layer is a "p-type" semiconductor with an abundance of holes, which have a positive electrical charge.

Although both materials are electrically neutral, n-type silicon has excess electrons and p-type silicon has excess holes. Sandwiching these together creates a p-n junction at their interface, thereby creating an electric field. Figure: 2.1 shows the p-n junction of a PV cell.

When n-type and p-type silicon come into contact, excess electrons move from the n-type side to the p-type side. The result is the buildup of positive charge along the n-type side of the interface and of negative charge along the p-type side, which establishes an electrical field at the interface.

The electrical field forces the electrons to move from the semiconductor toward the negative surface to carry current. At the same time, the holes move in the opposite direction, toward the positive surface, where they wait for incoming electrons.

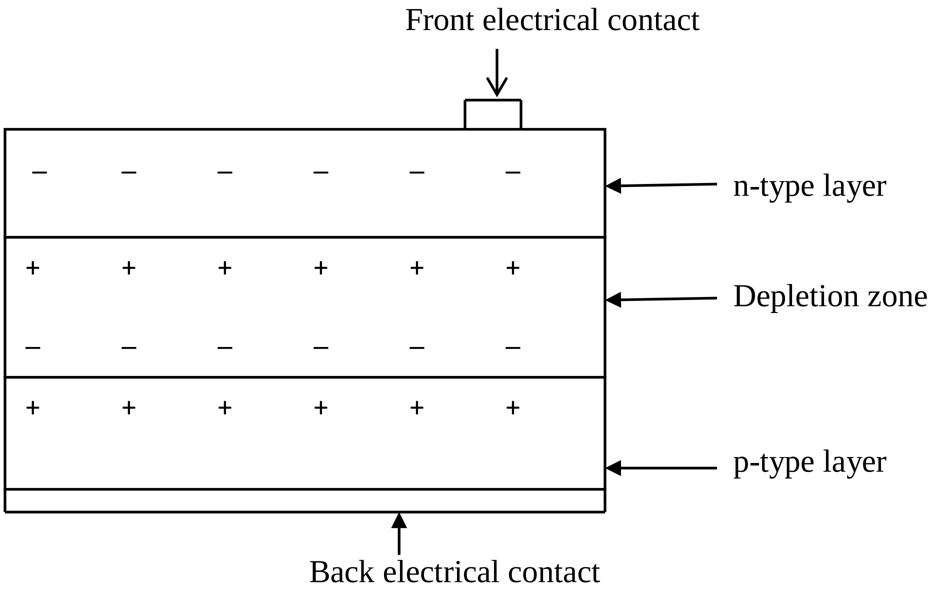
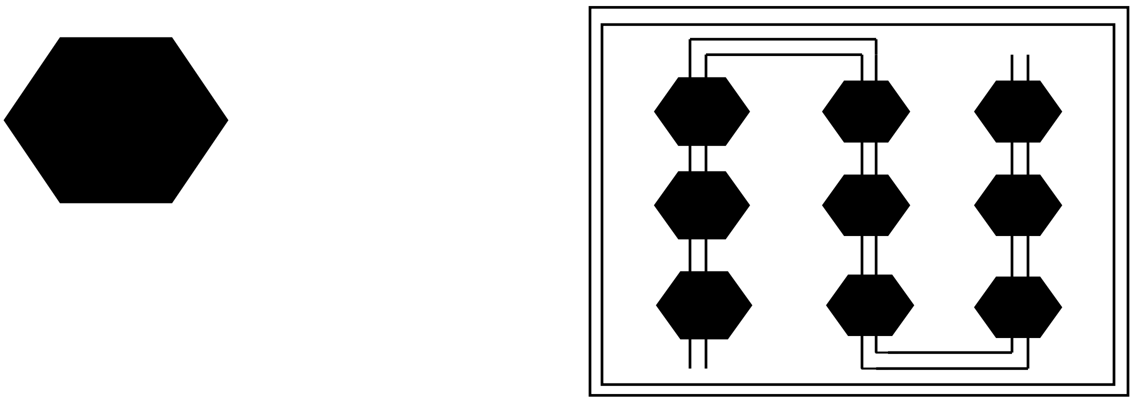


Figure: 2.1 p-n junction of the PV cell

Light travels in packets of energy called photons. As a PV cell is exposed to sunlight, many of the photons are reflected, pass right through, or absorbed by the solar cell. The generation of electric current happens inside the depletion zone of the p-n junction. The depletion region is the area around the p-n junction where the electrons from the “n-type” silicon, have diffused into the holes of the “p-type” material. When a photon of light is absorbed by one of these atoms in the “n-type” silicon it will dislodge an electron, creating a free electron and a hole. The free electron and hole has sufficient energy to jump out of the depletion zone. If a wire is connected from the cathode (n-type silicon) to the anode (p-type silicon) electrons will flow through the wire. The electron is attracted to the positive charge of the “p-type” material and travels through the external load creating a flow of electric current. The hole created by the dislodged electron is attracted to the negative charge of “n-type” material and migrates to the back electrical contact. As the electron enters the “p-type” silicon from the back electrical contact it combines with the hole restoring the electrical neutrality.

2.3 Photovoltaic Modules/Array

A PV or solar cell is the basic building block of a PV (or solar electric) system. An individual PV cell is usually quite small, typically producing about 1 or 2W of power. To boost the power output of PV cells, they have to be connected together to form larger units called modules. The modules, in turn, can be connected to form larger units called arrays, which can be interconnected to produce more power. By connecting the cells or modules in series, the output voltage can be increased. On the other hand, the output current can reach higher values by connecting the cells or modules in parallel.


a)

b)

c)

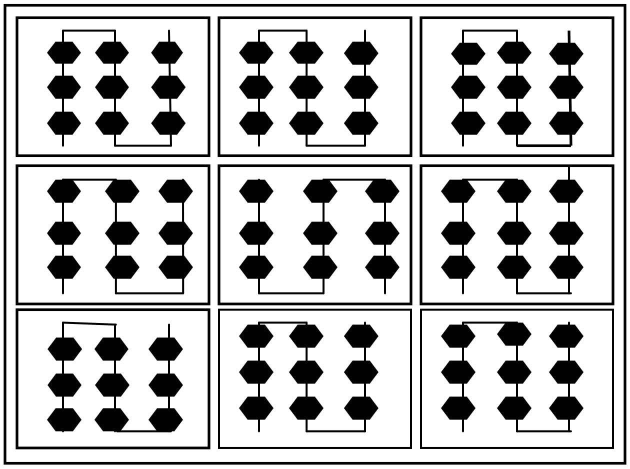


Figure 2.2: (a) PV cell, (b) PV module, (c) PV array

PV devices can be made from various types of semiconductor materials, deposited or arranged in various structures. The three main types of materials used for solar cells are silicon, polycrystalline thin films, and single crystalline thin film.

Solar energy systems are typically classified into two systems: Passive and Active system. Passive systems do not involve panel system or other moving mechanisms to produce energy. Active systems typically involve electrical and mechanical components to capture sunlight and process it into usable forms such as heating, lighting and electricity.

2.4 Photovoltaic cell model

The use of equivalent electric circuits (Figure: 2.3) makes it possible to model characteristics of a PV cell. The PV model consists of a current source (I_{sc}), a diode (D) and a series resistance (R_s). The effect of parallel resistance (R_p), represents the leakage resistance of the cell is very small in a single module, thus the model does not include it. The current source represents the current generated by photons (I_{Ph}), and its output is constant under constant temperature and constant incident radiation of light.

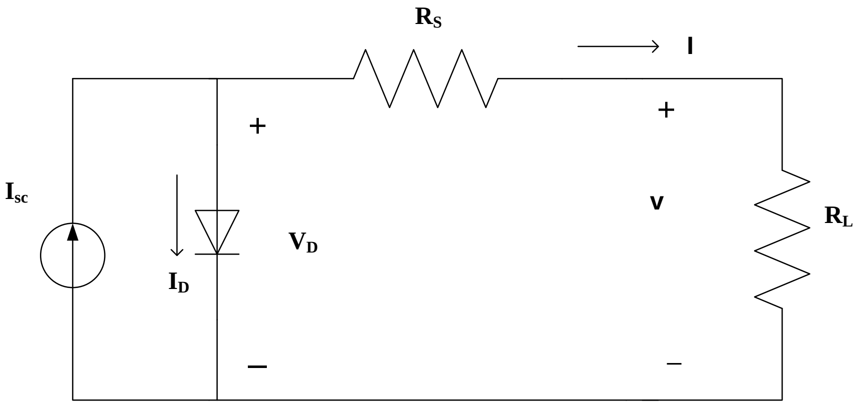


Figure: 2.3 PV cell with its equivalent electric circuit

Current-voltage (I-V) curves are obtained by exposing the cell to a constant level of light, while maintaining a constant cell temperature, varying the resistance of the load, and measuring the produced current. I-V curve typically passes through two points:

- Short-circuit current (I_{sc}): $I_{sc}$is the current produced when the positive and negative terminals of the cell are short-circuited, and the voltage between the terminals is zero, which corresponds to zero load resistance. Figure: 2.4(a)
- Open-circuit voltage (V_{oc}): V_{oc} is the voltage across the positive and negative terminals under open-circuit conditions, when the current is zero, which corresponds to infinite load resistance. Figure: 2.4(b)

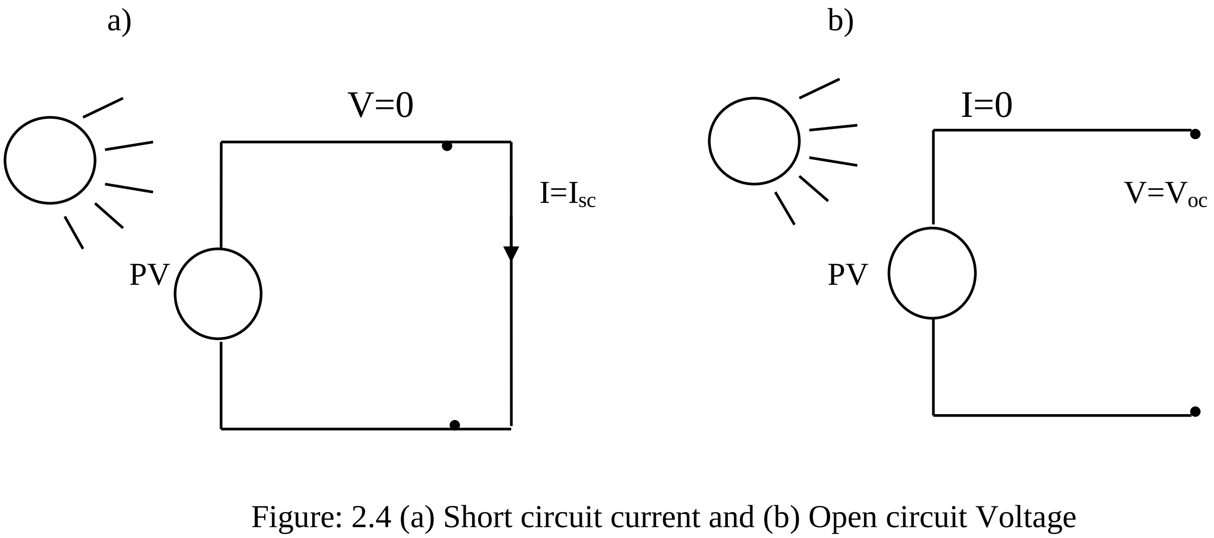


Figure: 2.4 (a) Short circuit current and (b) Open circuit Voltage

The current-voltage relationship of a PV cell is given below:

$$I = I_{SC}\text{-}I_D \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.1)$$

$$I_D = I_S[\frac{qV_D}{e^{nKT}} - 1] \dots\dots\dots\dots\dots\dots\dots\dots (2.2)$$

From equation (1) and (2) we get,

$$I = I_{sc}\text{-}I_s[\frac{qV_D}{e^{nKT}} - 1] \dots\dots\dots\dots\dots\dots\dots\dots (2.3)$$

Where, I= output current (A)

I_{SC}= short circuit current (A)

I_S= reverse saturation current (A)

V_D= voltage (V) across the diode

q= electron charge (1.6x10^{-19}C)

k= boltzmann’s constant (1.381x10^{-23} J/K)

T= junction temperature (K)

n= diode ideality factor (1~2)

The reverse saturation current can be calculated by setting V_D=V_{oc}, I=0 and n=1.6

$$I_S = \frac{I_{sc}}{e^{\frac{qV_{oc}}{nKT}}} - 1 \dots\dots\dots\dots\dots\dots\dots\dots\dots (2.4)$$

In PV panel 36 cells are connected in series. Following specifications as mentioned at the back of the panel were used for calculation. n=1.6 has been used for the calculation.

Table 2.1

I_{sc} (A)	V_{ocm} (V)	T (K)
1.25	21.9	298

I-V characteristic of a PV panel simulated by MATLAB using Eq. (2.3) is shown below in Figure: 2.5. For any given set of operational conditions, cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. The power P is given by P=VI. A plot of panel output power vs. panel voltage is shown in figure: 2.5 which have a peak point indicated by MPP which falls off on both sides. This is known as the maximum power point (MPP) and corresponds to the "knee" of the curve, at which the module operates with the maximum efficiency and produces the maximum output power.

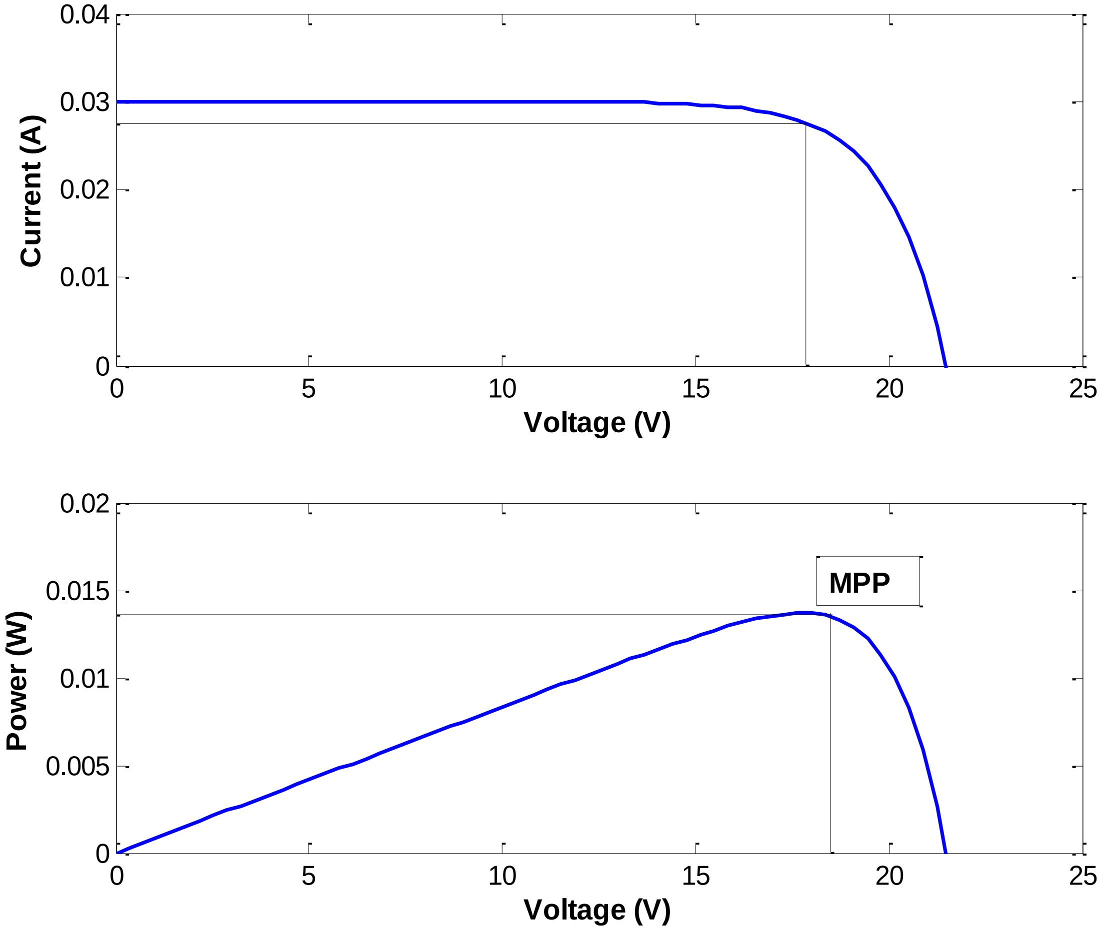


Figure: 2.5 I-V (top) and P-V (bottom) characteristic of a PV cell

2.5 I-V curve with load resistor

When a PV module is directly coupled to a load, the PV module's operating point will be at the intersection of its I–V curve and the load line which is the *I-V* relationship of load. For example in Figure: 2.6, the load current,

$I = \frac{V}{R}$ ……………………………….. (2.5)

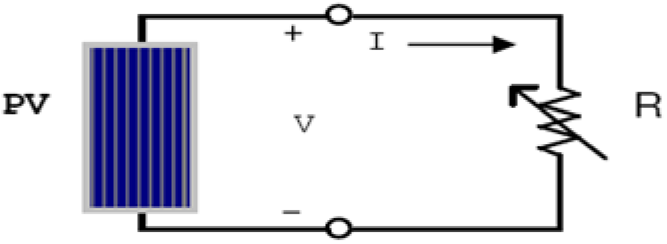


Figure: 2.6 PV module is directly connected to a (variable) resistive load

For PV panel,

$I = I_{sc} - I_s[\frac{qV}{e^{KT}} - 1]$ .... (2.6)

Plot of equation (2.5), shown as the load line, intersects the I-V characteristics of the P-V module, plotted using (2.6), at different points determined by the load resistance R.

The intersection determines the operating voltage and current and the power delivered to the load R. Figure: 2.7 shows load lines drawn for three different values of load resistance R. As it can be seen,

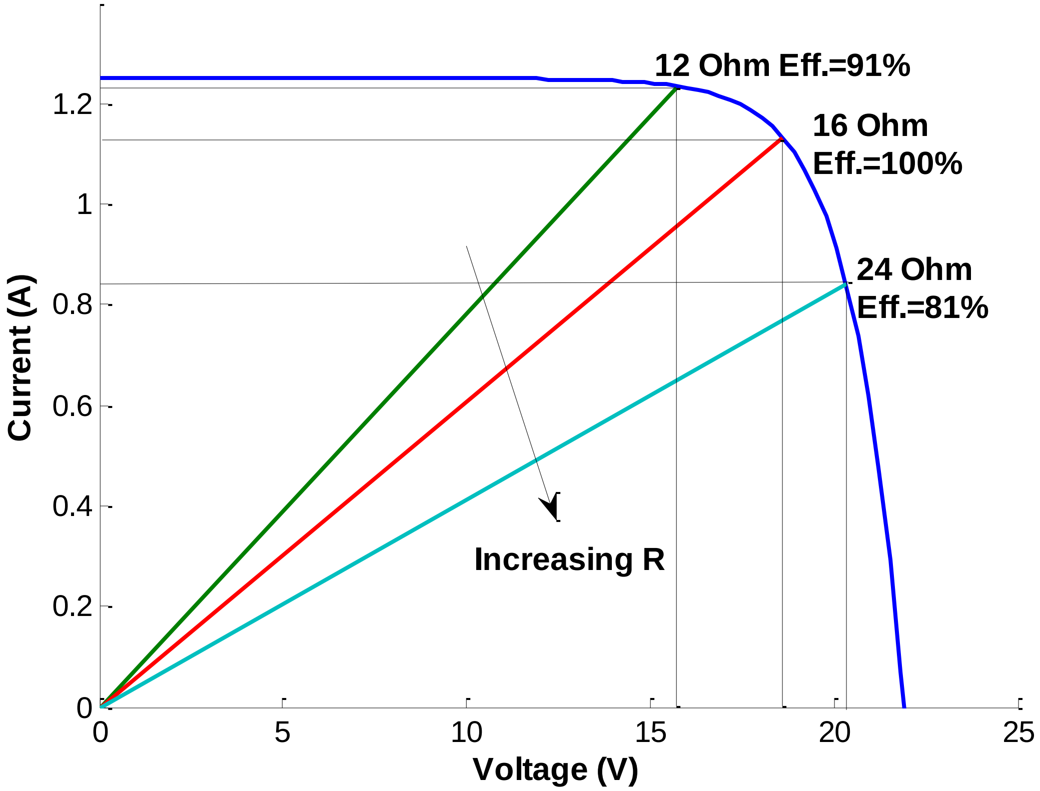


Figure: 2.7 I-V curve for different resistive load

The load line with R=16Ω intersects the I-V characteristics at the MPP and therefore, draws the maximum power. However, at any other value of R, the intersecting point shifts away from the MPP and power absorbed will be less than the maximum power.

In other words, the impedance of load dictates the operating condition of the PV module. In general, this operating point is seldom at the PV module's MPP, thus it is not producing the maximum power. This mismatching between a PV module and a load requires further over-sizing of the PV array and thus increases the overall system cost.

DC-DC converter is widely used in DC power supplies and DC motor drives for the purpose of converting unregulated DC input into a controlled DC output at a desired voltage level. MPPT uses the same converter for a different purpose which is, regulating the input voltage at the PV

MPP and providing load matching for maximum power transfer. It can provide the output voltage that is higher or lower than the input voltage.

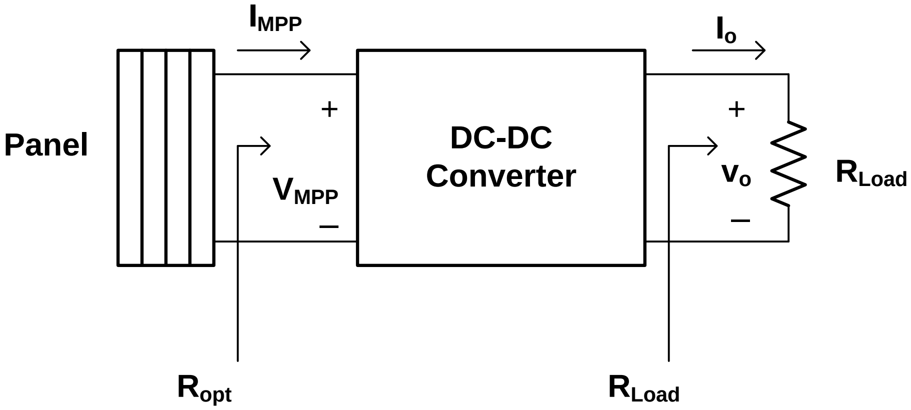


Figure: 2.8 PV with Load

When PV is directly coupled with a load, the operating point of PV is dictated by the load (or impedance to be specific). The impedance of load is described as below,

$R_{load}=\frac{v_0}{I_0}$ …………………………… (2.7)

Where, v_0 is the output voltage, and I_o is the output current.

The optimal load for PV is described as,

$R_{opt}=\frac{V_{MPP}}{I_{MPP}}$ …………………………... (2.8)

Where, V_{MPP} and I_{MPP} are the voltage and current at the MPP respectively.

When the value of R_{load} matches with that of R_{opt}, the maximum power transfer from PV to the load will occur. These two are, however, independent and rarely matches in practice. The goal of the DC-DC converter is to match the impedance of load to the optimal impedance of PV.

However, the MPP of a PV panel is not fixed but varies with different factors such as solar irradiance and tempareture. In the following sections, we describe the variation of MPP with different irradiance and temperature.

2.6 Effects of solar irradiance on MPP

There are two key parameters frequently used to characterize a PV cell. Shorting together the terminals of the cell, the photon generated current will follow out of the cell as a short-circuit current (I_{sc}). When there is no connection to the PV cell (open-circuit), the photon generated current is shunted internally by the intrinsic p-n junction diode. This gives the open circuit voltage (V_{oc}). The PV module or cell manufacturers usually provide the values of these parameters in their datasheet.

In a PV cell current is generated by photons and output is constant under constant temperature and constant incident radiation of light. Varying the irradiation we can get different output levels.

The current voltage relationship of a PV cell is given below,

$$I = I_{sc} - I_S[e^{\frac{qV}{KT}} - 1] \text{ ……………………….. (2.9)}$$

To a very good approximation, the photon generated current, which is equal to I_{sc} is directly proportional to the irradiance (G), the intensity of illumination, to PV cell.

$$I_{sc} \infty\, G$$

If $I_{sc}(G_o)$ is the photo current at irradiance Go=1000W/m^2 at the air mass AM = 1.5, then the photon generated current at any other irradiance, G (W/m^2), is given by,

$$I_{sc}(G) = (\frac{G}{G_0})I_{sc}(G_o) \text{ ……………………….. (2.10)}$$

So, the equation for varying irradiance,

$$I = (\frac{G}{G_0})I_{sc} - I_s[\, e^{qV/nKT} - 1] \text{ ……………… (2.11)}$$

The MATLAB simulation of I-V characteristics according to equation (2.11) for different irradiance of a PV panel is shown in Figure: 2.9. The value of I_s as calculated using equation (2.4) has been used.

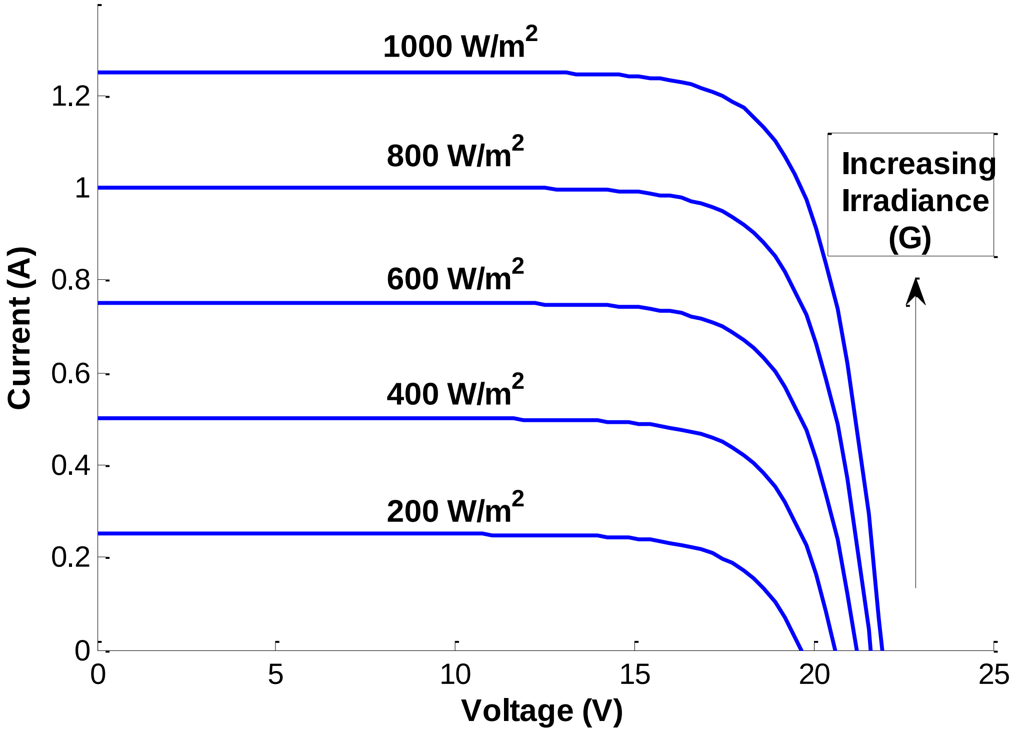


Figure 2.9: I-V curve with different irradiance

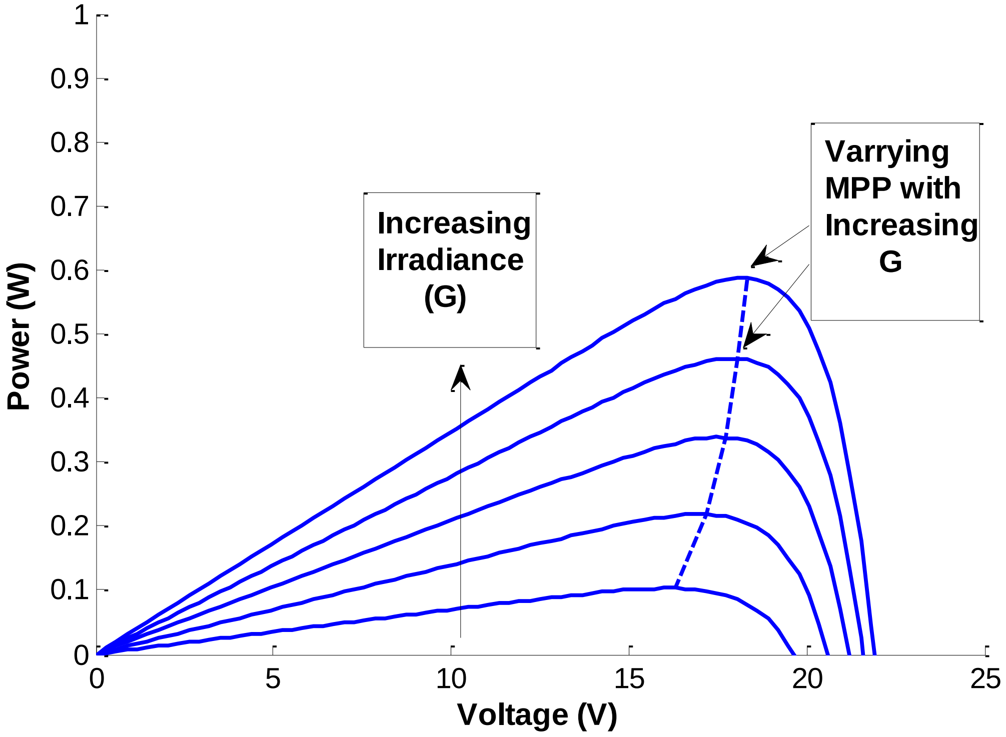


Figure: 2.10 P-V curve with different irradiance

The PV cell output is both limited by the cell current and the cell voltage, and it can only produce a power with any combinations of current and voltage on the I-V curve. As in Figure: 2.10 the P-V curve shifts with different irradiance so the MPP also shifts.

Now, as the I-V curve of a PV cell changes with different irradiance so it reveals that the amount of power produced by the PV module varies greatly depending on its irradiance. It is important to operate the system at the MPP of PV module in order to exploit the maximum power from the module.

2.7 Effects of temperature on MPP

I-V characteristic of a PV module varies at various module temperatures.

At first, calculate the short circuit current (I_{sc}) at a given cell temperature (T).

$$I_{sc}\,(T) = I_{sc}\,(T_r)[1 - a(T - T_r)] \text{ ....} \quad (2.12)$$

Where,

T_r= reference temperature of PV cell (298K, measured under irradiance of 1000W/m^2)

a=the temperature co-efficient (percent change in I_{sc} per degree temperature)

I_s=reverse saturation current of diode

V_{oc}=open circuit voltage

The I_s of diode at the T_r is given by the equation with the diode ideality factor,

$$I_s = \frac{I_{sc}}{e^{\frac{qV_{oc}}{KT_r}}} - 1 \text{ ....} \quad (2.13)$$

The reverse saturation current(I_s) is temperature dependent and the current (I) at a given temperature (T) is calculated by the following equation,

$$I_S(T) = I_s(T_r)\left(\frac{T}{T_r}\right)^{\frac{3}{n}} e^{-\frac{2E_g}{nK}\left(\frac{1}{T} - \frac{1}{T_r}\right)} \text{ ....} \quad (2.14)$$

$I(T)=I_{sc}(\mathrm{T})\text{-}I_s(\mathrm{T})[e^{\frac{qV}{nKT}}-1]$ …………………….. (2.15)

Using equation (2.12) to (2.15), I-V characteristic of the panel is plotted for three different temperatures, T=273K, 298K and 323K and are shown in figure: 2.11.

Here, $a=\frac{.065}{100}$ has been used.

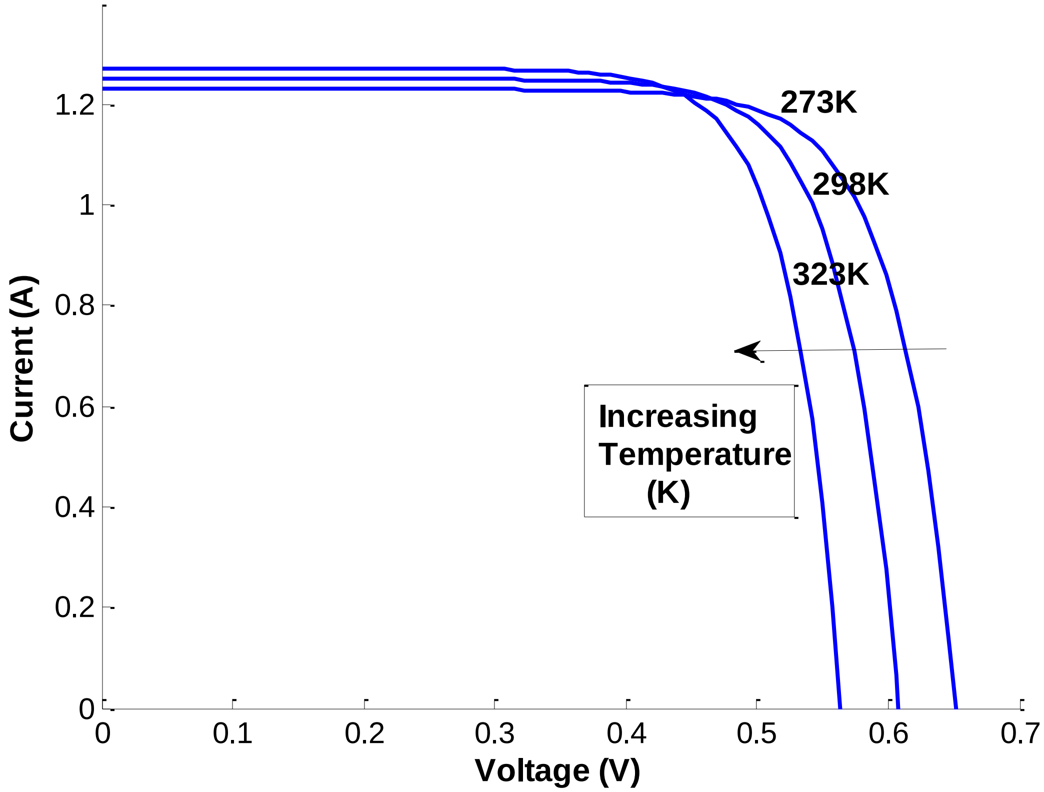


Figure: 2.11 I-V curve for varying temperature

With the increase of temperature the I-V characteristics of a PV cell shifts toward lefts and so the MPP decreases with increase in temperature.

Because of the photovoltaic nature of solar panels, their current-voltage, or IV, curves depend on temperature and irradiance levels. Therefore, the operating current and voltage which maximize power output will change with environmental conditions.

Therefore, the MPP needs to be located by a tracking algorithm, which is the heart of MPPT controller. MPPT algorithm tells controller how to move the operating voltage. Then, it is a MPPT controller’s task to bring the voltage to a desired level and maintain it .To obtain a stable voltage from an input supply (PV cells) that is higher and lower than the output, a high efficiency and minimum ripple DC-DC converter required in the system.

Buck-boost (Cuk) converters make it possible to efficiently convert a DC voltage to either a lower or higher voltage. Buck-boost converters are especially useful for PV maximum power tracking purposes, where the objective is to draw maximum possible power from solar panels at all times.

In this chapter we have discussed the structure and the I-V characteristics of a photovoltaic cell and corresponds to the knee of the P-V curve we get the MPP. We have seen the MPP varies with the load resistance. Here, we can use a Buck-Boost converter to reach the MPP. But the MPP shifts with some other factors such as solar irradiance and temperature. Therefore, we need to track the MPP at any irradiance and temperature. So we have to use MPPT to get the maximum power output.

CHAPTER 3

MAXIMUM POWER POINT TRACKER

3.1 Introduction

In a (Power-Voltage or current-voltage) curve of a solar panel, there is an optimum operating point such that the PV delivers the maximum possible power to the load. This unique point is the maximum power point (MPP) of solar panel.

Because of the photovoltaic nature of solar panels, their current-voltage, or IV, curves depend on temperature and irradiance levels. Therefore, the operating current and voltage which maximize power output will change with environmental conditions. As the optimum point changes with the natural conditions so it is very important to track the maximum power point (MPP) for a successful PV system. So in PV systems a maximum power point tracker (MPPT) is very much needed. In most PV systems a control algorithm, namely maximum power point tracking algorithm is utilized to have the full advantage of the PV systems.

In this chapter, we attempt to design a charge controller's MPPT by presenting algorithms for different MPPT methods and comparing their advantages and drawbacks.

3.2 Maximum Power Point Tracking

For any given set of operational conditions, cells have a single operating point where the values of the current (I) and voltage (V) of the cell result in a maximum power output. These values correspond to a particular load resistance, R= V/I, as specified by Ohm's Law. The power P is given by P = V*I. From basic circuit theory, the power delivered from or to a device is optimized where the derivative of the I-V curve is equal and opposite the I/V ratio. This is known as the maximum power point (MPP) and corresponds to the "knee" of the curve.

The load with resistance R=V/I, which is equal to the reciprocal of this value and draws the maximum power from the device is sometimes called the characteristic resistance of the cell. This is a dynamic quantity which changes depending on the level of illumination, as well as other factors such as temperature and the age of the cell. If the resistance is lower or higher than this value, the power drawn will be less than the maximum available, and thus the cell will not be used as efficiently as it could be. Maximum power point trackers utilize different types of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.

3.3 Methods of MPPT algorithms

Maximum Power Point Tracking (MPPT) is used to obtain the maximum power from these systems. In these applications, the load can demand more power than the PV system can deliver. There are many different approaches to maximizing the power from a PV system, this range from using simple voltage relationships to more complexes multiple sample based analysis.

MPPT Methods

There are some conventional methods for MPPT. Seven of them are listed here.

These methods include:

1. Constant Voltage method
2. Open Circuit Voltage method
3. Short Circuit Current method
4. Perturb and Observe method
5. Incremental Conductance method
6. Temperature method
7. Temperature Parametric method

Method 1 to 5 is covered in this paper for their simplicity and reliability.

3.3.1 Constant Voltage Method

The constant voltage method is the simplest method. This method simply uses single voltage to represent the V_{mp}. In some cases this value is programmed by an external resistor connected to a current source pin of the control IC. In this case, this resistor can be part of a network that includes a NTC thermistor so the value can be temperature compensated. For the various different irradiance variations, the method will collect about 80% of the available maximum power. The actual performance will be determined by the average level of irradiance. In the cases of low levels of irradiance the results can be better.

3.3.2 Open Circuit Voltage Method

An improvement on this method uses V_{oc} to calculate V_{mp}. Once the system obtains the V_{oc} value, V_{mp} is calculated by,

$$V_{mp} = kV_{OC}$$

The k value is typically between to 0.7 to 0.8. It is necessary to update V_{oc} occasionally to compensate for any temperature change. Sampling the V_{oc} value can also help correct for temperature changes and to some degree changes in irradiance. Monitoring the input current can indicate when the V_{oc} should be re-measured. The k value is a function of the logarithmic function of the irradiance, increasing in value as the irradiance increases. An improvement to the V_{oc} method is to also take this into account.

Benefits:

1. Relatively lower cost.
2. Very simple and easy to implement.

Drawbacks:

1. Not accurate and may not operate exactly at MPP.
2. Slower response as V_{mp} is proportional to the V_{oc}.

3.3.3 Short Circuit Current Method

The short circuit current method uses a value of I_{sc} to estimate I_{mp}.

$$I_{mp} = kI_{SC}$$

This method uses a short load pulse to generate a short circuit condition. During the short circuit pulse, the input voltage will go to zero, so the power conversion circuit must be powered from some other source. One advantage of this system is the tolerance for input capacitance compared to the V_{oc} method. The k values are typically close to 0.9 to 0.98.

Benefits:

1. It is simple and low cost to implement.
2. This method does not require an input.
3. In low insulation conditions, it is better than others.

Drawbacks:

1. Irradiation is never exactly at the MPP due to variations on the array that are not considered (it is not always accurate).
2. Data varies under different weather conditions and locations.
3. It has low efficiency.

In these two methods we have to choose the right constant k value carefully, to accurately calibrate the solar panel.

3.3.4 Incremental Conductance Method

The incremental conductance method based on the fact that, the slope of the PV array of the power curve is zero at the MPP, positive on the left of the MPP. And negative on the right on the MPP. This can be given by,

$$\frac{dp}{dv} = 0, \text{ at MPP}$$

$$\frac{dp}{dv} > 0, \text{ at left of MPP}$$

$$\frac{dp}{dv} < 0, \quad \text{at right of MPP}$$

Since, $$\frac{dp}{dv} = \frac{d(IV)}{dv}$$

$$\frac{dp}{dv} = \frac{d(IV)}{dv}$$

$$= I + V\,\frac{dI}{dV}$$

$$= I + V\frac{\Delta I}{\Delta V}$$

So that, $\frac{\Delta I}{\Delta V} = \frac{-I}{V}$ at MPP………………………………. (3.1)

$\frac{\Delta I}{\Delta V} > \frac{-I}{V}$, at left of the MPP…………….………… (3.2)

$\frac{\Delta I}{\Delta V} < \frac{-I}{V}$, at right of the MPP………………….. (3.3)

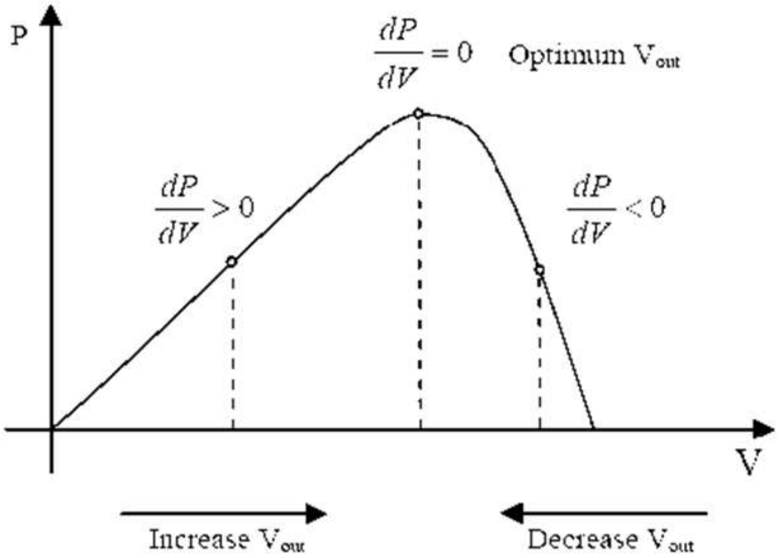


Figure: 3.1 P-V curve and IncCond algorithm

The flowchart shown in Figure: 3.2 explain the operation of this algorithm. It starts with measuring the present values of PV module voltage and current. Then, it calculates the incremental changes, dI and dV, using the present values and previous values of voltage and current. The main check is carried out using the relationships in the equations. If the condition satisfies the inequality equation (3.1), it is assumed that the operating point is at the left side of the MPP thus must be moved to the right by increasing the module voltage. Similarly, if the condition satisfies the inequality equation (3.3), it is assumed that the operating point is at the right side of the MPP, thus must be moved to the left by decreasing the module voltage. When the operating point reaches at the MPP, the condition satisfies the equation (3.1), and the algorithm bypasses the voltage adjustment. At the end of cycle, it updates the history by storing the voltage and current data that will be used as previous values in the next cycle.

The flowchart of this algorithm is given below,

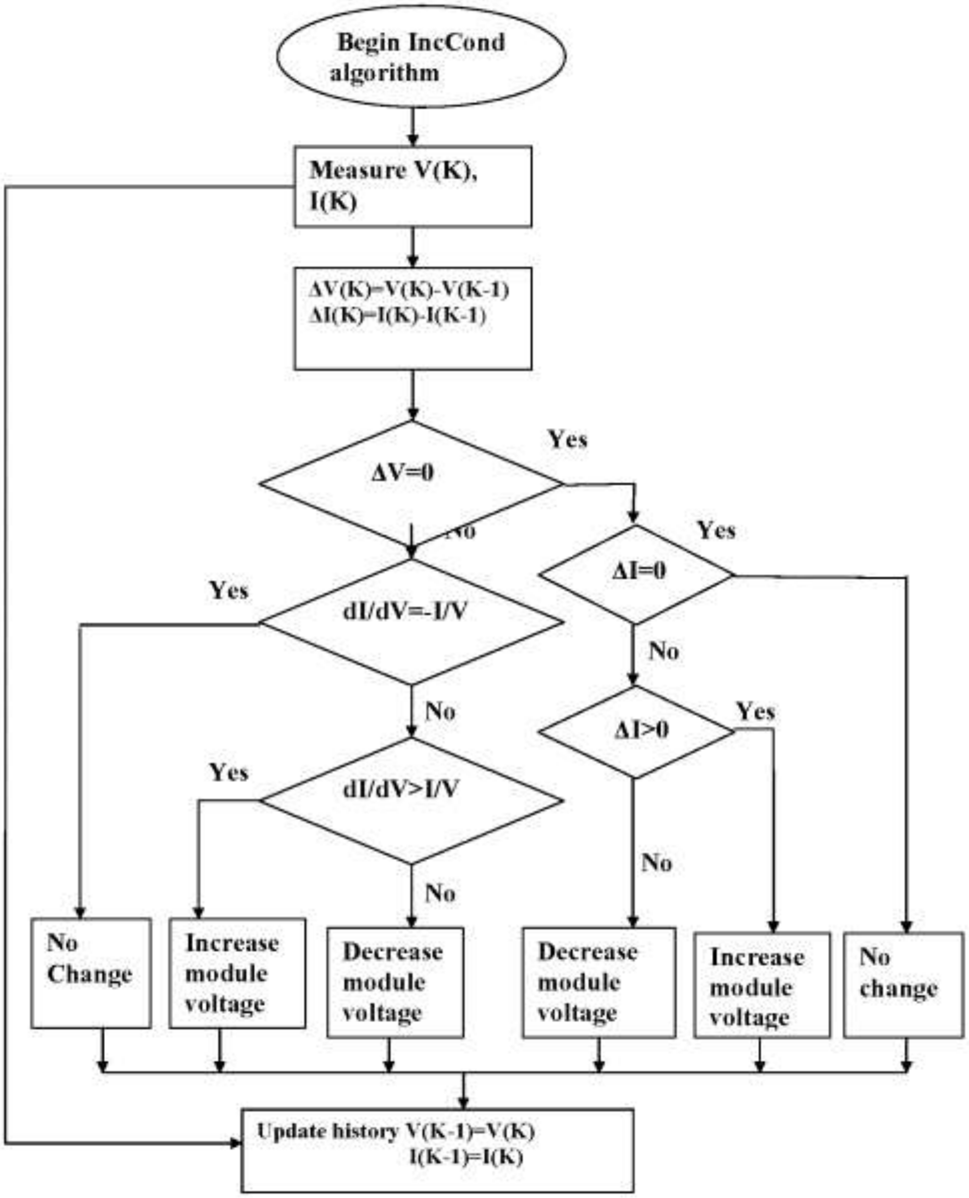


Figure: 3.2 The Flowchart of IncCond method

Benefits:

1. It can determine the maximum power point without oscillating around this value.

Drawbacks:

1. The incremental conductance method can produce oscillations and can perform erratically under rapidly changing atmospheric conditions.
2. The computational time is increased due to slowing down of the sampling frequency resulting from the higher complexity of the algorithm compared to the P&O method.

3.3.5 Perturb and Observe Method

In this method the controller adjusts the voltage by a small amount from the array and measures power, if the power increases, further adjustments in the direction are tried until power no longer increases. This is called P&O method. Due to ease of implementation it is the most commonly used MPPT method.

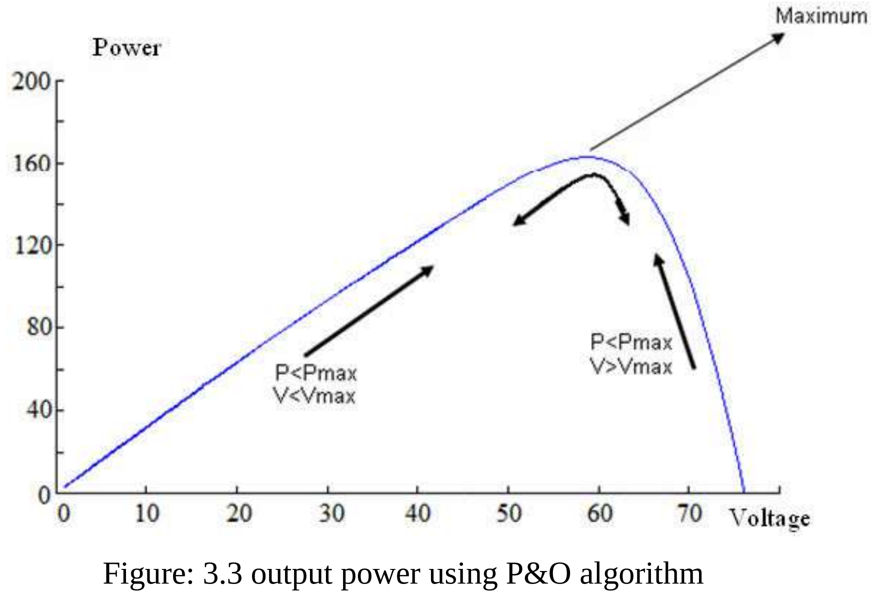


Figure: 3.3 output power using P&O algorithm

The voltage to a cell is increased initially, if the output power increase, the voltage is continually increased until the output power starts decreasing. Once the output power starts decreasing, the voltage to the cell decreased until maximum power is reached. This process is continued until the MPPT is attained. This result is an oscillation of the output power around the MPP.

PV module's output power curve as a function of voltage (P-V curve), at the constant irradiance and the constant module temperature, assuming the PV module is operating at a point which is away from the MPP. In this algorithm the operating voltage of the PV module is perturbed by a small increment, and the resulting change of power, P is observed. If the P is positive, then it is supposed that it has moved the operating point closer to the MPP. Thus, further voltage perturbations in the same direction should move the operating point toward the MPP. If the P is negative, the operating point has moved away from the MPP, and the direction of perturbation should be reversed to move back toward the MPP.

The flowchart of this algorithm is given below:

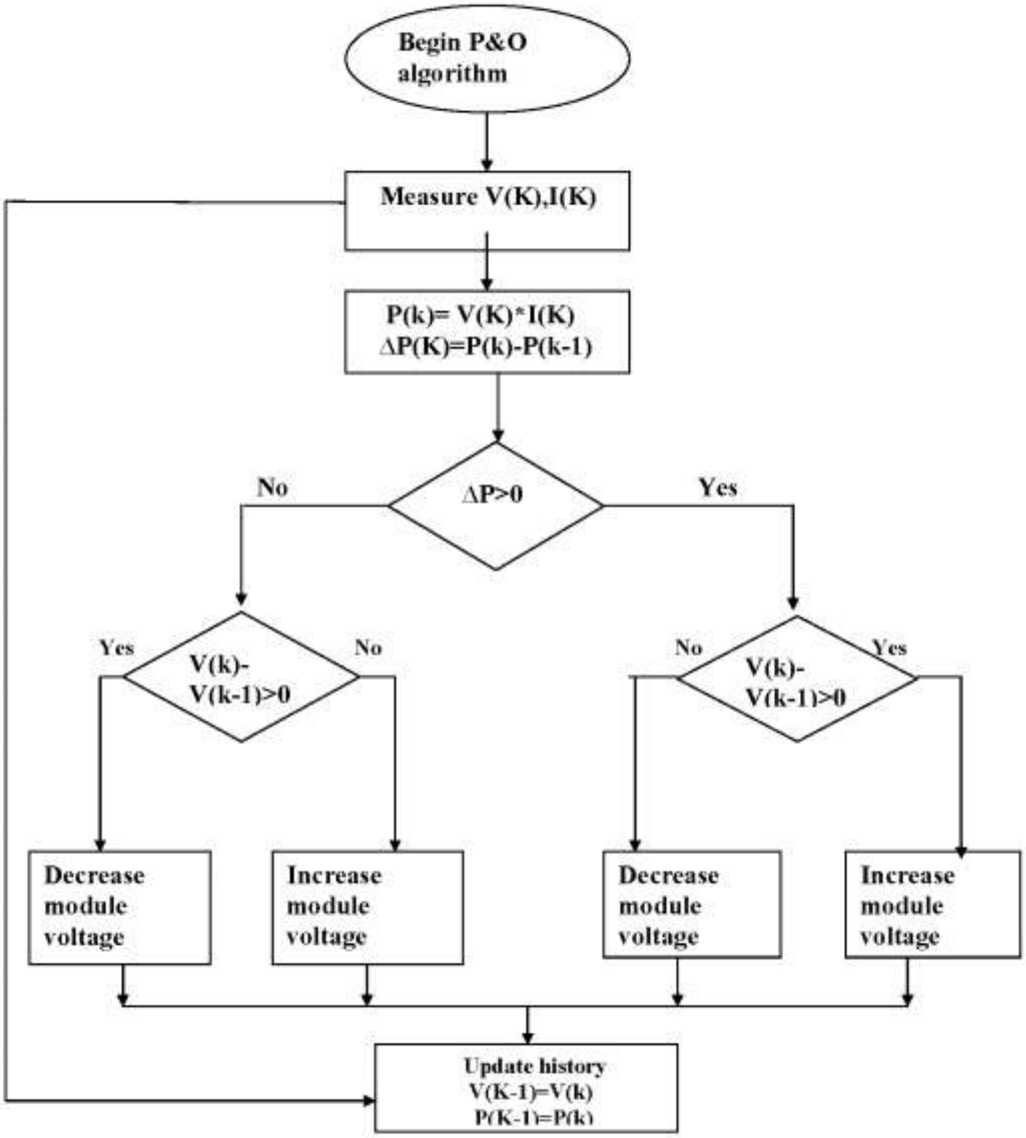


Figure: 3.4 Perturb and Observe algorithm flow chart

Perturb and Observe tracking efficiency:

Here the chart of P&O method’s efficiency during several conditions.

Table 3.1

Sky conditions	Days of data	MPPT
Clear	20	98.7
Partially cloudy	14	96.5
Cloudy	9	98.1
Overall	43	97.8
TOTAL		99.3

Benefits:

P&O is very popular and most commonly used in practice because of

1. Its simplicity in algorithm.
2. Ease of implementation.
3. Low cost
4. It is a comparatively an accurate method

Drawbacks:

There are some limitations that reduce its MPPT efficiency. They are,

1. It cannot determine when it has actually reached the MPP. Under steady state operation the output power oscillates around the MPP.

For our project we choose the Perturb and observe algorithm as it has more advantages over drawbacks. The oscillation problem can easily be minimized using minimization techniques by controller.

3.4 Techniques for minimization

The advent of digital controller made implementation of algorithm easy.. The problem of oscillations around the MPP can be solved by the simplest way of making a bypass loop which skips the perturbation when the power is very small which occurs near the MPP. The tradeoffs are a steady state error and a high risk of not detecting a small power change. Another way is the addition of a “waiting” function that causes a momentary cessation of perturbations if the direction of the perturbation is reversed several times in a row, indicating that the MPP has been reached. It works well under the constant irradiation.

3.4.1 Control technique

As explained in the previous section, the MPPT algorithm tells a MPPT controller how to move the operating voltage. Then, it is a MPPT controller’s task to bring the voltage to a desired level and maintain it. There are several methods often used for MPPT.

I. PI control

MPPT takes measurement of PV voltage and current, and then tracking algorithm calculates the reference voltage (V_{ref}) where the PV operating voltage should move next. The task of MPPT algorithm is to set V_{ref} only, and it is repeated periodically with a slower rate (typically 1~10) samples per second).

II. Direct control

This control method is simpler and uses only one control loop, and it performs the adjustment of duty cycle within the MPP tracking algorithm. The way how to adjust the duty cycle is totally based on the theory of load matching.

III. Output sensing control

The system usually requires another set of sensors for the output to detect the over voltage and over-current condition of load. This output sensing method measures the power change of PV at the output side of converter and uses the duty cycle as a control variable. This control method employs the P&O algorithm to locate the MPP.

To obtain a stable voltage from an input supply (PV cells) that is higher and lower than the output, a high efficiency and minimum ripple DC-DC converter required in the system for residential power production. Buck boost type converters are most efficient for this purpose. The MPPT algorithm drives the converter so that it can draw the maximum power always.

CHAPTER 4

DC-DC CONVERTER

4.1 Introduction

A DC-DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. The DC-DC converters are widely used in regulated switch-mode dc power supplies and in dc motor drives applications. Often the input of these converters is an unregulated dc voltage, which is obtained by rectifying the line voltage, and therefore it will fluctuate due to changes in the line voltage magnitude. Switch-mode DC-DC converters are used to convert the unregulated dc input into a controlled dc output at a desired voltage level. The heart of MPPT hardware is a switch-mode DC-DC converter. MPPT uses the converter for a different purpose: regulating the input voltage at the PV MPP and providing load matching for the maximum power transfer.

In this chapter we have discussed about the different topologies of DC-DC converters. We have explained Buck-Boost, SEPIC, Cuk converters and their operation mode. We simulated and implemented the Cuk converter and in this chapter we have given the data and shown the output with the help of different curves. Considering every sides, in this thesis we are using Cuk topology though it can step up and down the voltage and can provide a better input and output current characteristic due to the inductor on the stages.

4.2 Topologies

There are many topologies are used as DC-DC converter. They are categorized into isolated or non-isolated topologies.

The isolated topologies use a small-sized high-frequency electrical isolation transformer which provides the benefits of DC isolation between input and output, and step up or down of output voltage by changing the transformer turns ratio. They are very often used in switch mode DC power supplies. Popular topologies for a majority of the applications are:

I. Flyback
II. Half-bridge and
III. Full-bridge.

In PV applications, the grid-tied systems often use these types of topologies when electrical isolation is preferred for safety reasons.

Non-isolated topologies do not have isolation transformers. They are almost always used in DC motor drives. These topologies are further categorized into three types:

I. Step down (Buck)
II. Step up (Boost) and
III. Step up & down (Buck-Boost).

The buck topology is used for voltage step-down. In PV applications, the buck type converter is usually used for charging batteries. The boost topology is used for stepping up the voltage. The grid-tied systems use a boost type converter to step up the output voltage to the utility level before the inverter stage.

There are topologies able to step up and down the voltage such as:

1. Buck-Boost
2. SEPIC (Single Ended Primary Inductor Converter) and
3. Cuk.

For PV system with batteries, the MPP of commercial PV module is set above the charging voltage of batteries for most combinations of irradiance and temperature. A buck converter can operate at the MPP under most conditions, but it cannot do so when the MPP goes below the battery charging voltage under a low-irradiance and high-temperature condition. Thus, the additional boost capability can slightly increase the overall efficiency.

4.3 Buck-boost converter

To obtain a stable voltage from an input supply (PV cells) that is higher and lower than the output, a high efficiency and minimum ripple DC-DC converter required in the system for residential power production. Buck-boost converters make it possible to efficiently convert a DC voltage to either a lower or higher voltage. Buck-boost converters are especially useful for PV maximum power tracking purposes, where the objective is to draw maximum possible power from solar panels at all times, regardless of the load.

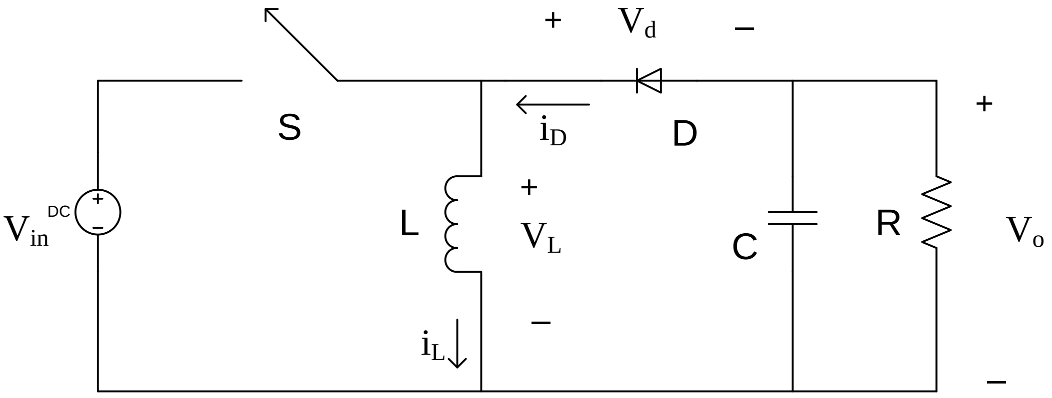


Figure: 4.1 Basic schematic of buck-boost converter

The buck boost converter can be obtained by the cascade connection of two basic converters: step up (Boost) and step down (Buck) converter.

In PV applications, the buck type converter is usually used for charging batteries. The boost topology is used for stepping up the voltage. The grid-tied systems use a boost type converter to step up the output voltage to the utility level before the inverter stage.

The input output voltage conversion ratio is the product of the conversion ratios of the two converters in cascade (assuming that the switches sin the both converters have the same duty ratio).

$$\frac{V_0}{V_{in}} = \frac{D}{1-D} \quad \text{……………………………..} \quad (4.1)$$

This the output voltage to be higher or lower than the input voltage based on the duty ratio.

The cascade connection of the step up step down converters can be combined into single buck boost converters, when the switch is closed the input provides energy to the inductor and the diode is reversed biased. When the switch is open the energy stored in the inductor is transferred to the output. No energy is supplied to the output in this interval. The output capacitor is considered to be very large which results in a constant output voltage v_0.

The basic principle of the buck–boost converter is fairly simple.

- While in the On-state, the input voltage source is directly connected to the inductor (L). This results in accumulating energy in L. In this stage, the capacitor supplies energy to the output load.
- While in the Off-state, the inductor is connected to the output load and capacitor, so energy is transferred from L to C and R.

4.3.1 Continuous conduction mode

In the continuous mode the current can flow continuously through the inductor. When the switch is turned-on, the input voltage source supplies current to the inductor, and the capacitor supplies current to the resistor (output load). When, the switch is opened, the inductor supplies current to the load via the diode D.

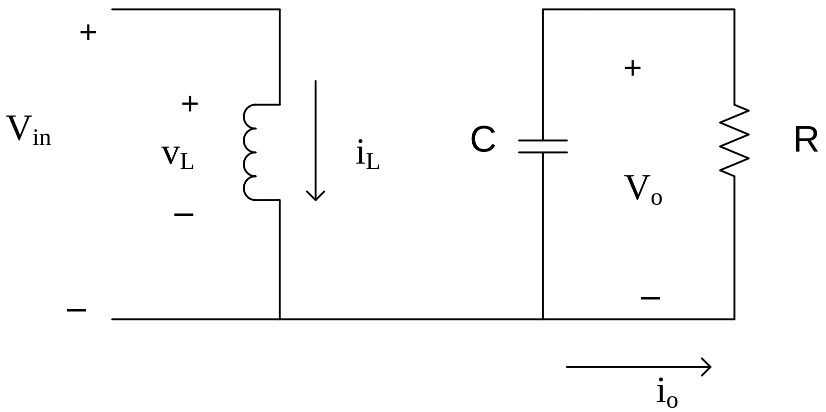


Figure: 4.2 Continuous mode operation

Equating the integral of the inductor voltage over one period to zero yields

$$V_{in}.D.T_s + (-V_0)\ (1-D)T_s = 0 \text{ .... } (4.2)$$

$$\frac{V_0}{V_S} = \frac{D}{1-D} \text{ .... } (4.3)$$

4.3.2 Discontinuous conduction mode

In the discontinuous mode the current cannot flow continuously. The amount of energy required by the load is small enough to be transferred in a time smaller than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period.

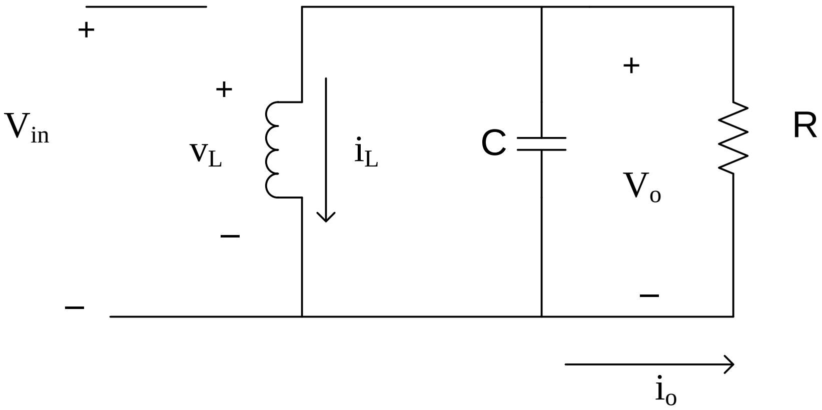


Figure: 4.3 discontinuous mode operation

Benefits:

1. Buck-boost DC-DC switching converter is good for home appliances for high efficiency.
2. Minimum ripple voltage.
3. Programmable without external components.

Drawbacks:

The disadvantage of the buck boost converter is that input current is discontinuous because of the switch located at the input.

4.4 SEPIC converter

A SEPIC is similar to a traditional buck-boost converter. Its full name is Single-ended primary-inductor converter. (SEPIC) is a type of DC-DC converter allowing the electrical potential (voltage) at its output to be greater than, less than, or equal to that at its input; the output of the SEPIC is controlled by the duty cycle of the control transistor.

The diagram for a basic SEPIC is shown in Figure: 4.4,

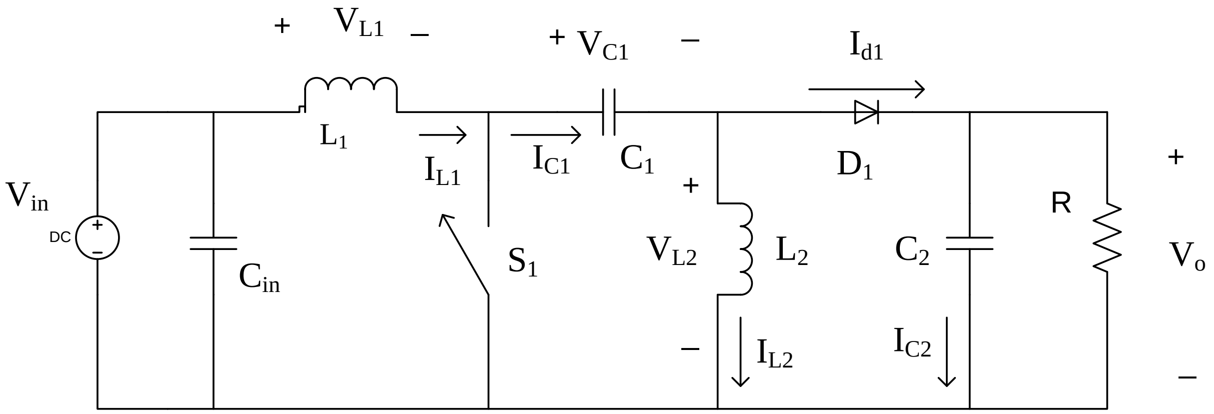


Figure: 4.4 Diagram for a basic SEPIC converter

With other switched mode power supplies (specifically DC-to-DC converters), the SEPIC exchanges energy between the capacitors and inductors in order to convert from one voltage to another. The amount of energy exchanged is controlled by switch, which is typically a transistor such as a MOSFET.

4.4.1 Continuous mode

A SEPIC is said to be in continuous-conduction mode ("continuous mode") if the current through the inductor L_1 never falls to zero. During a SEPIC's steady-state operation, the average voltage across capacitor C_1 (V_{C1}) is equal to the input voltage (V_{in}). Because capacitor C_1 blocks direct current (DC), the average current across it (I_{C1}) is zero, making inductor L_2 the only source of load current. Therefore, the average current through inductor L_2 (I_{L2}) is the same as the average load current and hence independent of the input voltage.

Looking at average voltages, the following can be written:

$V_{in} = V_{L1} + V_{C1} + V_{L2}$ ………………….. (4.4)

Since, the voltages are the same in magnitude, the ripple currents from the two inductors will be equal in magnitude.

The average currents can be summed as follows:

$I_{D1} = I_{L1} - I_{L2}$ ……………………………. (4.5)

When switch S_1 is turned on, current I_{L1} increases and the current I_{L2} increases in the negative direction. (Mathematically, it decreases due to arrow direction.) The energy to increase the current I_{L1} comes from the input source. Since S1 is a short while closed, and the instantaneous voltage V_{C1} is approximately V_{IN}, the voltage V_{L2} is approximately $-V_{IN}$. Therefore, the capacitor C_1 supplies the energy to increase the magnitude of the current in I_{L2} and thus increase the energy stored in L_2. The easiest way to visualize this is to consider the bias voltages of the circuit in a dc state, then close S_1.

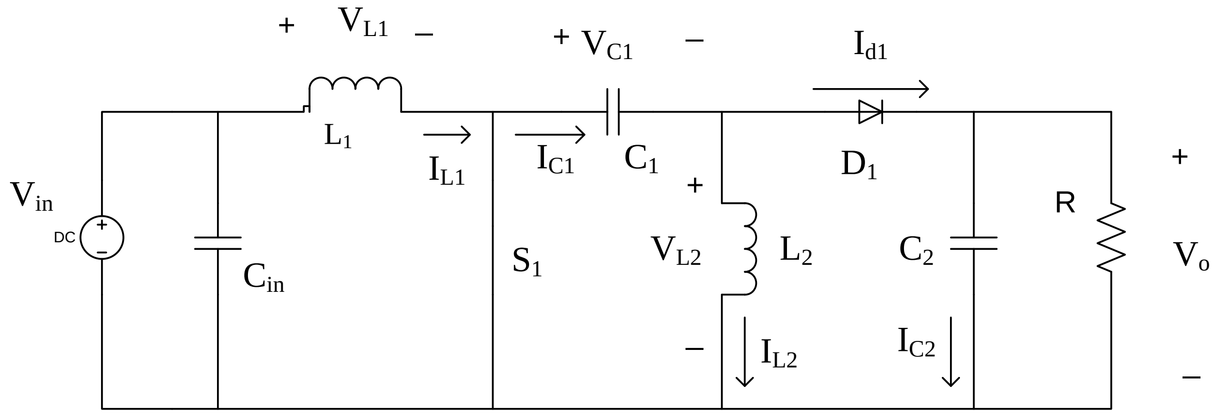


Figure: 4.5 Voltage and Current of SEPIC converter with Switch Close

When switch S_1 is turned off, the current I_{C1} becomes the same as the current I_{L1}, since inductors do not allow instantaneous changes in current. The current I_{L2} will continue in the negative direction, in fact it never reverses direction. It can be seen from the diagram that a negative I_{L2} will add to the current I_{L1} to increase the current delivered to the load. Using Kirchhoff's Current

Law, it can be shown that $I_{D1} = I_{C1} - I_{L2}$. It can then be concluded, that while S_1 is off, power is delivered to the load from both L_2 and L_1. C_1, however is being charged by L_1 during this off cycle, and will in turn recharge L_2 during the on cycle.

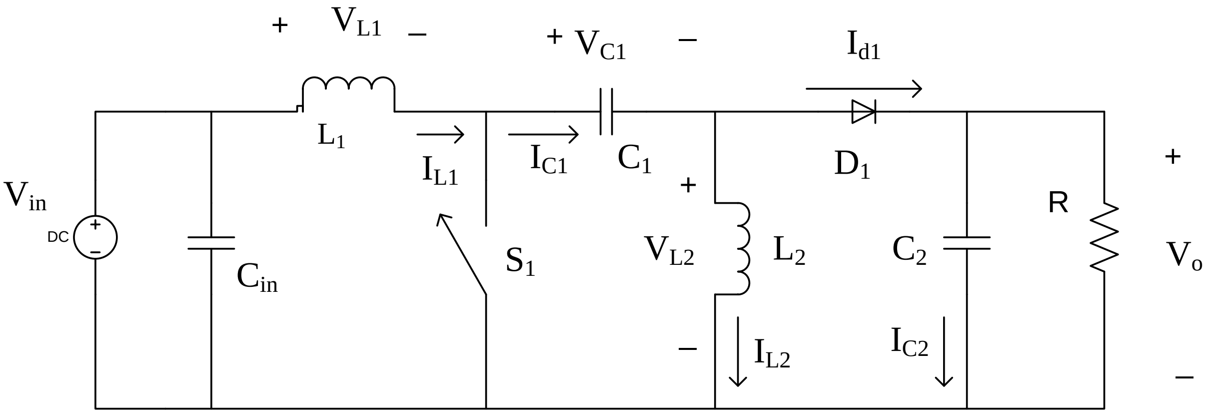


Figure: Voltage and Current of SEPIC converter with Switch Open

Because the potential (voltage) across capacitor C_1 may reverse direction every cycle, a non-polarized capacitor should be used. C_1 will not change unless the switch is closed long enough for a half cycle of resonance with inductor L_2, and by this time the current in inductor L_1 could be quite large.

4.4.2 Discontinuous mode:

A SEPIC is said to be in discontinuous-conduction mode (or, discontinuous mode) if the current through the inductor L1 is allowed to fall to zero.

Benefits:

- SEPICs are useful in applications in which a battery voltage can be above and below that of the regulator's intended output. For example, a single lithium ion battery typically discharges from 4.2 volts to 3 volts; if other components require 3.3 volts, then the SEPIC would be effective.

Drawbacks:

- Like buck–boost converters, SEPICs have a pulsating output current.

- Since the SEPIC converter transfers all its energy via the series capacitor, a capacitor with high capacitance and current handling capability is required.
- The fourth-order nature of the converter also makes the SEPIC converter difficult to control, making them only suitable for very slow varying applications.

4.5 Cuk converter

4.5.1 Circuit Description and Operation

The Cuk converter is obtained by using the duality principle on the circuit of a buck-boost converter. Similar to the buck-boost converter, the Cuk converter provides a negative-polarity regulated output voltage with respect to the common terminal of the input voltage. The output voltage magnitude can be same, larger or smaller than the input, depending on the duty cycle.

The inductor on the input acts as a filter for the dc supply, to prevent large harmonic content. Here, the capacitor C_1 acts as the primary means storing and transferring energy from the input to the output.

The analysis begins with these assumptions:

- Both inductors are very large and the currents in them are constant.
- Both capacitors are very large and the voltages across them are constant.
- The circuit is operating in the steady state, meaning the voltage and current waveforms are periodic.
- For the duty ratio of D, the switch is closed for time DT and open for (1-D)T.
- The switch and the diode are ideal.

In steady state, the average inductor voltages V_{L1} and V_{L2} are zero. Therefore by Figure: 4.7,

$$V_{C1} = V_s + V_o \text{ ……………………….. (4.6)}$$

Therefore, V_{C1} is larger than both V_s and V_o. Assuming C_1 to be sufficiently large, in steady state the variation in v_{C1} from its average value V_{C1} can be assumed to be negligibly small ($V_{C1} \approx v_{C1}$), even though it stores and transfers energy from the input to the output.

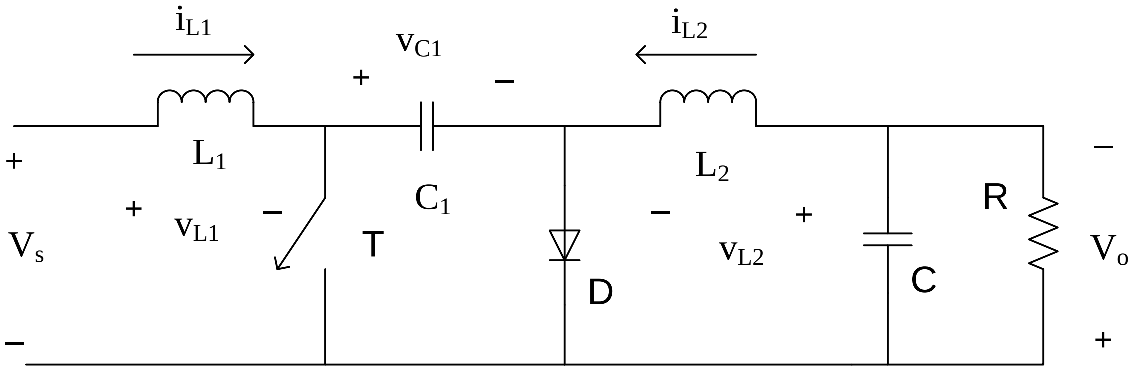


Figure: 4.7 Circuit diagram of a Cuk converter

When the switch is off, the inductor currents i_{L1} and i_{L2} flow through the diode. Capacitor C_1 is charged through the diode. The circuit is shown in Figure: 4.8, Capacitor C_1 is charged through the diode by energy from both the input and L_1. Current i_{L1} decreases because V_{C1} is larger than V_s. Energy stored in feeds the output. Therefore i_{L2} also decreases.

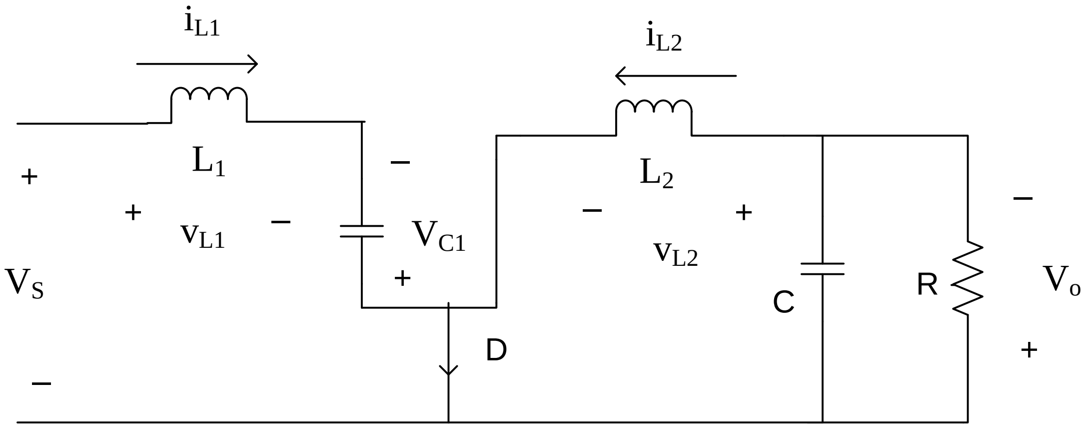


Figure: 4.8 Voltage and Current in a Cuk converter with Switch Off

When the switch is on, V_{C1} reverse biases the diode. The inductor currents i_{L1} and i_{L2} flow through the switch as shown in Figure: 4.9. Since $V_{C1} > V_o$, C_1 discharges through the switch, transferring energy to the output and L_2. Therefore i_{L2} increases the input feeds energy to L_1 causing i_{L1} to increase.

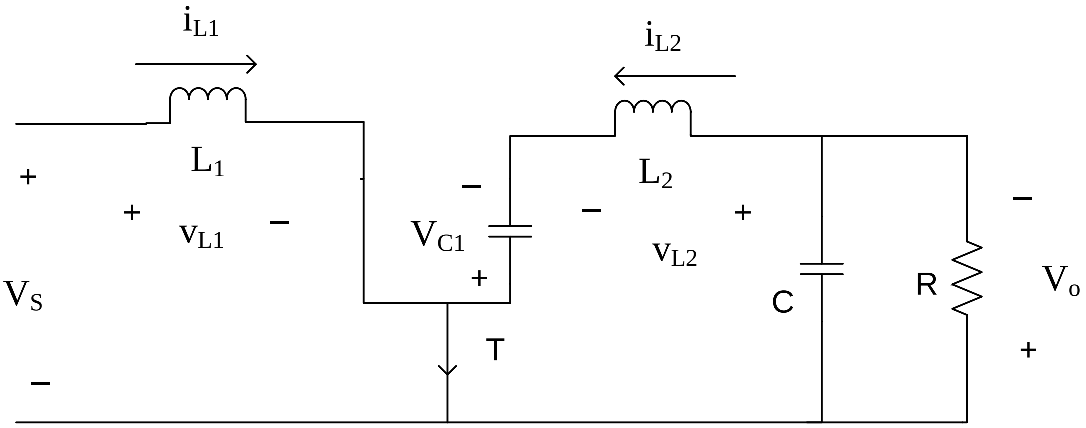


Figure: 4.9 Voltage and Current in a Cuk converter with Switch On

The inductor currents i_{L1} and i_{L2} are assumed to be continuous. The voltage and the current expressions in steady state can be obtained in two different ways.

If we assume the capacitor voltage V_{C1} to be constant, then equating the integral of the voltages across L_1 and L_2 over one time period to zero yields

$$L_1: V_s D T_S - (V_s - V_{C1})(1-D)T_S = 0 \quad \text{……………………..} (4.7)$$

$$L_2: (V_{C1} - V_o) D T_S + (-V_o)(1-D)T_S = 0 \quad \text{……………….. } (4.8)$$

$$V_{C1} = \frac{1}{1-D} V_s \quad \text{…………………… } (4.9)$$

$$V_{C1} = \frac{1}{D} V_o \text{………………………… } (4.10)$$

From equation (4.9) and (4.10) we get,

$$\frac{V_o}{V_S} = \frac{D}{1-D} \quad \text{(4.11)}$$

Next, the average power supplied by the source must be same as the average power absorbed by the load.

$$P_s = P_o$$

$$V_S I_{L1} = V_o I_{L2} \quad \text{(4.12)}$$

$$\frac{I_{L1}}{I_{L2}} = \frac{V_o}{V_S} \quad \text{(4.13)}$$

$$\frac{I_o}{I_S} = \frac{1-D}{D} \quad \text{(4.14)}$$

Where, $I_{L1}=I_s$ and $I_{L2}=I_o$.

In practical circuits, the assumption of a nearly constant V_{C1} is reasonably valid.

Its relationship to the duty cycle (*D*) is:

- If 0 < *D* < 0.5 the output is smaller than the input.
- If *D* = 0.5 the output is the same as the input.
- If 0.5 < *D* < 1 the output is larger than the input.

Benefits:

1) An advantage of this circuit is that both the input current and the current feeding the output stage are reasonably ripple free. It is possible to simultaneously eliminate the ripples in i_{L1} and i_{L1} completely, leading to lower external filtering requirements.
2) This converter is also able to step up and down the voltage. It uses a capacitor as the main energy storage. As a result, the input current is continuous.
3) This circuit has low switching losses and high efficiency.
4) This converter does not allow electromagnetic interference like others.

Drawbacks:

- A significant disadvantage is the requirement of a capacitor C_1 with a large ripple-current-carrying capability.

In our thesis we have designed Cuk topology and simulated by P-Spice and implemented in hardware. For our design the value of C_1, C_2, L_1, and L_2 we have taken using the following formulas,

$$L_{1min} = \frac{(1-D)^2 R}{2Df} \text{ …………………… } (4.15)$$

$$L_{2min} = \frac{(1-D)R}{2f} \text{ ……………………. } (4.16)$$

$$C_{1min} = \frac{V_O D}{Rf\Delta v_{C1}} \text{ …………………….. } (4.17)$$

$$C_{2min} = \frac{1-D}{(\frac{\Delta v_O}{v_O})8L_2 f^2} \text{ .... } (4.18)$$

We have found the value of L_1 and L_2 is same if the duty cycle is 50%. The value of L_1 and L_2 decreases with the increase in frequency as in Figure: 4.10,

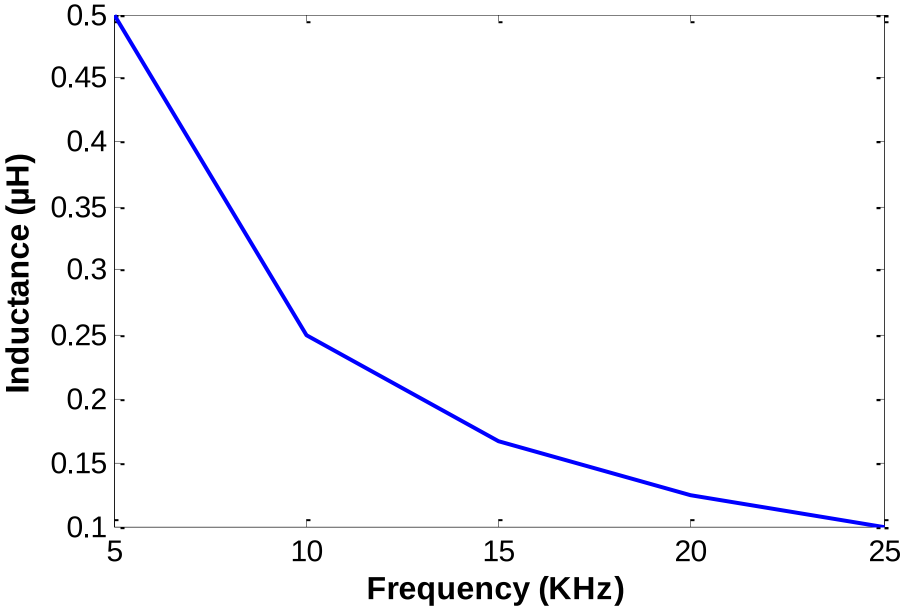


Figure: 4.10 Variation of Inductor (L_1/L_2) size with Frequency

We have also plotted the value of C_1 and C_2 with respect to Frequency. As shown in Figure: 4.11 and 4.12 the value of C_1 and C2 decreases with the increase in frequency.

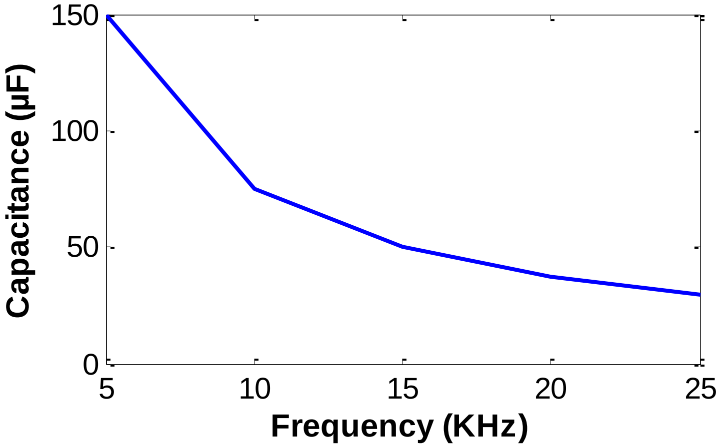


Fig: 4.11 Variation of C_1 size with frequency

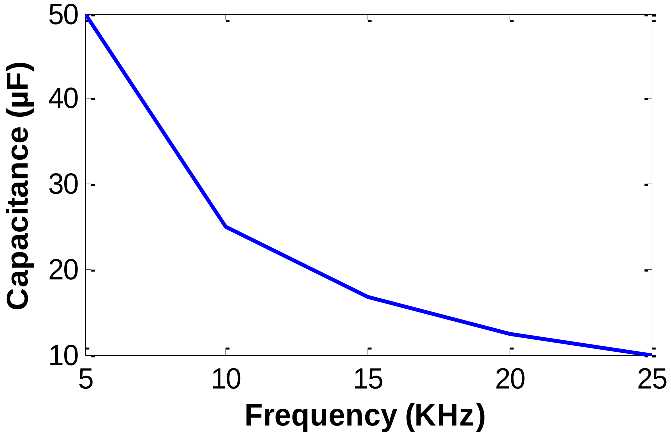


Fig: 4.12 Variation of C_2 size with frequency

In Figure: 4.13 we can see the output power (P_o) increases with respect to increase in frequency (F).

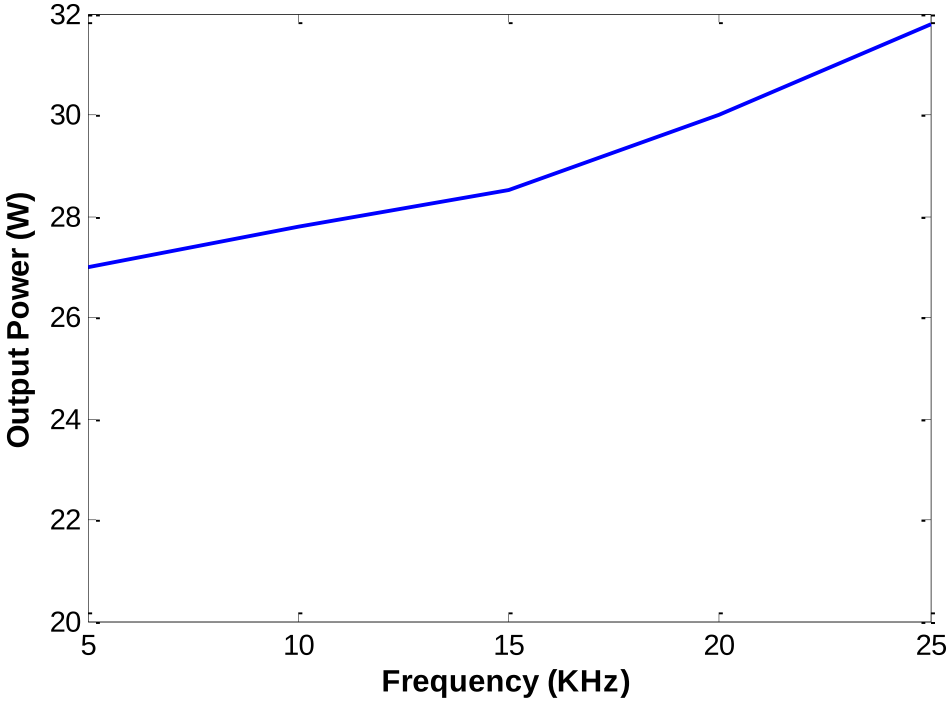


Figure: 4.13 Variations in Output Power with Frequency

We have selected 25 KHz frequency for our design because if the frequency is more higher the switching loss more increases.

In P-Spice Simulation we have assumed, f=25K, D=50%, R=10

$V_o = 15V$

$\frac{\Delta V_o}{V_o} = .1V$

$\Delta v_{C1} = 1V$

Using equation (4.15), (4.16), (4.17), (4.18) we get,

$L_1 = 225\mu H$

$L_2 = 225\mu H$

$C_1 = 15\mu F$

$C_2 = 10\mu F$

We have simulated varying duty cycles and we get different output. From the Figure: 4.14 we can see with increase in duty cycle (D), the output voltage (V_o) increases.

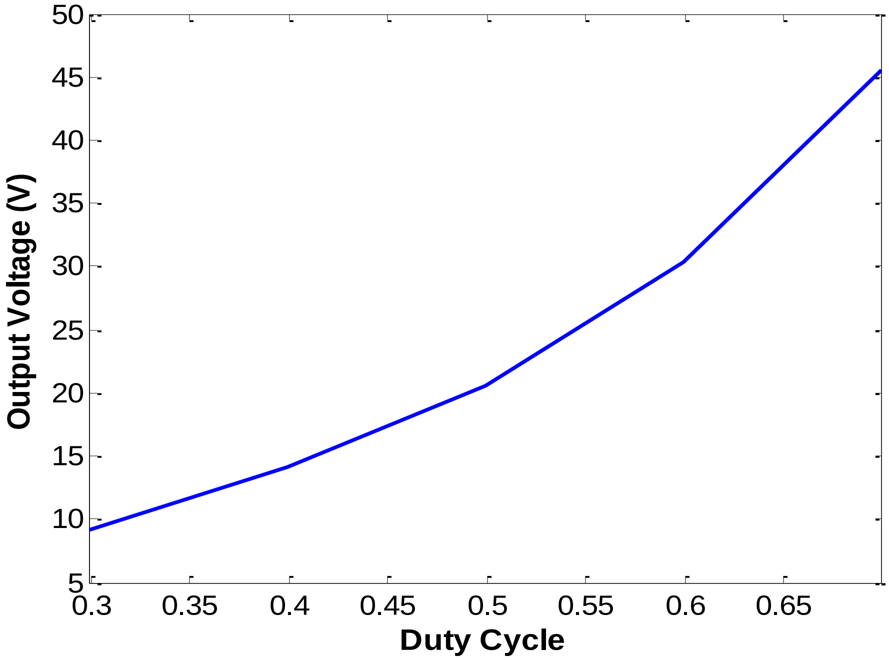


Figure: 4.14 Curve for V_o-D, obtained by P-Spice Simulation

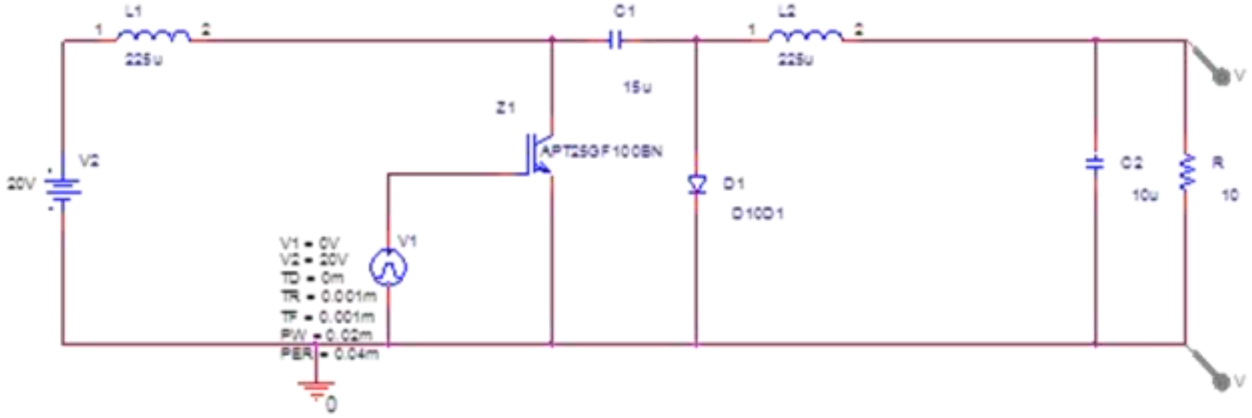
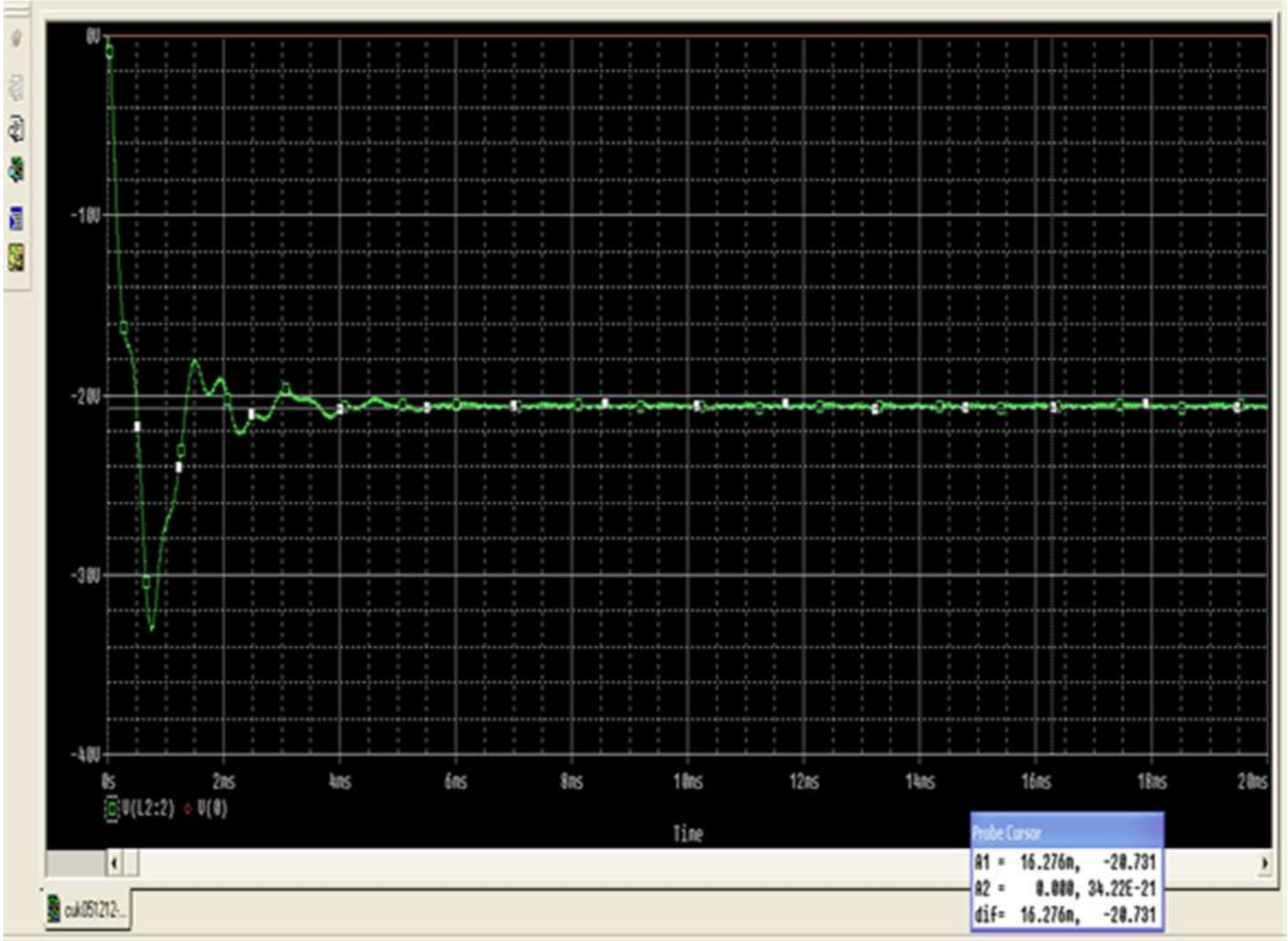


Figure: 4.15 Design of a Cuk converter circuit for P-Spice simulation



```
A1 =  16.276m,   -20.731
A2 =    0.000, 34.22E-21
dif=  16.276m,   -20.731
```

Figure: 4.16 Simulated Output Voltage from Cuk converter

In hardware part we have taken R=40Ω and other values were same as the simulation part. We have collected the data by varying the duty cycle (D).

Table 4.1

Duty Cycle (D)	Input Voltage ,V_{in} (V)	Input Current, I_{in} (A)	Output Voltage, V_o (V)
20%	20	.23	10.95
30%	20	.43	15.50
40%	20	.67	19.30
50%	20	.75	20.15
60%	20	1.25	26.30
70%	20	2.74	33.30

We have plotted the data from Table 4.1 and Figure: 4.15 show the relationship between duty cycle and output voltage.

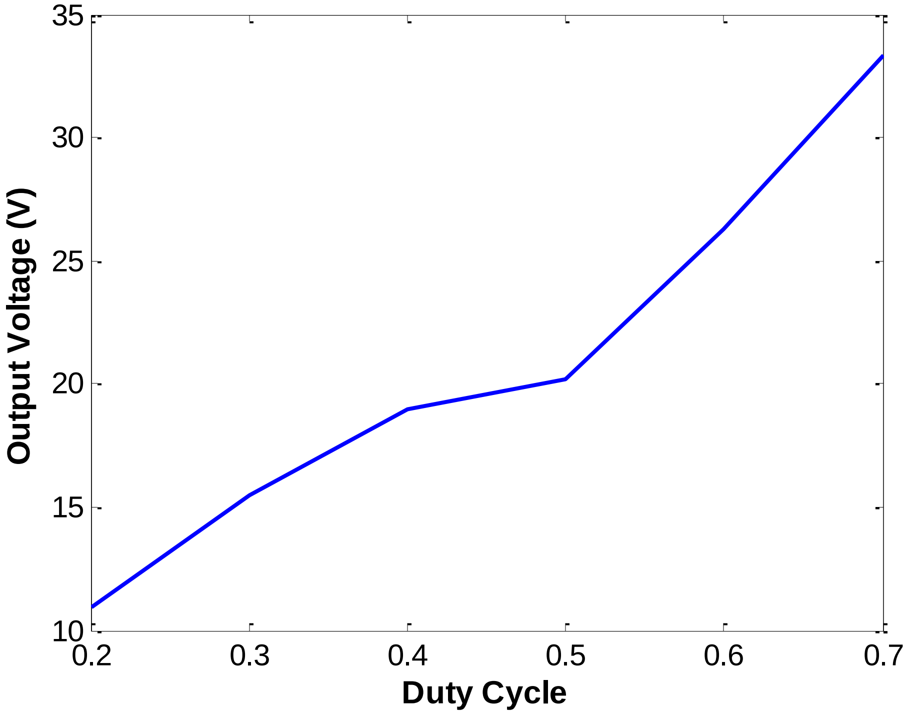


Figure: 4.17 curve for V_o-D, obtained by hardware implementation

From the simulation and implementation parts we get, when the duty cycle is 50% the output voltage is same as input voltage, when the duty cycle is less than 50% the output voltage is less than input voltage and when the duty cycle is more than 50% the output voltage is more than input voltage which satisfies our theoretical design.

In this paper, DC-DC Cuk converter design and implement for photovoltaic application. The proposed Cuk converter has a significant advantage over other inverting topologies since they enable low voltage ripple on both the input and the output sides of the converter. So, the performance of photovoltaic system and the output efficiency of converter are improved.

CHAPTER 5

THE PROPOSED CHARGE CONTROLLER DESIGN

In our project, the Maximum Power Point Tracker (MPPT) will be implemented by using a microcontroller that is programmed to execute the desired algorithm. The program will control the charge controller of the PV array by sensing the panel voltage (V) and current (I) and the battery voltage of to determine the single operating point where the values of current (I) and voltage (V) result in a maximum power output. This is the Maximum Power Point (MPP). The goal of the MPPT is to match the impedance of the battery to the optimal impedance of the panel.

After taking the measurements of voltage and current, and decides the tracking algorithm (Perturb and Observe) which is the heart of the MPPT controller. The algorithm that is used is written using C# programming language on an interface known as Micro C. The program built generates a ".hex" file which is burned onto the microcontroller by means of a lock burner.

5.1 Microcontroller and Voltage Regulator

The microcontroller that will be used in this system is PIC16F876A. It is a 28 pin IC. It has a memory of 368 bytes and external programmable memory (EEPROM) of 256 bytes.

The microcontroller senses both the panel and battery voltages and takes decisions to activate different components of the circuits such as, transistors, relays and LED indicators. It is powered up by the lead-acid battery connected to it through a voltage regulator (LM7805) which converts the 12V into 5V and is connected to a RESET (pin 1). The microcontroller is also powered by a 5V supply at pin 20 and ground at pin 8 and 19.

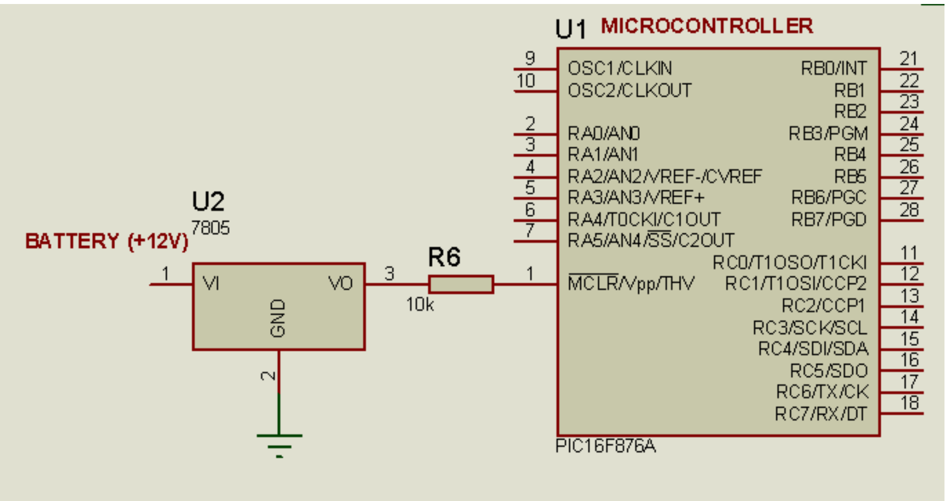


Figure: 5.1 Voltage Regulator (LM 7805) connected to the RESET (pin 1).

5.2 Analog to Digital Conversion (ADC):

Voltage Sensing:

The microcontroller consists of built in Analog- to- Digital (ADC) converters. These enable the conversion of our analog inputs into quantized values. The ADCON registers will need to be configured with their required binary values to enable ADC to begin.

The voltage inputs from the panel and the battery must be “stepped down” by using voltage division principle. The node voltages between the two resistors () connected to the panel is fed to one ADC pin (AN0). Similarly, the node voltages from the resistors connected to the battery are connected to AN1 (pin 3).

The ADC of the microcontroller divides these analog inputs into 1024 quantized levels. These values are 0 (for 0V input) and 1023 (for 5V input). In this way, voltage sensing of the panel and battery is achieved.

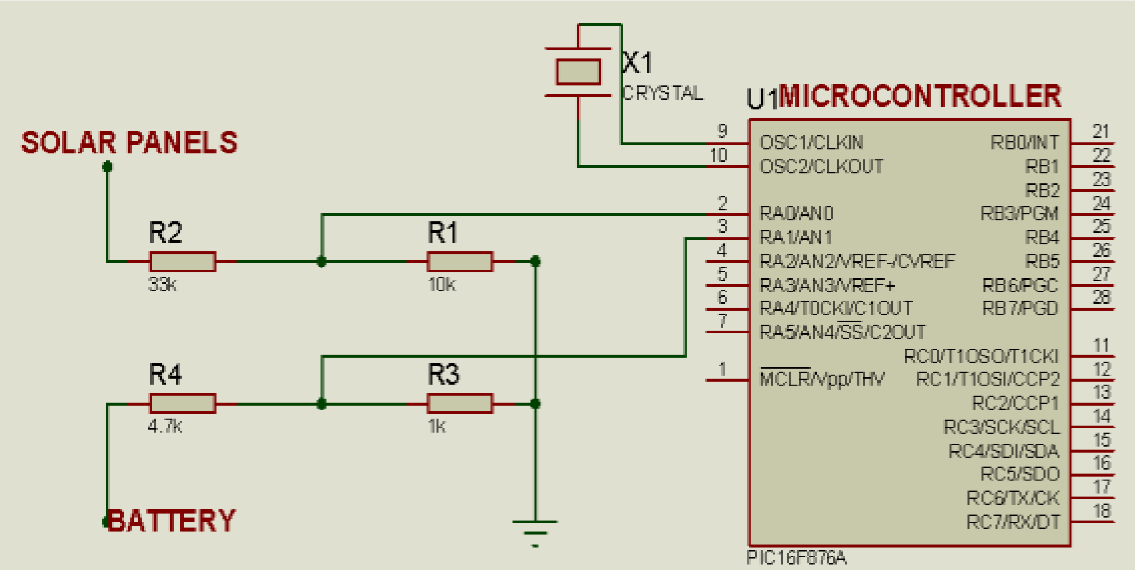


Figure: 5.2 Voltage sensing circuit diagram.

Current Sensing:

To read the current supplied by the PV module, a shunt resistor is placed in series with an ADC input. This value is amplified and connected to the ADC port AN2. The shunt resistor gives a voltage that is proportional to the current, e.g.: if 1A gives 5mV, 10A gives 50mV. This voltage output is then connected to another ADC port, AN2 and run in the algorithm as an input.

Conversely, a Hall effect sensor may be used. This includes HAL 710 (Hall effect sensor with Direction Detection) and 6851, of which 6851 is more convenient. The 6851 is an integrated Hall effect latched sensor. The device includes an on-chip Hall voltage generator for magnetic sensing, a comparator that amplifies the Hall voltage, and a Schmitt trigger to provide switching hysteresis for noise rejection, and output driver with pull-high resistor. If a magnetic flux density larger than threshold βOP, D0 is turned ON (low). The output state is held until a magnetic flux density reversal falls below βOP causing DO to be turned OFF(high) [Pi Labs]. In this way, the sensor detects the magnetic flux produced by the analog input, and reads current as a voltage. However, for our purpose, we have used a shunt resistor and the voltage across it amplified by and Op-Amp and connected to the ADC pin.

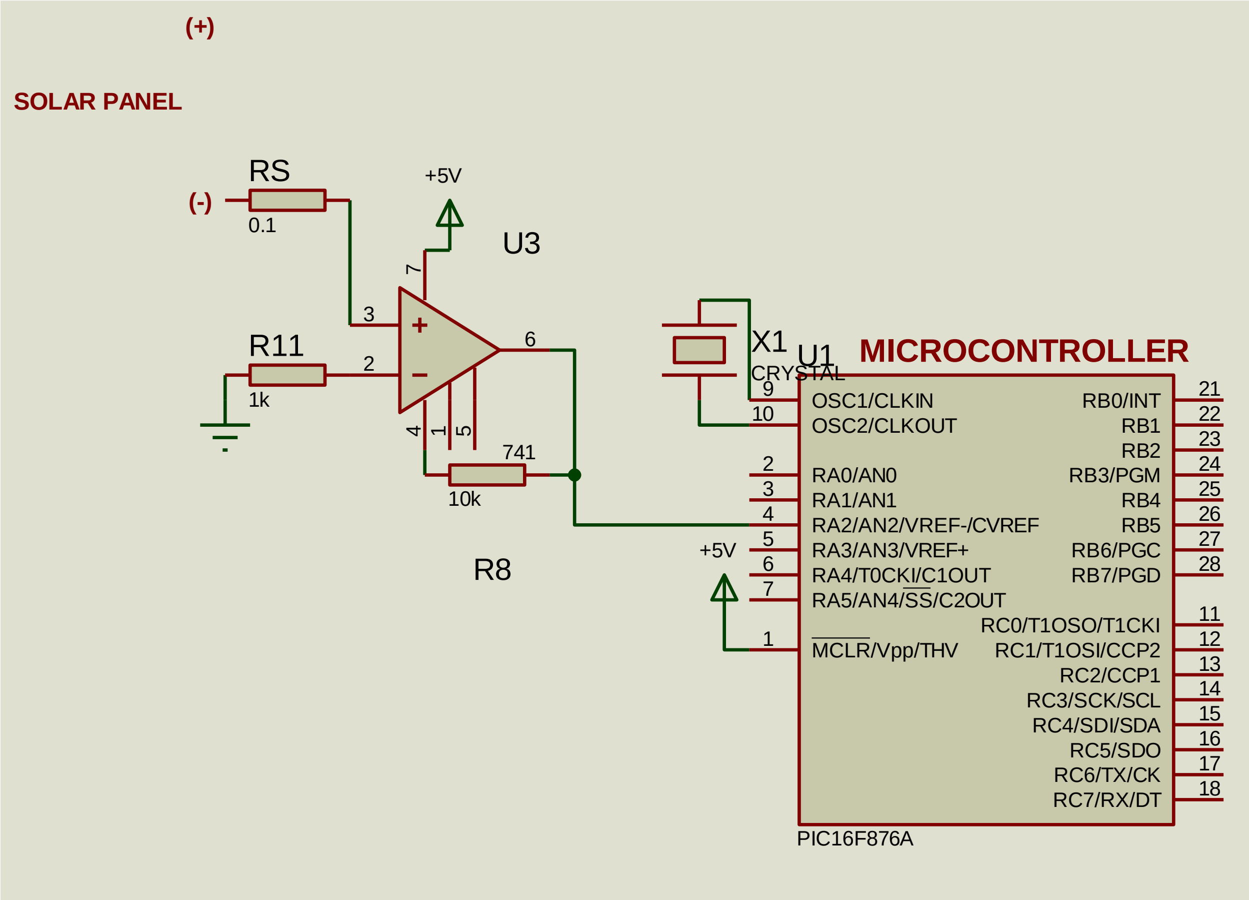


Figure: 5.3 Current sensing circuit diagram.

5.3 Pulse Width Modulation:

The charging of the battery at Maximum Power Point (MPP) is achieved by carrying out the process of Pulse Width Modulation (PWM) at the switch mode of the DC- DC converter.

The pulse width modulation uses time proportioning. This divides the signals into and low states. The proportion of time spent in the high state is known as the duty cycle. Our algorithm uses different duty cycles to match the impedances of the PV array and the battery to reach the MPP.

The duty cycle like the ADC, must be quantized into digital outputs. For this purpose the PORTB and PORTC are declared as outputs and the PWM port is initialized with input frequency (25000 Hz). The duty cycle of the PWM pin (CCC1/ pin 13) is set with a quantized value which is 0 for minimum (0%) duty cycle and 255 for maximum (100%) duty cycle.

If the battery is in need of charging, it only charged if the panel voltage is greater than 15V and less than or equal to 20V. The panel voltage and current flows to thee Cuk converter which is activated by a bipolar junction transistor (BJT- BC547) connected to the PWM port CCP1 (pin 13).

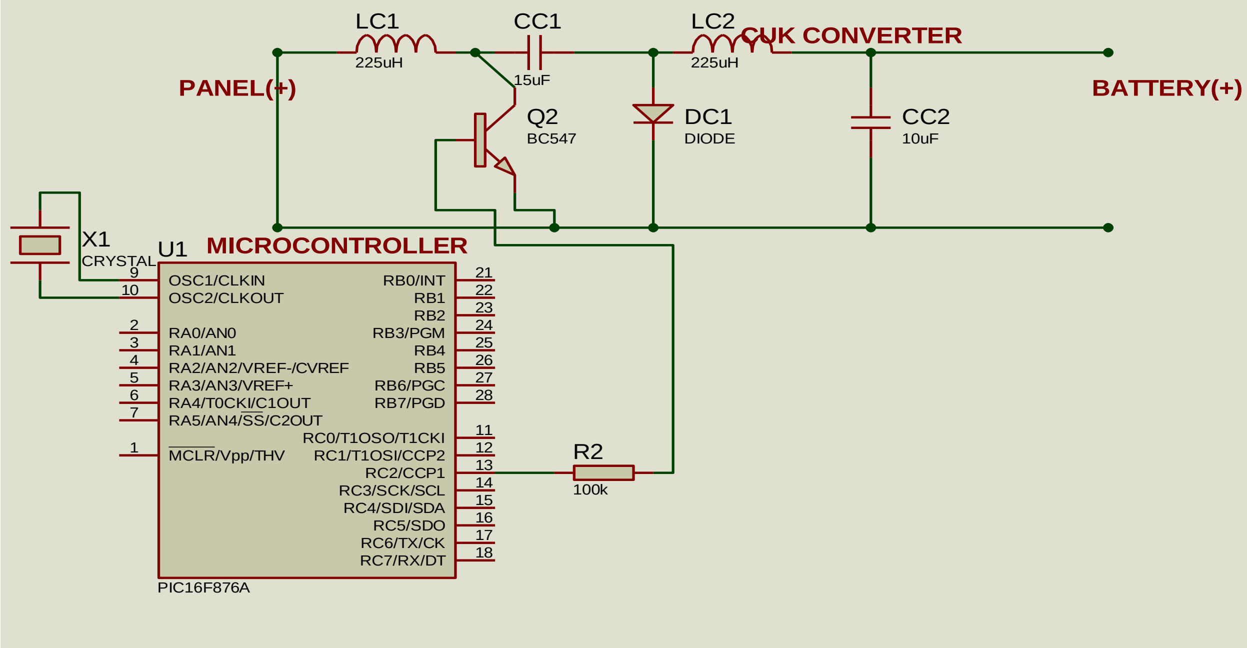


Figure: 5.4 Switching operation of the charging process from the panel to the battery by using the Cuk converter.

5.4 Battery Discharging:

Relay:

When a load is required to be operated by the battery, a relay (G5LE-1A- DC 12V) is used for providing the voltage and current to the battery. One end of the relay is connected to the battery. The other end is connected to the collector of the Darlington pair BJT (TIP122). The emitter is connected to ground and the base is controlled by a microcontroller port (the RB1 pin). When the battery is charging, the voltage of the battery allows a low current to flow in the relay coil. This low current, induces the load contact to be switched OFF. When the battery is sufficient enough to run a load, the base of the BJT is turned on and the current flows from the relay coil to the load. The relay is now ON.

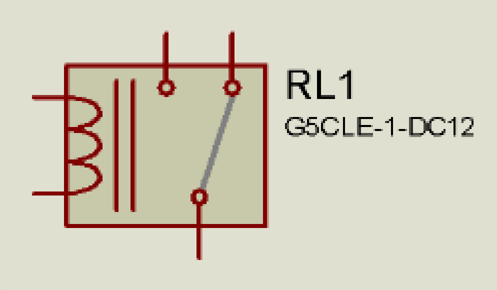


Figure: 5.5 Relay coil.

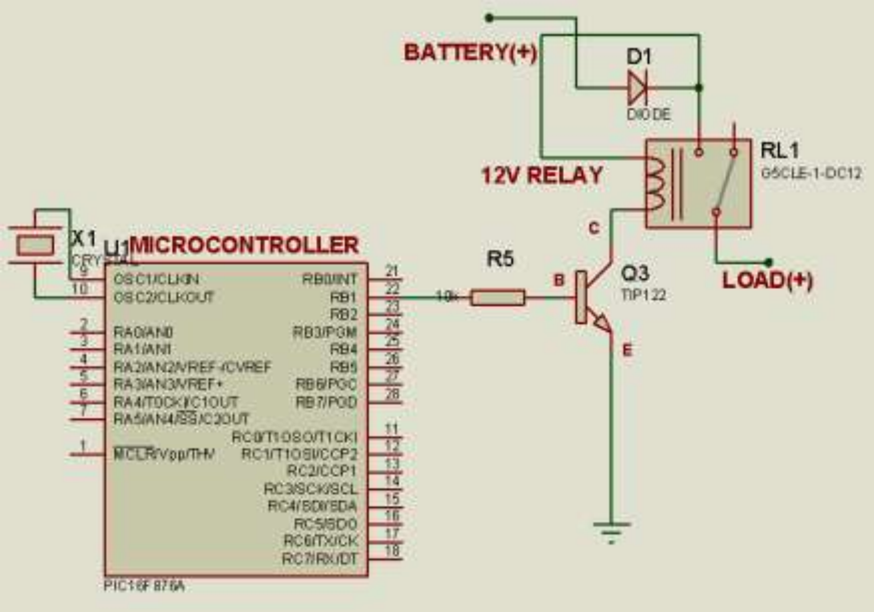


Figure: 5.6 Battery discharging operation of the circuit.

5.5 Design Functions:

When the program is run on the microcontroller, the ADC ports of the microcontroller divides the analog inputs into 1024 quantized levels and display the different voltages on a 16x2 LCD. In this way, voltage sensing of the panel and battery is achieved.

The current supplied by the PV module, a shunt resistor is placed in series with an ADC input. The shunt resistor gives a voltage that is proportional to the current, e.g.: if 1A gives 5mV, 10A gives 50mV. This voltage output is then connected to another ADC port, AN2 via an Op- Amp and run in the algorithm as an input.

If the battery is in need of charging, the PWM ports are activated. The battery is only charged if the panel voltage is greater than 15V and less than or equal to 20V. The panel voltage and current flows to the Cuk converter which is activated by a bipolar junction transistor (BJT-BC547) connected to the PWM pin.

During discharging, the panel voltage and current flows to the Cuk converter which is activated by a bipolar junction transistor (BJT- BC547) connected to the PWM pin. The switching mode of the Cuk converter matches the impedance of the battery to the optimal impedance of the panel. The point of intersection of the P-V curve of the panel and the battery gives the Maximum Power Point (MPP).

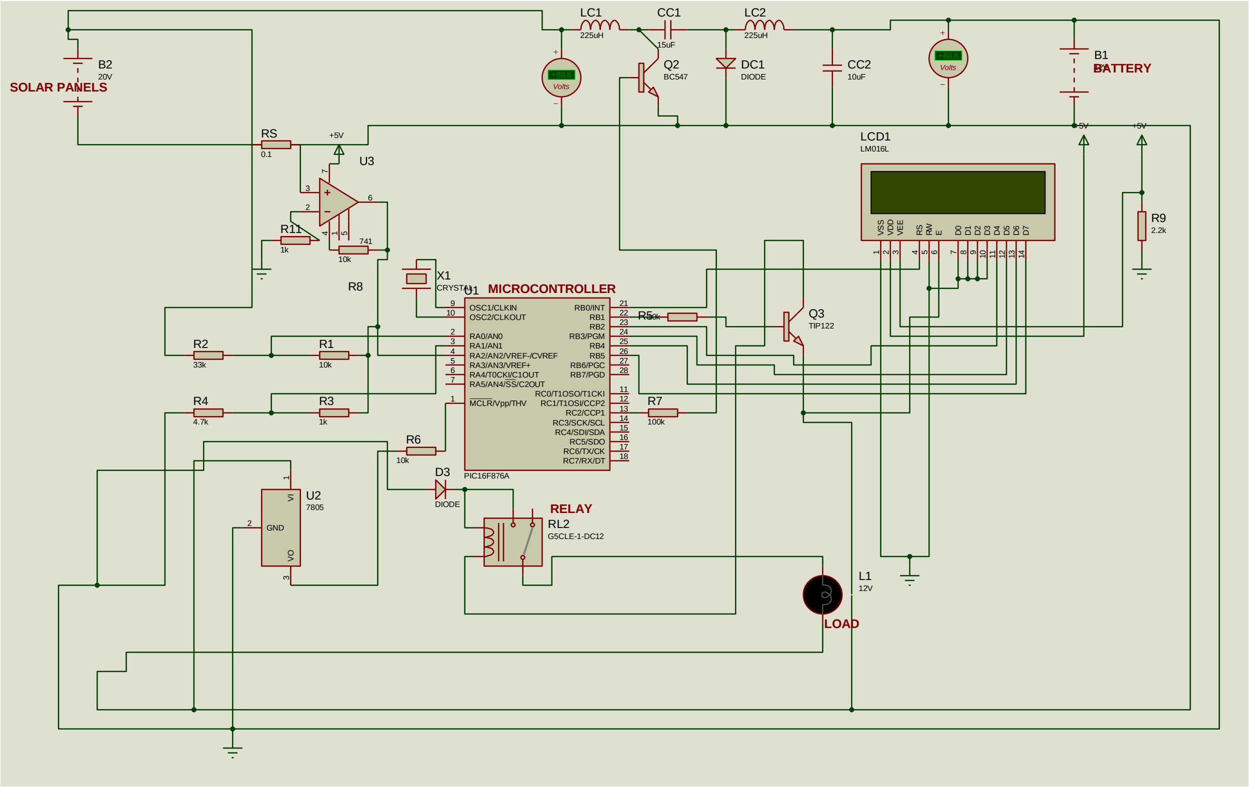


Figure: 5.7 Charge controller design schematic

The MPPT has not been implemented in hardware due to time constraint. Therefore, we were not able to find the actual values at which the MPP was reached. Our future work with include the implementation of the project. However, our analysis of the algorithm and understanding of the different functions shows that by ADC of the voltages and current and PWM of the Cuk converter, we will be able to attain the MPP and implement it on hardware.

CHAPTER 6

CONCLUSION

6.1 Summary

This study presents a simple but efficient photovoltaic system with maximum power point tracker. Description of each component like solar panel, DC-DC converter and charge controller is presented here. MATLAB simulations of I-V characteristics for different irradiance, load and temperature are shown here. As, our aim was to design a system which can extract maximum output power, so we explained about maximum power point (MPP) and maximum power point tracker (MPPT). Researches for different method of algorithms for are done. For better result we compared the Incremental conductance method with Perturb and observe method. Perturb and observe method shows narrowly better performance. The problems solving techniques are also here. This thesis adopts the direct control method which employs the P&O algorithm but requires only two sensors (voltage sensing and current sensing) for output. This control method offers another benefit of allowing steady-state analysis of the DC-DC converter. Various types of DC-DC converters and their topologies are presented in this paper. After analyzing a lot, we choose the Cuk converter for its efficiency. A clear sketch of Cuk converter and its different topologies are presented here. The P-spice simulated result and the relationship between frequency and inductance or capacitance is given here. Also relationship of duty cycle and output voltage and power are attached here. While we implemented in hardware we found that the results matched with the simulation. We designed the whole circuit using micro controller. Our analysis of the algorithm and understanding of the different functions shows that by ADC of the voltages and current and PWM of the Cuk converter, we will be able to attain the MPP. Our future work will include implementation of the system in hardware.

6.2 Concluding remarks:

PV has a powerful attraction because it produces electric energy from a free inexhaustible source, the sun, using no moving parts, consuming no fossil fuels, and creating no pollution or green house gases during the power generation. So, it is our wish to make the P-V system more efficient so that it can help for betterment of life.

References:

1. A. Khalighand O.C. Onar: Energy Harvesting-Solar, Wind, and Ocean Energy Conversion Systems; CRC Press, 2010.
2. Photovoltaic System Engineering [2nd Edition]
   By Roger A. Messenger and Jerry Ventre
3. http://courseware.ee.calpoly.edu/~jharris/research/super_project/ao_thesis.pdf
4. http://www.ti.com/lit/an/slva446/slva446.pdf
5. http://www.archives-ijaet.org/media/15I5-IJAET0511537-COMPARISON-OF-MAXIMUM-POWER-Copyright-IJAET.pdf
6. Power Electronics-Converters, Application and design-[2nd Edition]
   By Ned Mohan
7. Introduction to Power Electronics by Daniel W. Hart
8. http://en.wikipedia.org/wiki/Single-ended_primary-inductor_converter
9. http://en.wikipedia.org/wiki/Buck%E2%80%93boost_converter
10. Akihiro Oi, "Design And Simulation Of Photovoltaic Water Pumping System," California Polytechnic State University, San Luis Obispo, September 2005.
11. [39582b]: PIC16F87XA Data Sheet 28/40/44-Pin Enhanced Flash Microcontrollers, Microchip Technology Inc., 2003.
12. Wikipedia.
13. http://www.techshopbd.com/index.php/productcategories/miscellaneous/miscellaneous/hall-effect-sensor-6851.
14. Marzuq Rahman, et al; "Design of a Charge Controller Circuit for multilevel Solar Panels for Solar Home System," 2012.
15. World Academy of Science, Engineering and Technology 44 2008-A New Maximum Power Point Tracking for Photovoltaic Systems-Mohammed Azeb
16. Batteries and Charge Control in Stand-Alone Photovoltaic Systems Fundamentals and Application-Prepared by:James P. Dunlop, P.E.Florida Solar Energy Center1679 Clearlake RoadCocoa, FL 32922-5703

17. Mohamed Azab, "A New Maximum Power Point Tracking for Photovoltaic Systems," World Academy of Science, Engineering and Technology, 44 2008.