Design and Implementation of Cost-effective Solar Powered Portable Power Bank System for Multi-purpose Applications

Thesis Submitted Towards Partial Fulfilment of the

Requirements for the Degree Of

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VLSI Design and Microelectronics Technology

Submitted By

SAYANTANI BANERJEE

Exam Roll No.: M6VLS22002

Class Roll No.: 001910703002

Registration No.: 150130 of 2019-2020

Under The Guidance Of

ASST. PROF. NIRMOY MODAK

Department of Electronics and Tele-Communication Engineering

Faculty of Engineering and Technology

Jadavpur University, Kolkata – 700032

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FACULTY OF ENGINEERING AND TECHNOLOGY
JADAVPUR UNIVERSITY

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Asst. Prof. Nirmoy Modak
Supervisor
Department of Electronics and Telecommunication Engineering
Jadavpur University, Kolkata-700032

Prof. Ananda Shankar Chowdhury
Head of the Department
Department of Electronics and
Telecommunication Engineering
Jadavpur University, Kolkata-700032

Prof. Chandan Mazumdar
Dean
Faculty Council of Engineering
and Technology (FET)
Jadavpur University, Kolkata-700032

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NAME: **SAYANTANI BANERJEE**

EXAMINATION ROLL NUMBER: **M6VLS22002**

DEPARTMENT: **Electronics and Tele-Communication Engineering (ETCE)**

THESIS TITLE: **Design and Implementation of Cost-effective Solar Powered Portable Power Bank System for Multi-purpose Applications**

____

(Sayantani Banerjee)

Date: ______________

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Sayantani Banerjee

M.Tech. VLSI Design and Microelectronics Technology

Department of ETCE, Jadavpur University

Kolkata-700032, West Bengal, India

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Abstract

Energy is required to do any work. So, to perform any work, be it simply walking or lighting up a locality, energy is required. Different sources of energy can be used for the work to be done. In order to light up a bulb in our home, electricity is needed which is generated by burning Coal or Natural Gas or maybe by a nuclear reaction or probably by a hydroelectric plant set up on a river. These energy sources can be divided into two groups: Renewable (which can be easily replenished) and Non-renewable (that cannot be easily replenished). Most of the energy sources that are used, are non-renewable in nature and hence it is necessary to use energy more efficiently. Also, the rapid use of these exhaustible resources has affected the environment resulting in depletion of the biosphere and accountable for the increasing global warming. So sooner or later we have to rely on renewable resources for energy among which solar energy is an easily available source.

Over the last few years, the dependency on the non-renewable resources has increased to a great percentage due to the increase in population. Thus, research to rely more on the renewable resources is on high demand at present and renewable energy targets are increased in a consisting manner in many countries like the European Union and the United States.

In this work, an attempt has been made to find out an alternative solution towards the transfer of energy dependencies from replenishable energy to abundant solar energy in charging application with reduced cost. The solar powered portable power bank system incorporates an adequate level of charge protection to the li-ion cells in a highly reduced cost as compared to the market price which results in increased lifespan of the system, thus, proving it be economically feasible product. The study of the characteristics of solar cell and its implementation in solar charging is simulated using Matlab/Simulink before proceeding with the hardware design.

Chapter 1:

Introduction

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the present scenario of the world, energy is an important issue as non-renewable energy coming from fossil fuels such as oil, coal, natural gas is present in finite quantities and they will eventually be exhausted completely due to over and continuous extraction by human beings. Even though they are produced naturally but they cannot replenish as quickly as we use them. Also, the rapid use of these exhaustible resources has affected the environment resulting in depletion of the biosphere and accountable for the increasing global warming. So sooner or later we have to rely on renewable resources for energy among which solar energy is an easily available source. They are inexhaustible and most importantly they cause little or no damage to the environment. There have been findings indicating that if solar energy can be stored all over the world for a day, it will produce electricity for a year but it is not easy to store the energy that is generated from the sun. Superior methods of renewable energy resources usage have been introduced and there has been subsequent rapid advancement. This has led to diversify the applications of renewable resources particularly solar energy. As solar energy is available in abundant quantities, it can be used to supply power to the villages where still there is no electricity.

In this work, a cost effective solar powered charging device is being designed. This can be used for multiple purposes along with mobile phone charging. The characteristics of the solar cell is first studied through modelling in Simulink. The effects of variations in irradiance and temperature are also studied. The solar charging of battery is also implemented using Simulink.

Renewable and non-renewable energy resources

Renewable energy resources are those sources of energy which do not get exhausted even after being extensively used. Their availability in the environment is infinite and they can replenish themselves. Therefore, they do not become extinct. These resources are beneficial as they have very less effects on the environment creating less pollution and are sustainable for a long period of time. Renewable energy sources include the hydropower, solar power and wind power.

Non-renewable energy sources can be referred to as those sources which gets exhausted with continuous extraction of them by human beings. They come from natural processes but they take millions of years of time to replenish or renew themselves. Thus, they are termed as exhaustible or non-renewable resources. They also create a loss of damage to the environment. So, their usage is required to be limited in and usage of renewable sources of energy should be encouraged.

1.2 Literature Survey

Invention of Solar cell

The first solar cells made out of selenium wafers were described by made out of selenium in 1883 by an American inventor, Charles Fritts. The history of solar cells traces back to the early observation of the photovoltaic effect in 1839 when while working with metal electrodes in an electrolyte solution, French physicist Alexandre-Edmond Becquerel noticed production of small electric currents when the metals were exposed to light. The effect could not be explained then. After several decades, in 1873, Willoughby Smith, an English engineer made the discovery of the of the photoconductivity of selenium. In 1905, a paper on photoelectric effect describing the carrier excitation effect due to light was published by Albert Einstein along with a paper on relativity theory because of which he won the Noble Prize in Physics in 1921. Next major advancement in solar cell technology was made by Russel Shoemaker Ohl, a semiconductor researcher at Bell Labs in 1940. In 1954 the first photovoltaic cell was demonstrated publicly at Bell Laboratories by Daryl Chapin, Calvin Souther Fuller and Gerald Pearson [4]. Initially during the 1960s, the application of solar cells was limited in space only as they were expensive. Later, the cost of the solar cells reduced due to the invention of the integrated circuits.

Semiconductors

A semiconductor can be defined as a material which exhibit special properties of electrical conductivity. It shows properties of electrical conductivity which falls in an intermediate stage between the insulators and conductors. This provides extremely beneficial for applications in electronics. In 1782, Alessandro Volta used the term ‘semiconducting’ for the first time. The semiconductor effect was first observed by Michael Faraday in 1833 when he observed the decrease in electrical resistance of silver sulfide with temperature. Then in 1874, the first semiconductor diode effect was discovered and presented by Karl Braun. The very first semiconductor device named as ‘cat whiskers’ was patented by Jagadish Chandra Bose in 1901. Bose invented the device to detect radio waves and the device was actually a point-contact semiconductor rectifier. The transistor was co-invented by John Bardeen, Walter Brattain and William Shockley in 1947 at Bell Labs.

In general, group IV A elements silicon and germanium are used in construction of semiconductor devices due to the presence of 4 valence electrons in their outmost shell which adds to the ability of gaining or losing an equal number of electrons simultaneously. Mostly silicon is used in semiconductor devices, because it is the most abundant material on earth [10]. Silicon material can act as insulator, conductor and semiconductor by selective doping. Group III or V elements are doped into silicon to obtain a semiconductor. In this process impurities are added to silicon to change its conductivity and are called extrinsic semiconductors. There are two types of extrinsic semiconductors:

An n-type semiconductor is formed by doping an intrinsic semiconductor with group V elements which have five valence electrons, hence there will be an excess or free electron. 7 On the other hand, the p-type semiconductor is formed by doping an intrinsic semiconductor with group III elements which have three valence electrons hence it will be ready to accept an electron resulting in holes as the majority carrier [11]. By thermal variations the electrons act as minority carriers while a hole indicates the absence of an electron. In p-type semiconductors the Fermi level is below the Fermi level in intrinsic semiconductor. Hence the Fermi level is closer to the valence band compared to the conduction band. Generally, Boron which is a group III element is doped into silicon to get p-type semiconductors.

1.3 Problem Definition

The depletion of the non-renewable resources at an alarming rate and the potential environmental threat associated with the usage of them served as a major driving force to proceed with this work. The necessity to rely on more eco-friendly and unlimited energy resource to charge devices and to trap & store the energy for multiple future use is highly felt. It not only reduces environmental pollution but also facilitates availability of electricity at remote areas with scarcity of electricity. Also, at times of disasters or power shutdowns, this can be used with ease provided the days are sunny.

1.4 Objectives

The objectives of this thesis work are:

- To study the effect of variation of solar parameters on the I-V and P-V characteristics of the modelled photovoltaic cell and to implement solar charging of Li-ion battery using Matlab/Simulink.
- To design a solar powered portable power bank system for charging multiple devices at a reduced cost and to reduce the dependency on non-renewable resources and encourage the use of eco-friendly alternatives to exhaustible sources.

1.5 Organization of the Thesis

The chapters in this thesis are as follows:

Chapter 2 gives a detailed explanation of the history of solar cells, invention of solar cells, solar cell structure and function. Solar arrays and modules are also described.

Chapter 3 consists of the Simulink modelling of the photovoltaic module and the characteristic curves are obtained. Also, the effect of variation of solar parameters on the model are observed. It also consists of the implementation of the solar charging using Maximum Power Point Tracking through a DC-DC buck converter.

Chapter 4 describes the hardware implementation of the solar power bank system. The specifications and the working of the device are discussed thoroughly. The components used i.e. Lithium ion Battery, Solar Charge Controller, DC-DC Buck Converter are described in details.

Chapter 5 consists of the conclusion drawn from the thesis work and directions for future study.

At last, all the references have been given.

Chapter 2:
Solar or Photovoltaic Cell

CHAPTER 2

SOLAR OR PHOTOVOLTAIC CELL

2.1 Solar cell or photovoltaic cell

The Solar Cell is a simple PN junction diode which is capable of absorbing solar radiation and convert solar energy to electrical energy. The solar cell is also referred to as Photovoltaic Cell. The photo diode is used as a component to absorb the photons contained in the sunlight (solar energy) and to release recombined electron-hole pairs and then forming a free electron that gets attracted towards the cathode and the free hole gets attracted towards the anode creating a photo current. In order to achieve this, the n-type and p-type semiconductors are connected for this as shown in figure 2.1

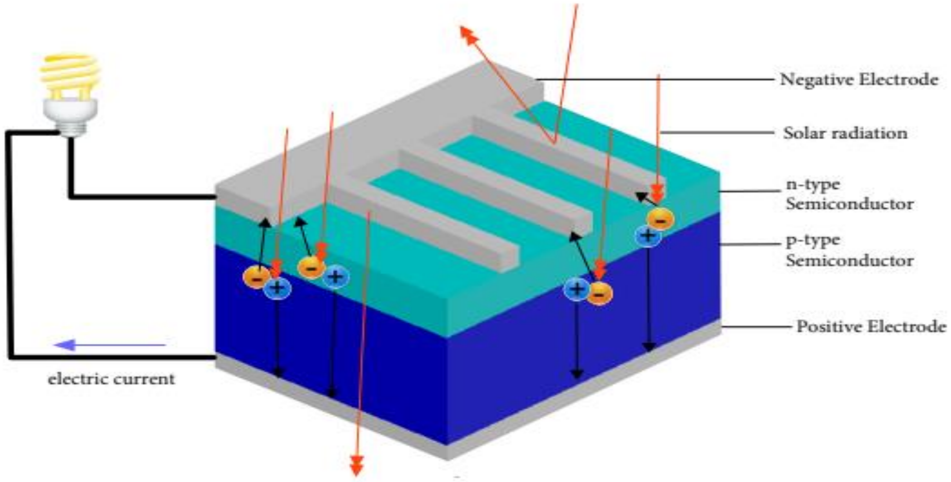


Figure 2.1. Photovoltaic cell structure

At the top, an anti-reflective material coating layer is applied in order to obtain more intensity from the solar energy. When the semiconductor absorbs the photon, it increases the energy of the electron in the valance band and it transitions into the conduction band [2]. The incident photon energy must be greater that the band gap energy in order to make this reaction to occur. These conducting electrons will produce a current through the semiconductor material which moves along the conductors to the load. In the figure the red arrows represent the solar rays, among which there are reflecting rays, rays which miss the solar cell and rays which penetrate through the anti-reflecting layer and break the electron-hole combination.

2.2 Solar Cells Evolution

2.2.1. First Generation

Initially in the first generation, group IV elements such as silicon or germanium were used to manufacture solar cells. As dopants, Boron (group III) and Phosphorous (group V) were used to fabricate p-type and n-type materials respectively. This generation solar cells were also called crystalline silicon based solar cells. Bulk silicon is categorized according to crystal size and crystal alignment which forms wafers [3]. The first generation solar cells are very poor in efficiency, which is around 15-20%. They are highly costly due to their manufacturing cost, yet they have been used a lot for roof tops.

2.2.2. Second Generation

Second generation solar cells, which are also known as thin film solar cells, are manufactured by developing a thin film on a conducting substrate. Some examples are:

(1) Amorphous Silicon Cells: To manufacture amorphous silicon cells requires lower temperatures than the first generation. The base is a metal on which n-layer, intrinsic and p-layer are constructed. Doping is done by introducing hydrogen on to silicon which allows it to form p-type and n-type with boron and phosphorous. By using a thin layer the solar cells are affected by the Staebler-Wronski effect which is a reduction in efficiency due to the increase in recombination current. Recombination increases due to the increased density of hydrogenated amorphous silicon due to light. This effect is reduced by using multiple thin layers.

(2) Polycrystalline silicon on low cost substrate: The polycrystalline silicon is achieved by using chemical decomposition of silane on to silicon wafers. In these cells anti reflection layers are used which increase the time light travels within the cell and by texturing the surface which changes the flat surface to anti reflecting surface.

(3) Copper Indium Diselenide (CIS) Cells: Copper Indium Diselenide is a composition of copper, gallium, indium and selenium. This material can absorb light more efficiently than any other material. It can absorb up to 99% of light within one µm inside the material. These cells are not widely used because they are not stable or efficient.

(4) Cadmium Telluride Cells: Cadmium Telluride cells are manufactured at the lowest cost compared to the conventional solar cells. Cadmium telluride is the base element in these cells. These cells can give energy payback in a short period of time. They are mainly used to generate energy by converting water into steam and use it to rotate a turbine. They are been discontinued because of their effect on the environment when they are recycled [4].

2.2.3. Third Generation

As compared to second generation cells, third generation cells have lower expenditure, thinner films and require lower temperature for more rapid working. Second generation cells are unstable and also sensitive to atmospheric components like oxygen and water. The material, composition of material, the design and architecture, synthesis, combination, layer stacking and the substrate that is used to build on vary to a large extent amongst both the generations. They are flexible, or rigid with high efficiency and huge potential. In this generation, utilisation of organic solar cells is carried out and they are scalable and free from toxic materials. Several technologies have been introduced in this generation for example Quantum Dot(QD) solar cells.

In Quantum Dot cells the quantum dot material has a diameter in nanometers. The smaller size makes its carriers to exhibit quantum confinement. This property gave quantum dots an opportunity to replace bulky semiconductors. To manufacture the Quantum Dot solar cells the principle of centrifugal force is used. Generally, when a photon hits a solar cell surface an electron-hole pair is excited, but in the case of quantum dot solar cells several pairs are excited producing more energy with the same amount of input, which ultimately increases the efficiency of the solar cell. Very active research is going on the solar cells to increase the efficiency by not only changing the chemical properties but also the structure of the cell. Smart solar cells are being invented which follow the direction of sun to absorb more irradiance [4].

2.3 Arrays and Modules

2.3.1Photovoltaic modules

Photovoltaic modules are simply solar cells connected electrically together which provide us with more output as compared to single cells. A module typically consists of 36 solar cells connected in series. They are then sandwiched using a strong material. This material can be either glass or tough plastic. Since solar cells break easily, they are needed to be protected by covering them with hard light transparent glass or plastic as per the application requirement. These solar cells have to be protected by glass on the top and with a backing sheet at the bottom. An aluminium frame is used to protect all these layers. By doing this, the module becomes stronger both physically and chemically and its utility increases. Physical damages include damages due to external forces, and chemical damage is reaction with the atmosphere mostly with water and water vapor which will short circuit the internal connections [4].

2.3.2 Arrays

A solar array or a photovoltaic array is a system which is made up of a group of solar panels connected together by electrically wired together to result in a much larger Photovoltaic system. Generally, if the total surface area of the array is more then, the solar electricity produced will also be more.

The single PV panels are connected to generally obtain an output voltage of 12V or 24V by connecting them in series for a higher voltage requirement and in parallel for a higher current requirement.

The size of the photovoltaic array depends on the energy requirement. It can vary from a few PV individual modules or panels connected together which is generally mounted on a rooftop of a house to consisting of hundreds of panels together connected in a field to facilitate power supply to a whole neighbourhood.

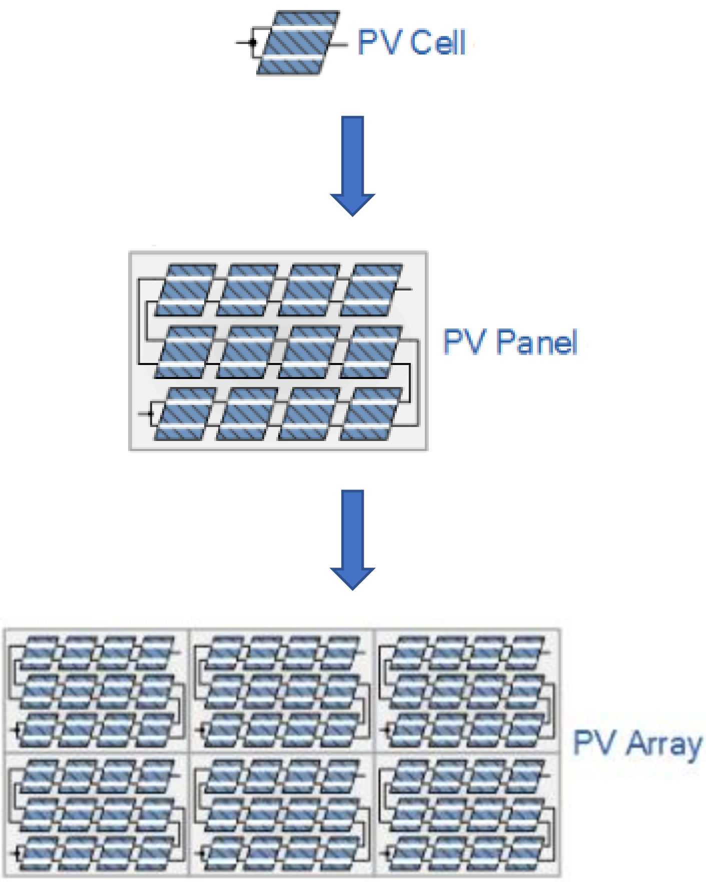


Figure2.3: PV Cell, PV Panel, PV Array[5]

Chapter 3:

Solar Cell Implementation using Simulink

CHAPTER 3

SOLAR CELL IMPLEMENTATION USING SIMULINK

3.1 Modelling of Solar Cell using Matlab/Simulink

3.1.1 Solar Cell Characteristics

A solar module generally contains various solar cells. The working principle of solar cells or photovoltaic module (PV module) is similar to that of photovoltaic effect. The photovoltaic effect is generally referred to as the generation of potential difference at the p-n junction when visible or other radiation comes in contact with it. The I-V and P-V curves of the solar module are of main importance as different types of techniques and algorithms are applied based on these curves which are analysed such as Maximum Power Point Tracking (MPPT) [6]. The following figure shows typical I-V and P-V curves of a solar module or solar cells.

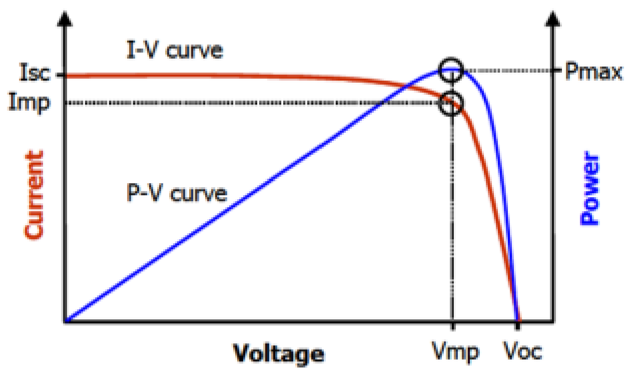


Figure 3.1 I-V and P-V Curves of Solar Cell/Module

3.1.2 Electrical Model of Solar Cell

The photovoltaic cells are represented by an electrical model by the equivalent circuit which consists of a current source, a diode, a shunt resistor and a series resistor. This is shown in the figure below [7]. The different I-V and P-V curves are obtained and analysed by varying various parameters of the solar cell.

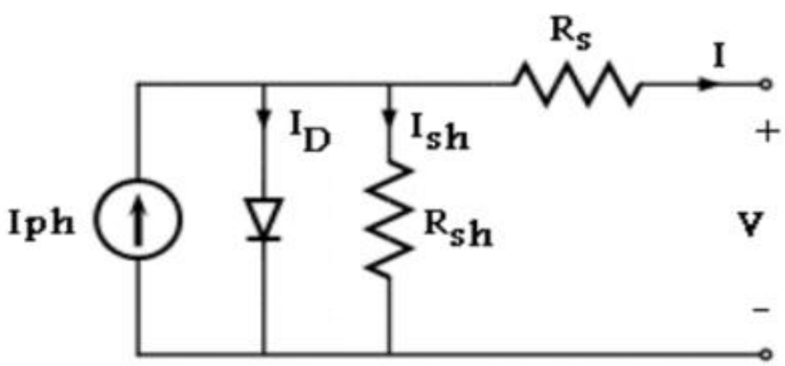


Figure 3.2 Equivalent Circuit diagram of Solar Cell

This section carried out a Matlab/SIMULINK model of Photovoltaic cell that made possible the prediction of the PV cell behaviour under different varying parameters such as solar radiation and ambient temperature.

As per the above circuit, the current to the load is given as:

$$I = I_{ph} - I_0 \cdot \left[\exp\left(\frac{q \cdot (V + I \cdot R_s)}{(n \cdot K \cdot N_s \cdot T)}\right) - 1\right] - I_{sh} \qquad 1$$

Here I_{ph} → photocurrent

I_0 → saturation current of the diode

I_{sh} → Current through shunt resistor

q → electron charge

V→ voltage across the diode

K→ Boltzmann Constant

T→ junction temperature

N_s → ideality factor of the diode

R_s → series resistor of the cell

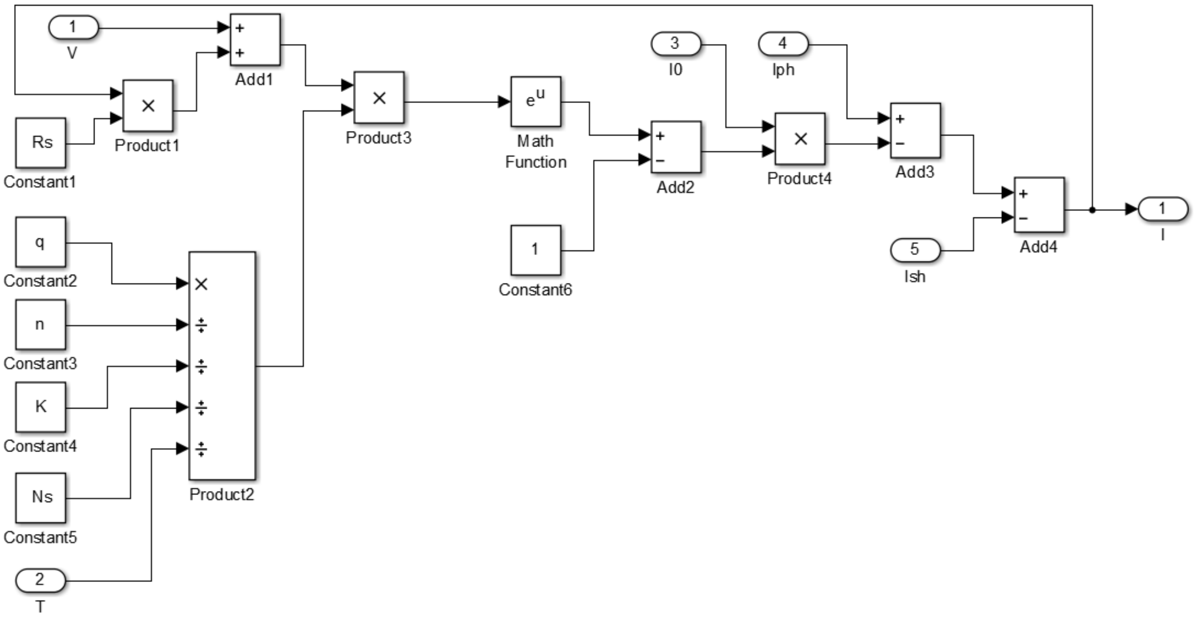
The current through the shunt resistor is given by:

$$I_{sh} = \left(\frac{V + I \cdot R_s}{R_{sh}}\right) \qquad 2$$

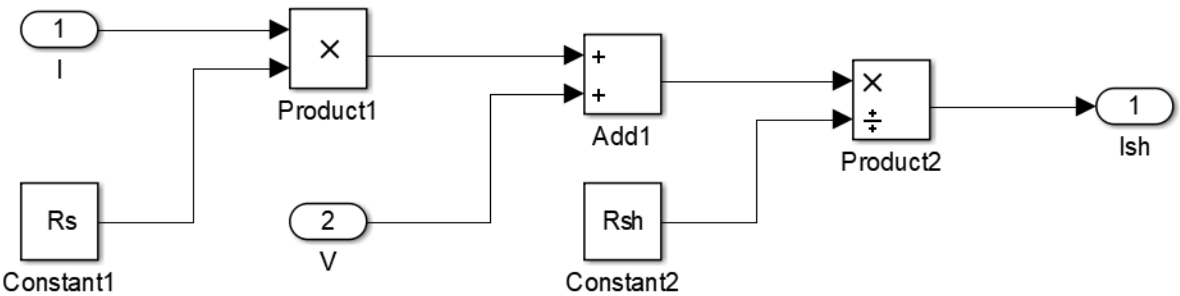
R_{sh} → shunt resistor of the cell

Therefore, it is understood that the total physical behavior of the PV cell is related to Iph, Is, Rs, Rsh from one hand and to environmental parameters which are the solar radiation(irradiance) and the temperature on the other hand.

PV Current subsystem



Shunt Current subsystem



3.1.3 Solar radiation Variation

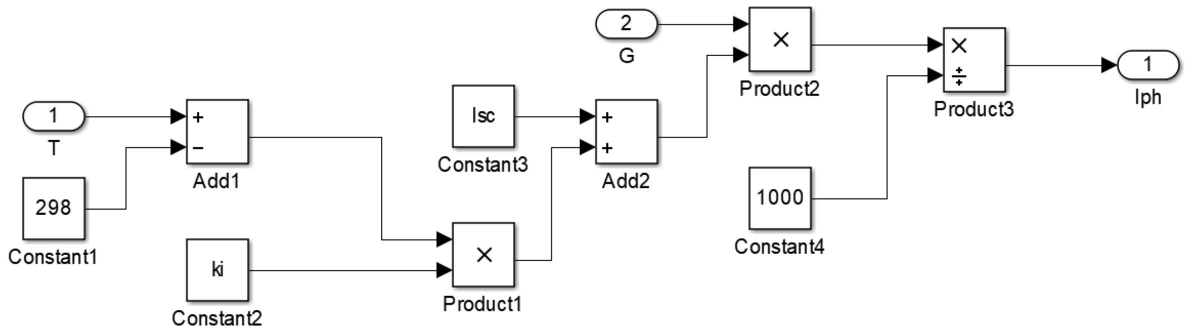
The photo current of the photovoltaic cell depends on the radiation and temperature of the sun according to the following equation:

$$I_{ph} = [I_{sc} + k_i \cdot (T - 298)] \cdot \left(\frac{G}{1000}\right) \qquad 3$$

Where ki=0.0017A /℃ → cell's short circuit temperature coefficient

G → solar radiation in W/m^2

Based on the above equation, the subsystem is obtained as:



3.1.4 Reverse saturation current

The reverse saturation current is given by the equation

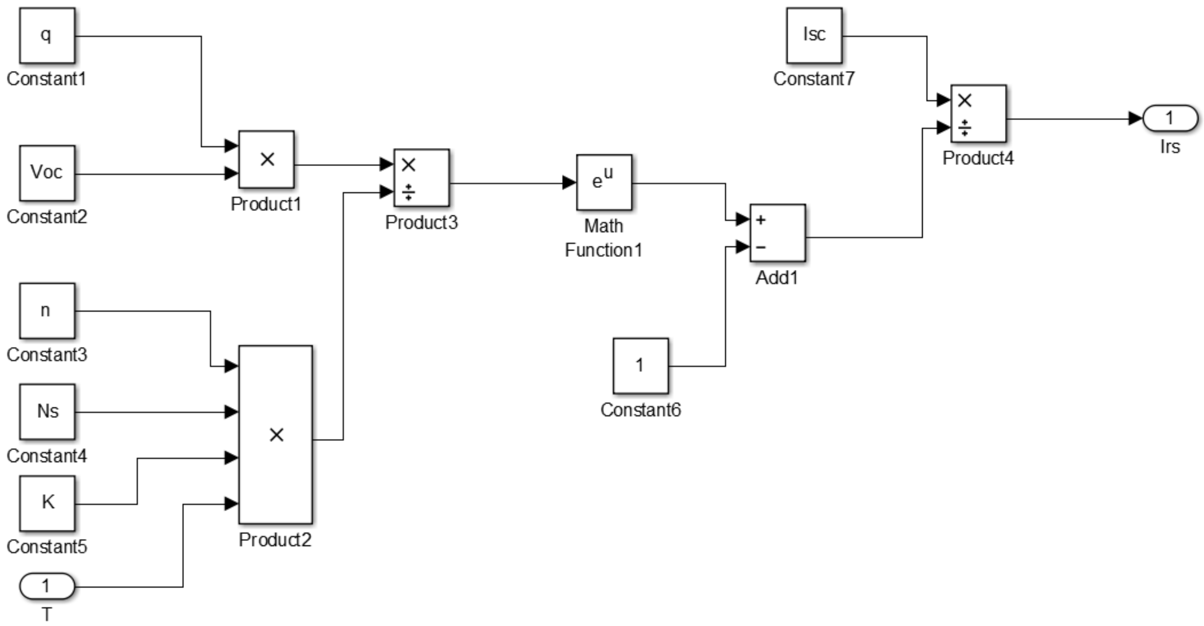
$$I_{rs} = \frac{I_{sc}}{\left(e^{\left(\frac{(q \cdot V_{OC})}{n \cdot N_S \cdot K \cdot T}\right)}\right) - 1} \qquad 4$$

And the (reverse) Saturation current as function of temperature can be expressed as:

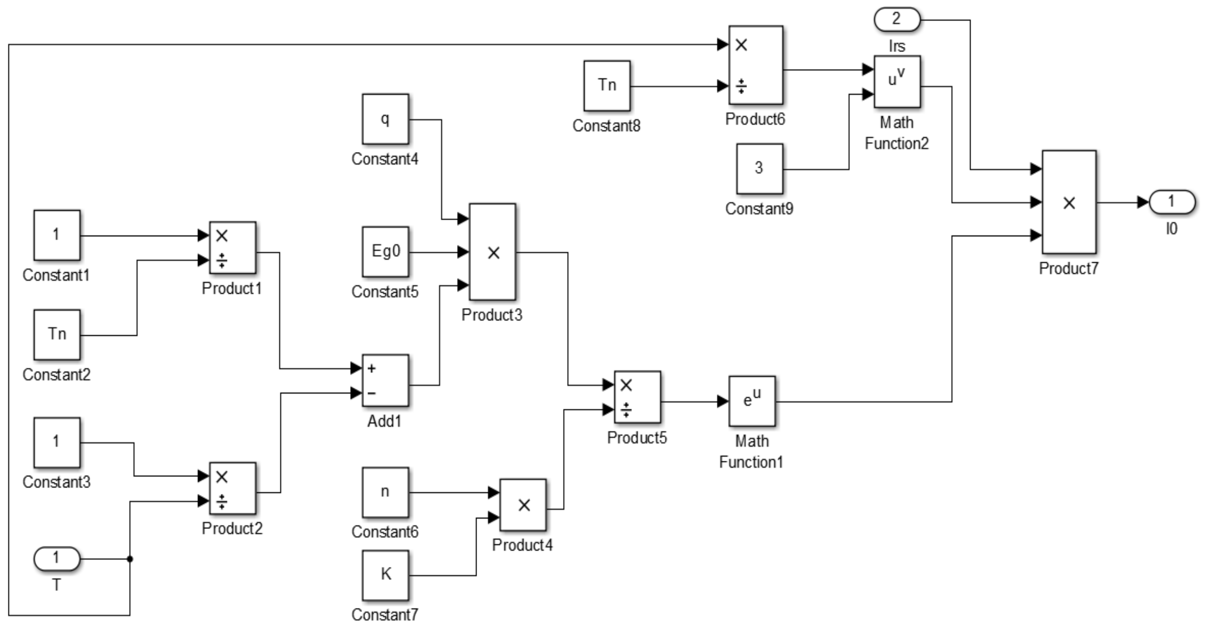
$$I_0 = I_{rs} \cdot \left(\frac{T}{T_n}\right)^3 \cdot \exp\left[\frac{q \cdot E_{g0} \cdot \left(\frac{1}{T_n} - \frac{1}{T}\right)}{n \cdot K}\right] \qquad 5$$

Thus, it can be seen that the diode reverse saturation current varies as a cubic function of the temperature.

Reverse Saturation Current



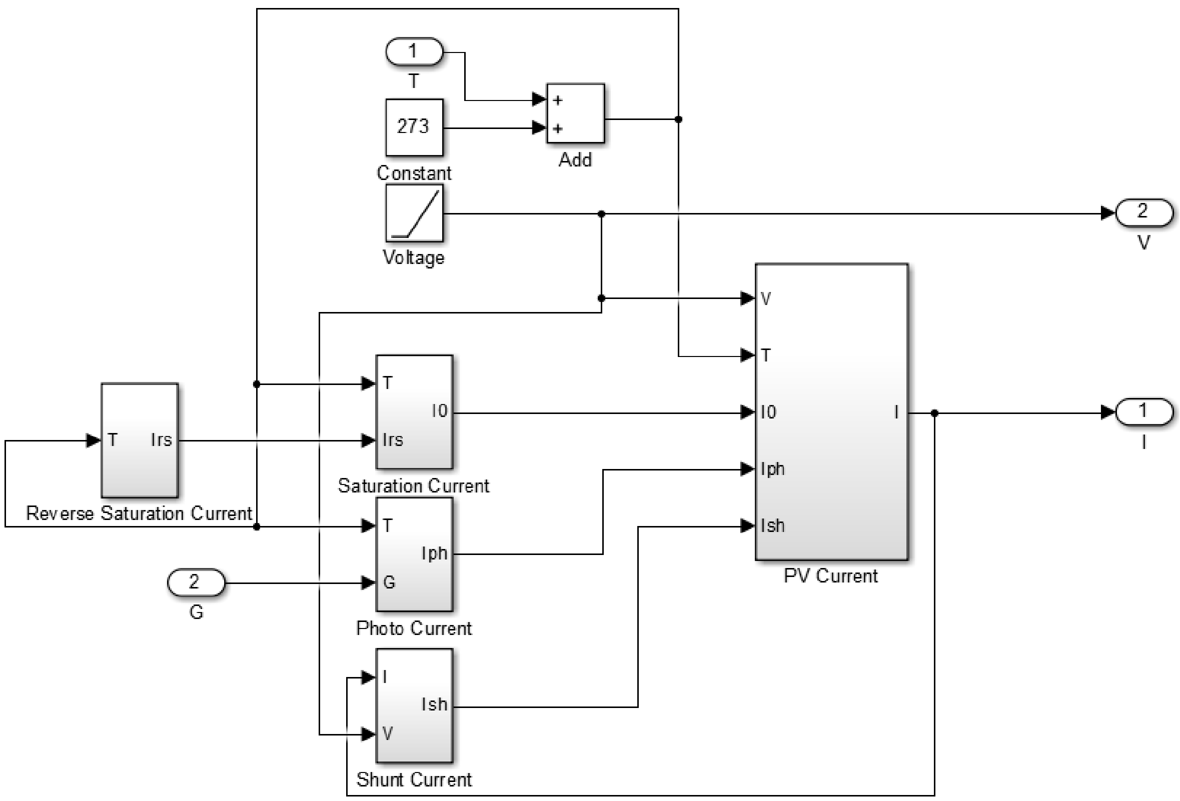
Reverse Saturation Current as function of Temperature



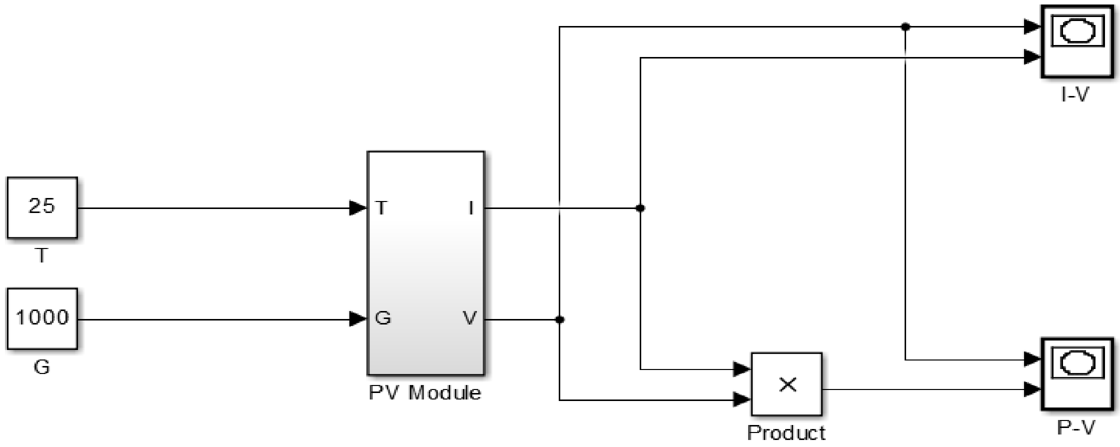
3.1.5 PV Module

PV Module is referred to as a group of PV cells that are in connection with each other in series.

All the subsystems together form the below model as one subsystem:



Finally, the above subsystem can be modelled as the PV Module as the following:



3.1.6 Result Analysis

Observations

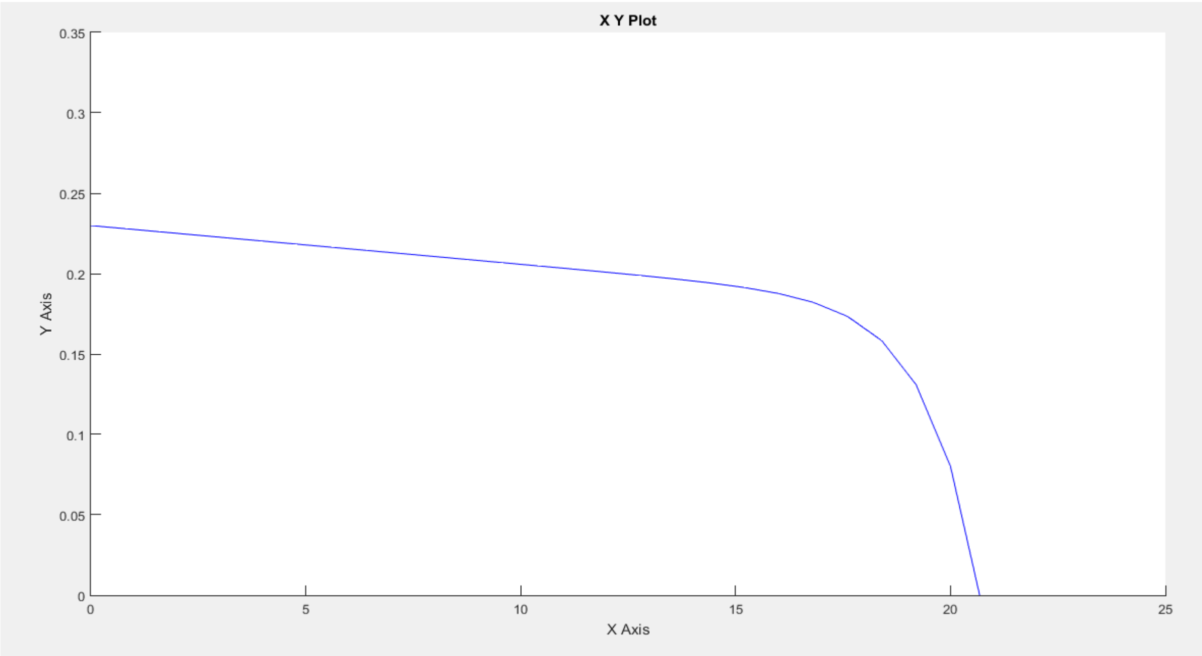
The I-V and P-V characteristics for the above model are obtained through simulation and the observations are noted and discussed.

1) **Effect of Variation in Radiation**

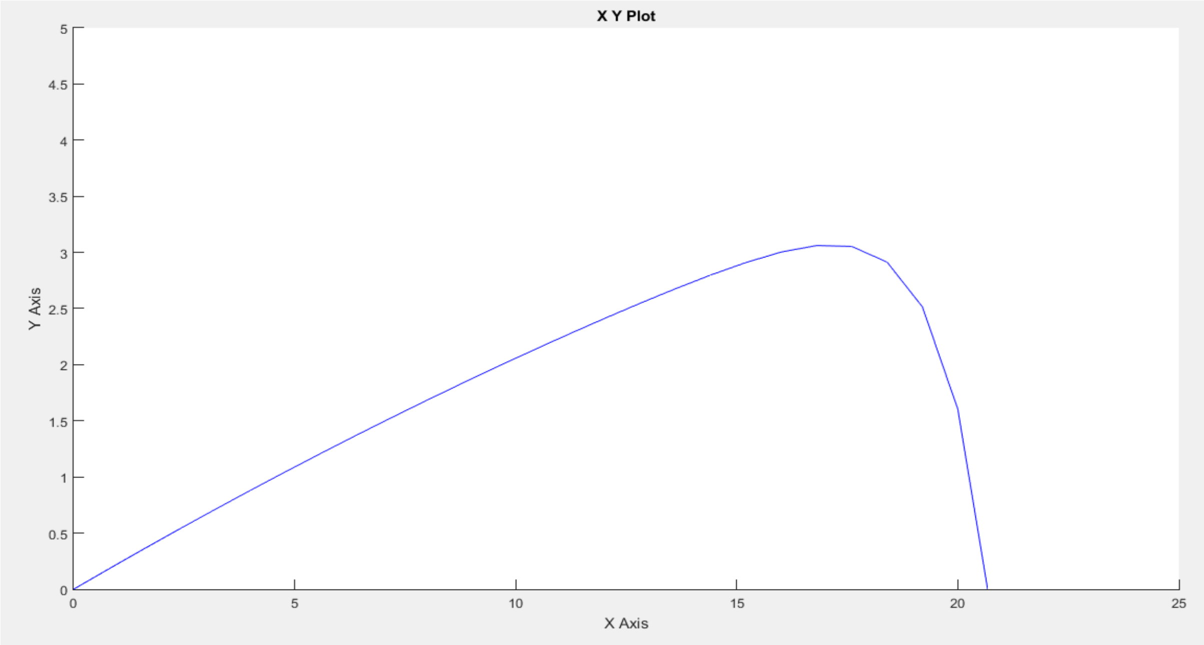
Keeping Temperature constant at 25℃ and varying the irradiance input of the solar panel:

At Irradiance(G)=1000W/m^2

I-V Characteristics

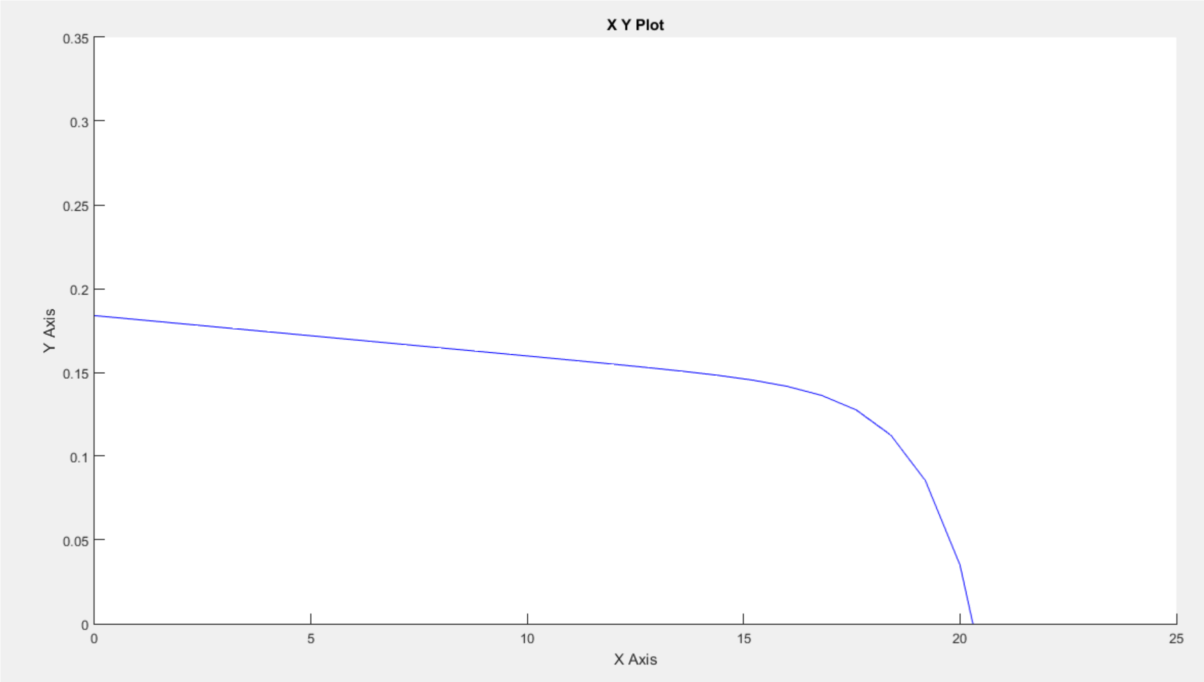


P-V Characteristics

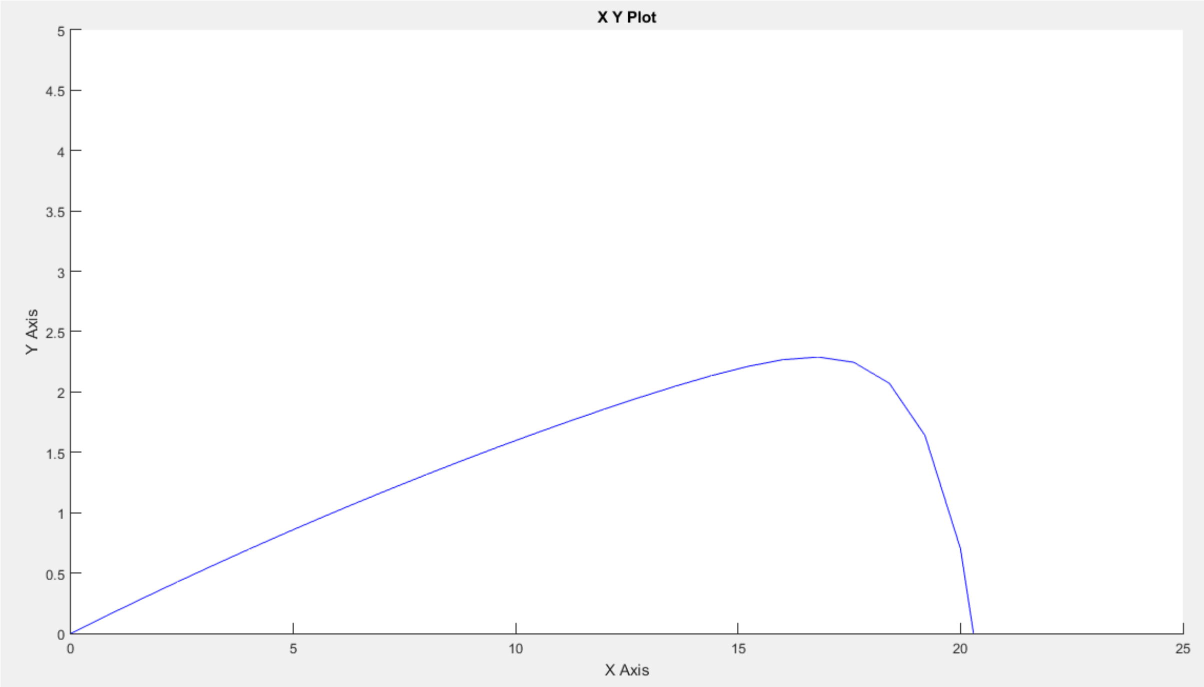


At Irradiance(G)=800W/m^2

I-V Characteristics

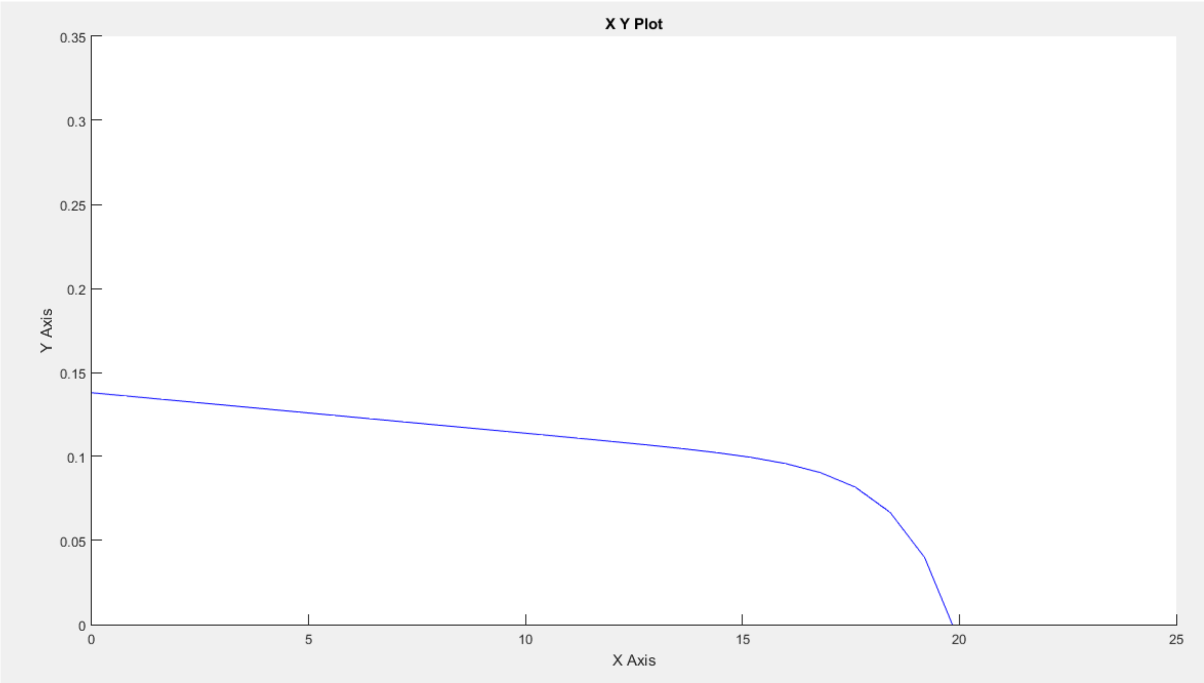


P-V Characteristics

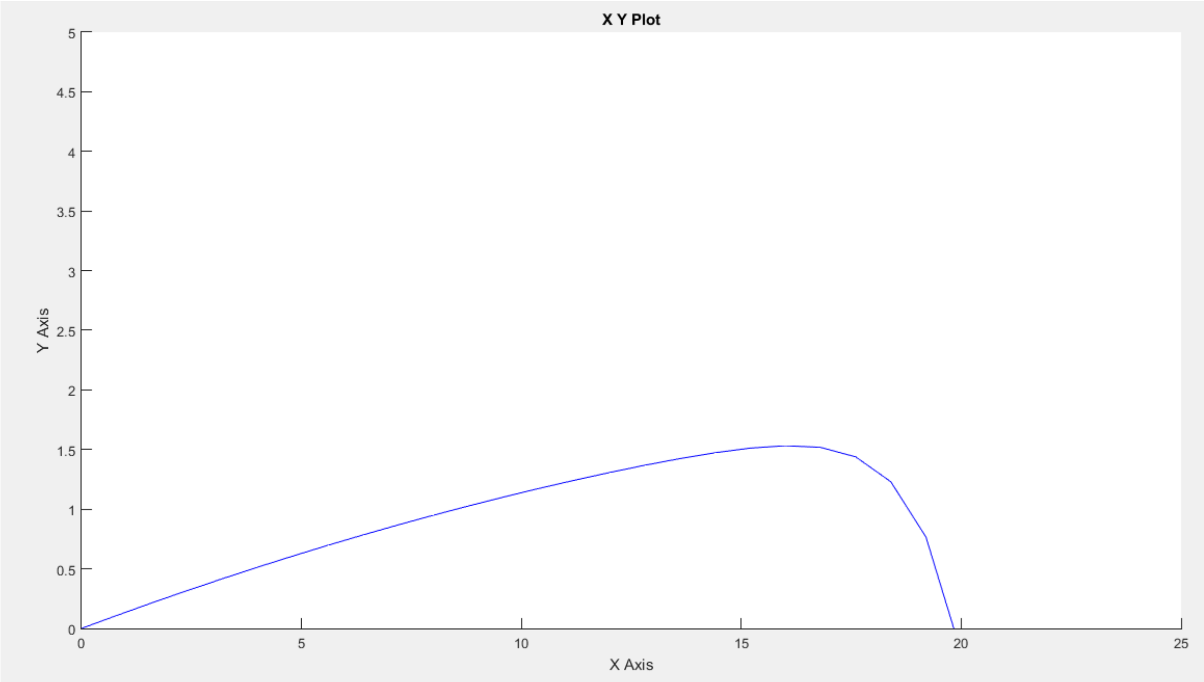


<u>At Irradiance(G)=600W/m^2</u>

I-V Characteristics

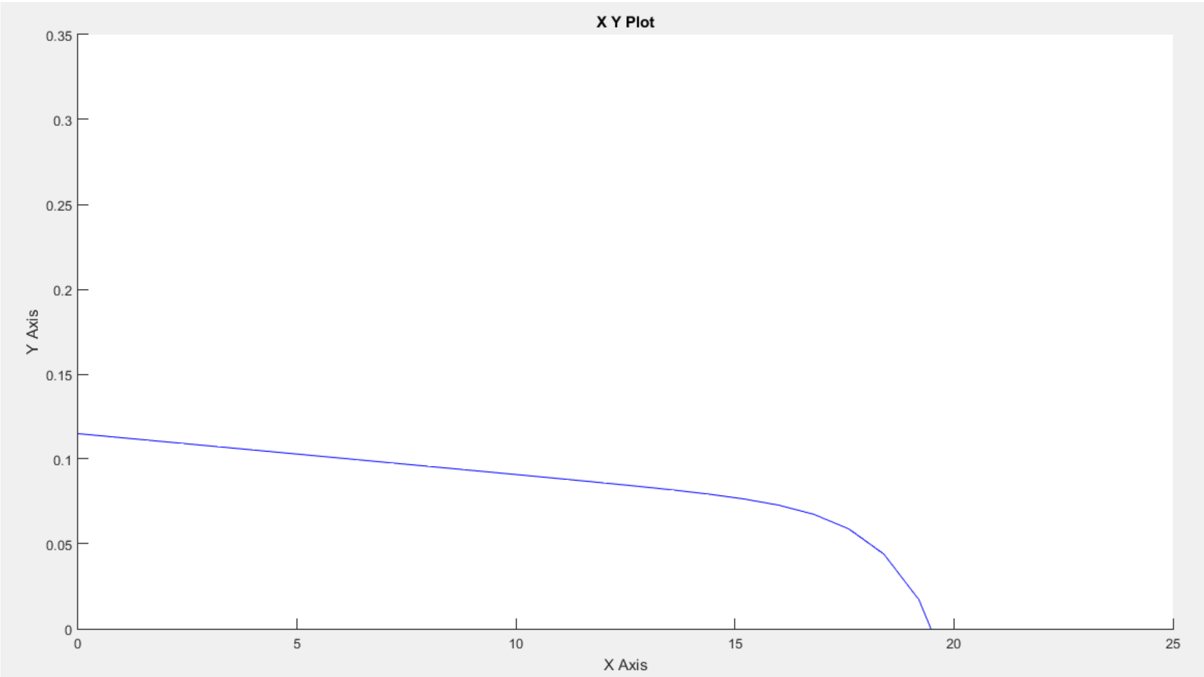


P-V Characteristics

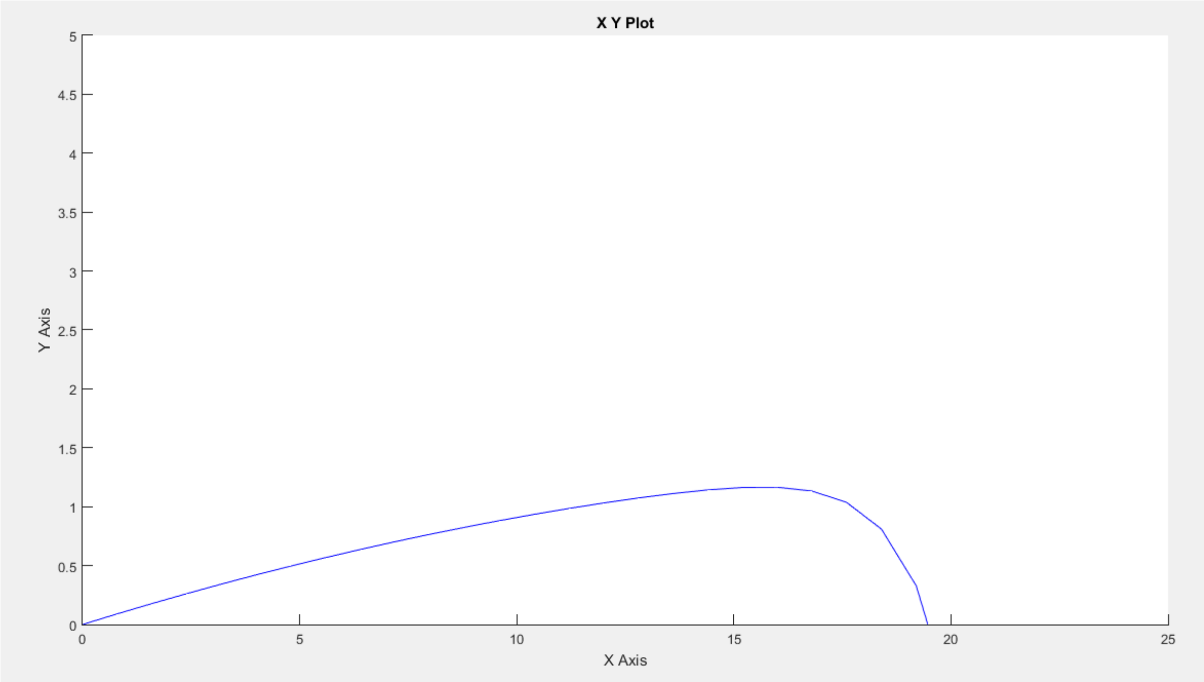


At Irradiance(G)=500W/m^2

I-V Characteristics



P-V Characteristics



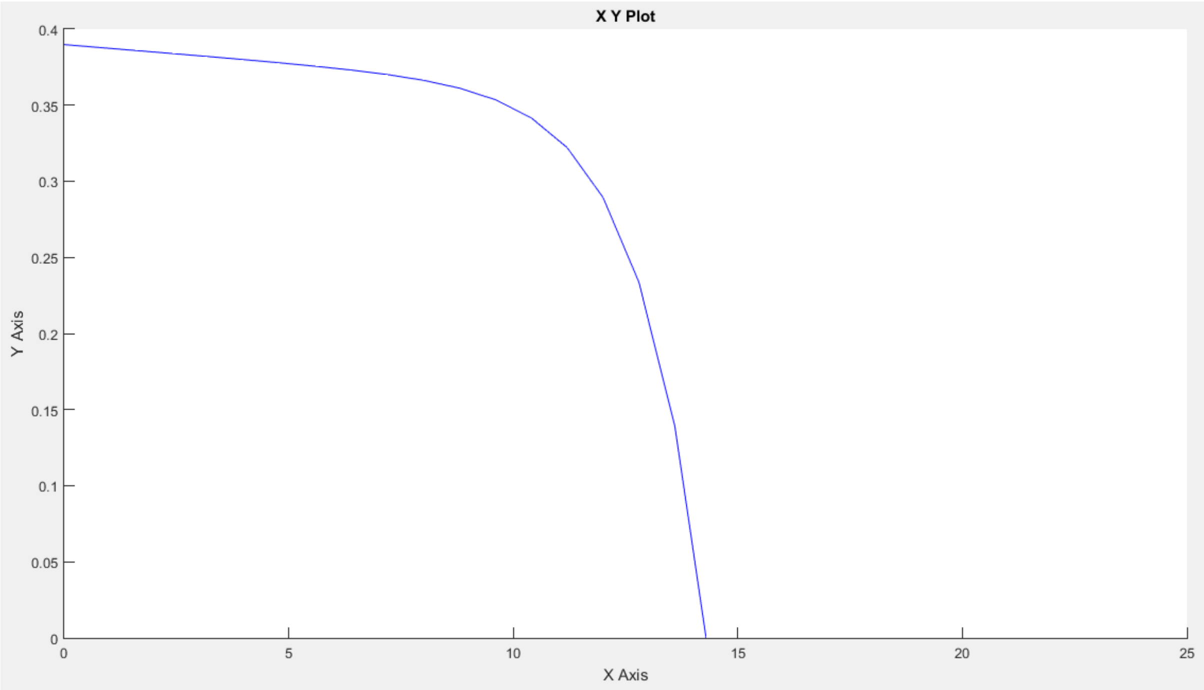
Observation: After simulating and obtaining the results, it can be observed that the Photovoltaic Cell current depends on the solar radiation or the irradiance. With increasing solar radiation from 500W/m^2 to 1000W/m^2, the current increase strongly. On the other hand, it is also seen that there is a rise of voltage from 500W/m^2 to 1000W/m^2 which is around 2V.

2) Effect of Variation in Temperature

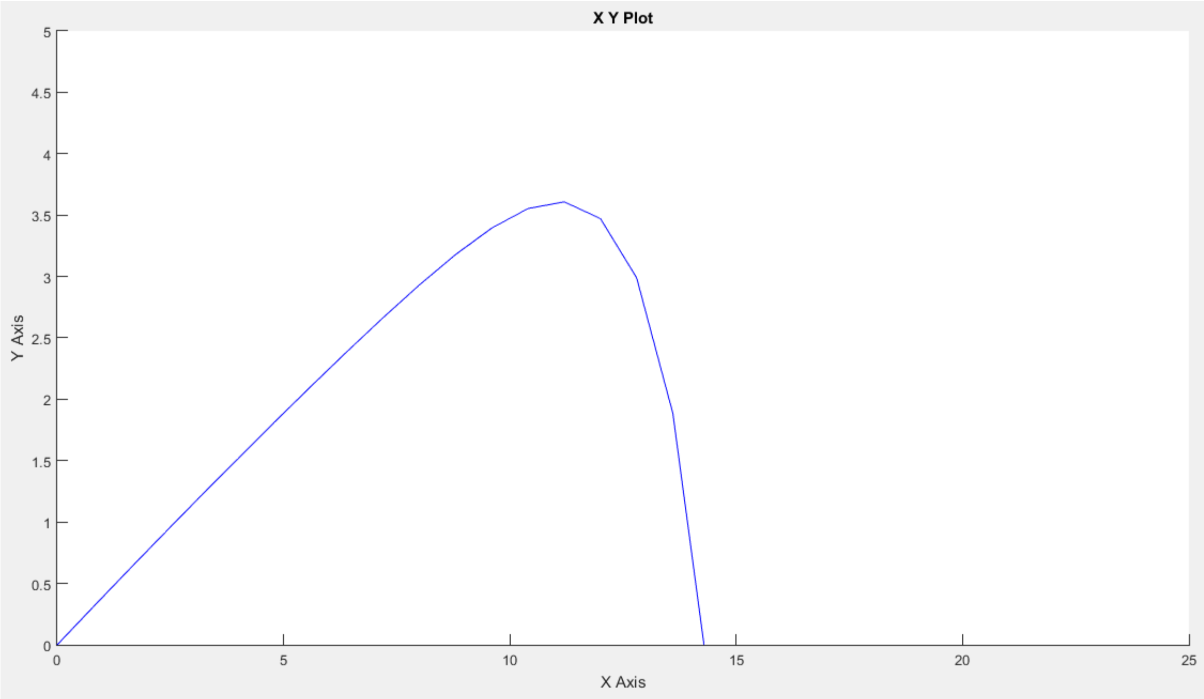
Keeping Solar radiation constant at 1000W/m^2 and varying the Temperature input of the solar panel:

At Temperature(T)= 75̊C

I-V Characteristics

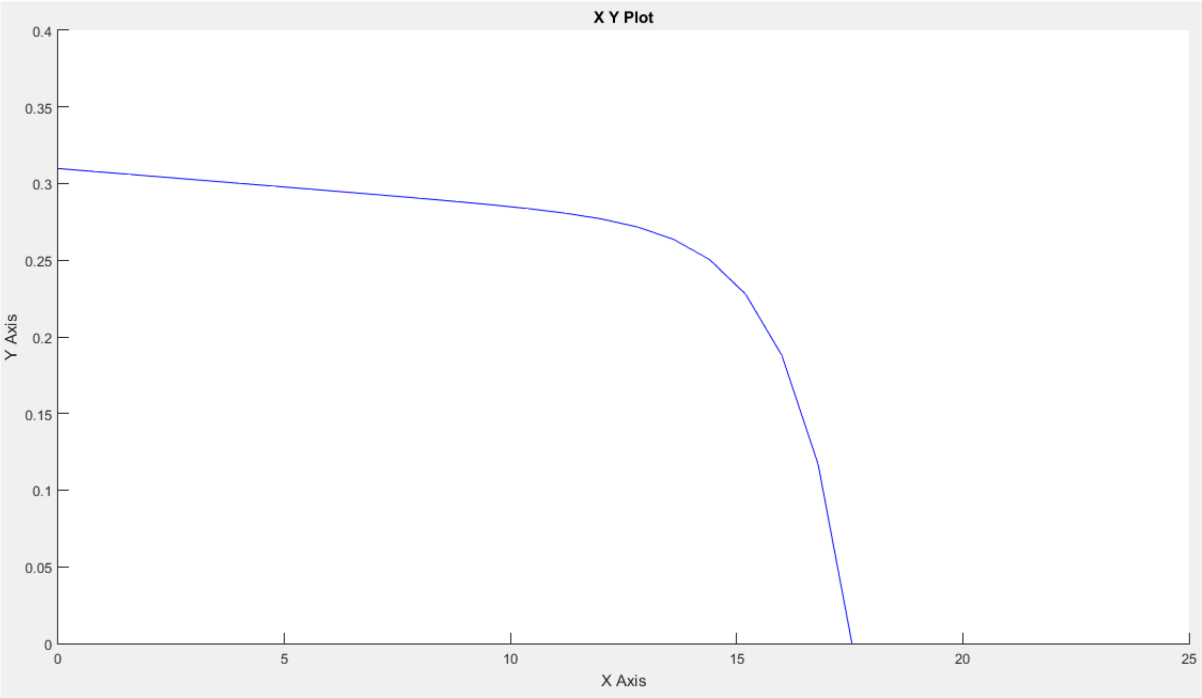


P-V Characteristics

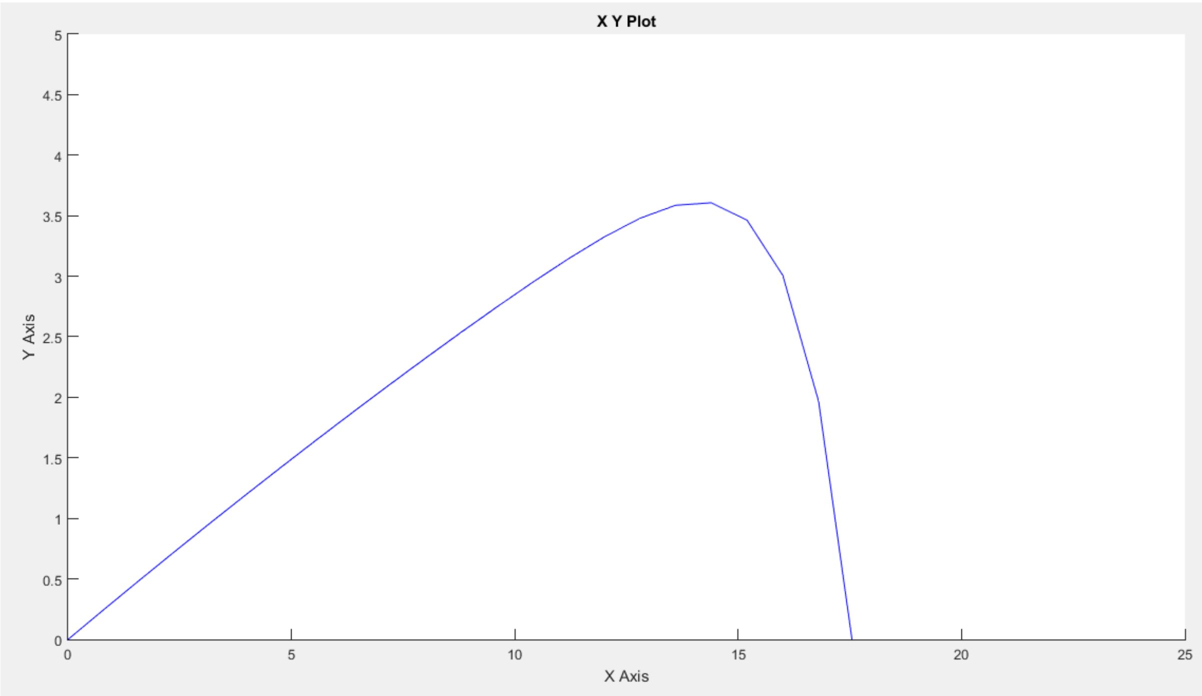


<u>At Temperature(T)= 50°C</u>

I-V Characteristics

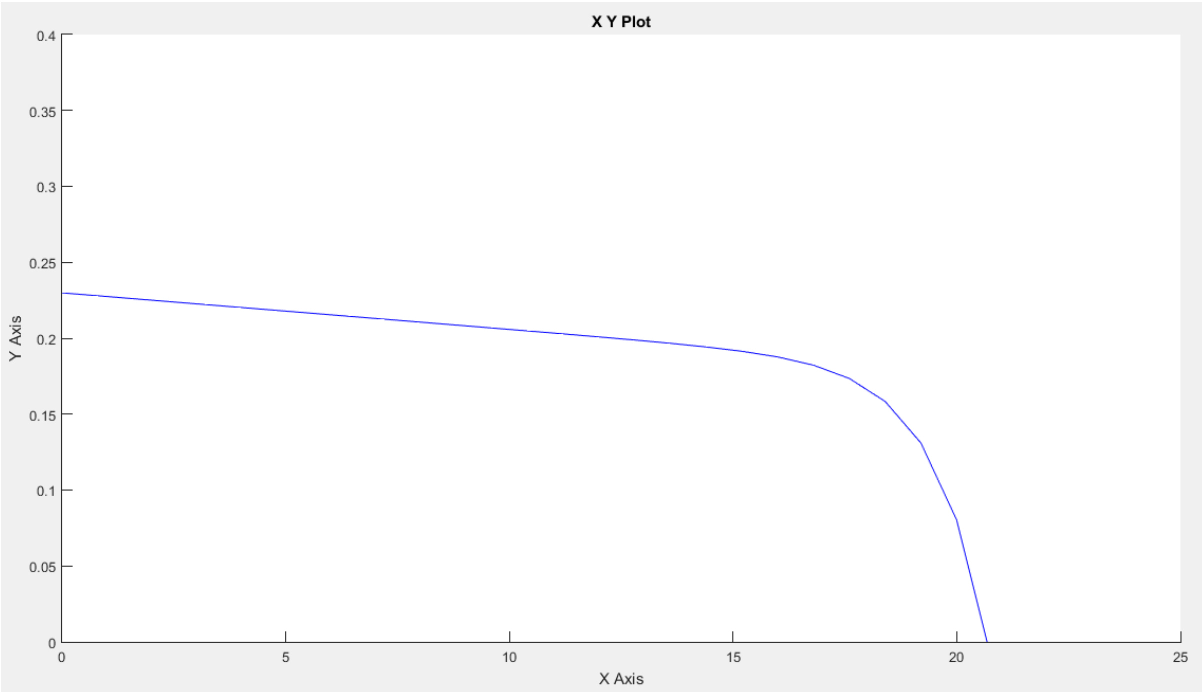


P-V Characteristics

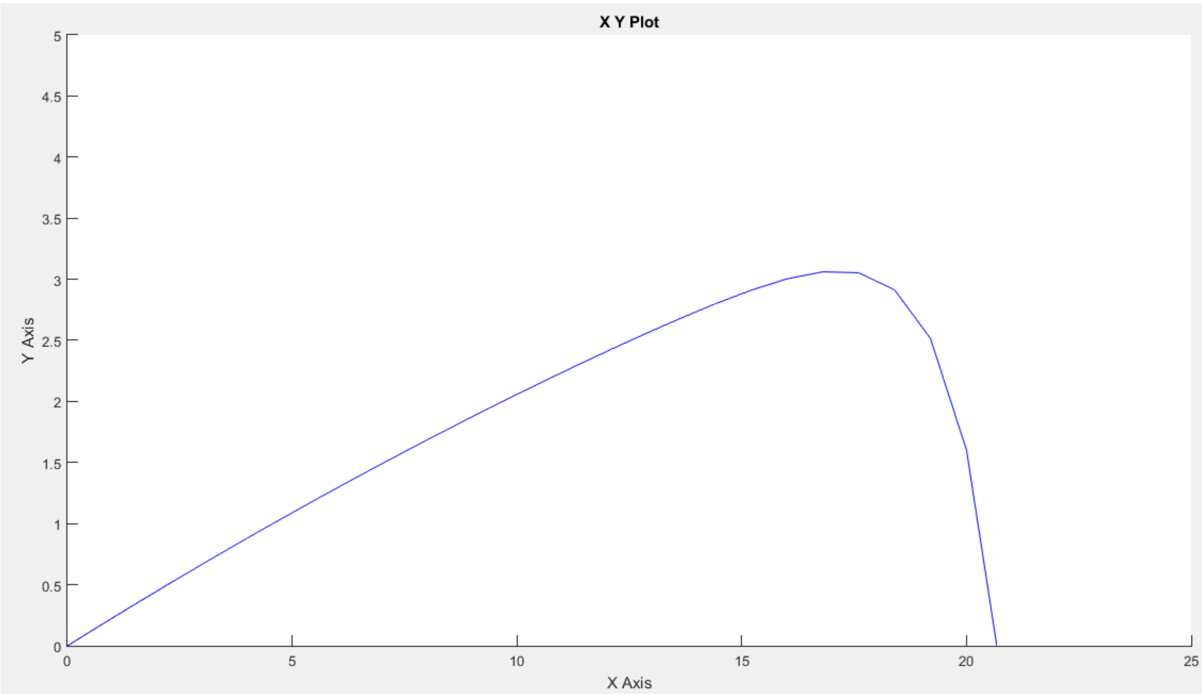


At Temperature(T)= 25℃

I-V Characteristics



P-V Characteristics



Observation: It is known that for a particular constant solar radiation, generally the open circuit voltage tends to drop when the cell temperature increases while on the other hand, the short circuit current increases with the rise in temperature. This behaviour is obtained and validated from the above figures.

3.2 Solar Charging of Li-ion Battery Simulink Implementation

In this section, the charging of a 12V lithium-ion battery using solar cell is implemented by utilising Matlab/Simulink. The components used in this model include Solar panel, DC-DC buck converter, MPPT subsystem.

3.2.1 Block Diagram

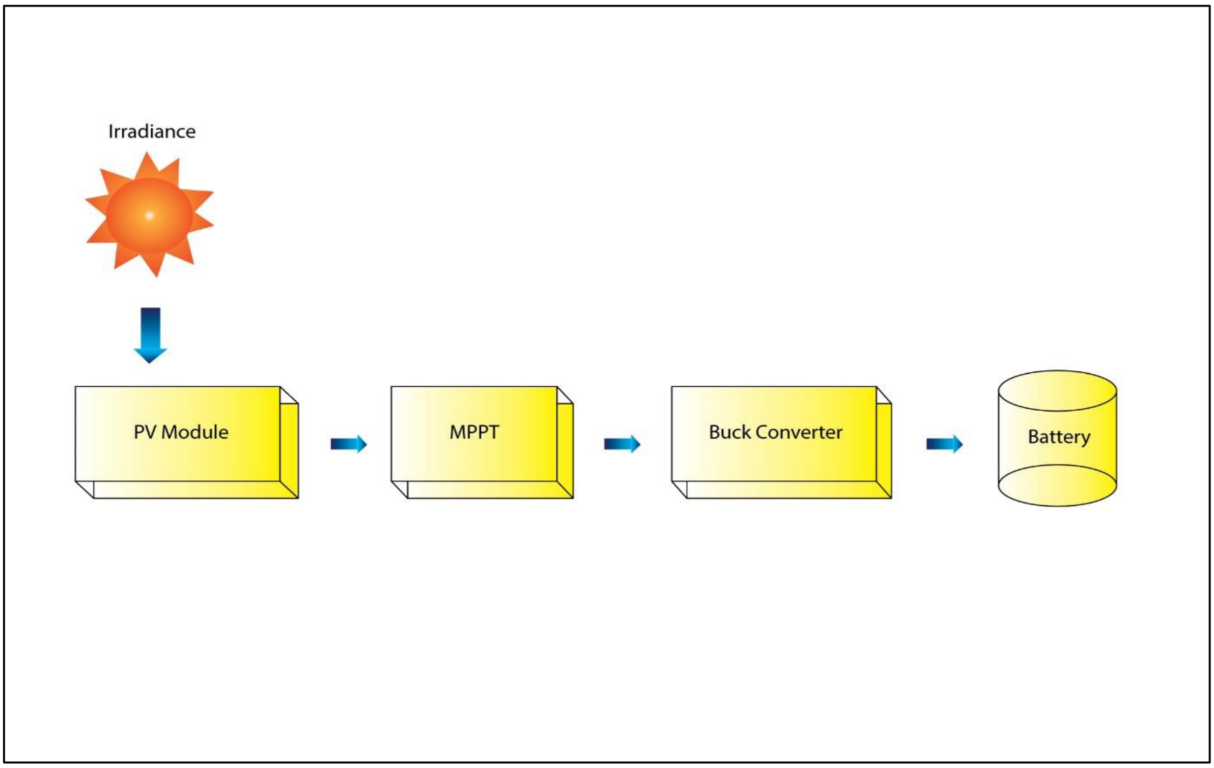


Figure 3.2.1: Block Diagram of Solar charging of Battery

3.2.2 Description & Working

MPPT: Maximum Power Point Tracker

As the name implies, a Maximum Power Point Tracker is referred to as an electronic converter which develops a barrier between the solar panel and the battery. The MPPT is needed as the source that is the Sun from where the solar cell module receives energy is not always constant and varies with time. So, the match between the solar cell module and battery should be optimized by some means. A solar photovoltaic array has one point on its current vs. voltage characteristic at which we get the maximum power output which is known as the maximum power point [8].

Systems which are not designed to operate at the maximum power point are wasting a significant amount of energy available.

In order to control the voltage and hence current, a controller (DC-DC converter) is required for better control over output voltage. The converter switch is controlled with an MPPT algorithm. Some of the popular MPPT algorithms are described below:

(1) <u>Incremental conductance:</u> This algorithm is based on the comparison of the incremental conductance to the instantaneous conductance in a PV system. The voltage is increased or decreased by the algorithm until the maximum power point (MPP), taking previous reading as the reference.

(2) <u>Fractional open-circuit voltage:</u> This algorithm is based on the principle that the maximum power point voltage is always a constant fraction of the open circuit voltage.

(3) <u>Perturbation and observation:</u> This algorithm perturbs the operating voltage to ensure maximum power. P and O algorithms have simple structure and few parameters to be measured. Periodically perturbing is the operation in which voltage is incremented and decremented and comparing the present output power with the previous output power. The perturbation direction will remain the same if the power is increasing, and will be reversed if the power is decreasing. The algorithm works when instantaneous PV array voltage and current are used, as long as the sampling occurs only once in each switching cycle. The process is repeated periodically until the MPP is reached. The system then oscillates about the MPP. The oscillation can be minimized by reducing the perturbation step size. However, a smaller perturbation size slows down the MPPT. To overcome the problem of this slow response in reaching the MPP, a new algorithm has been developed so that MPP can be reached faster compared to that of conventional P and O. The algorithm flow is presented in figure 3.2.2(a). The algorithm is based on algorithms proposed in [8,9].

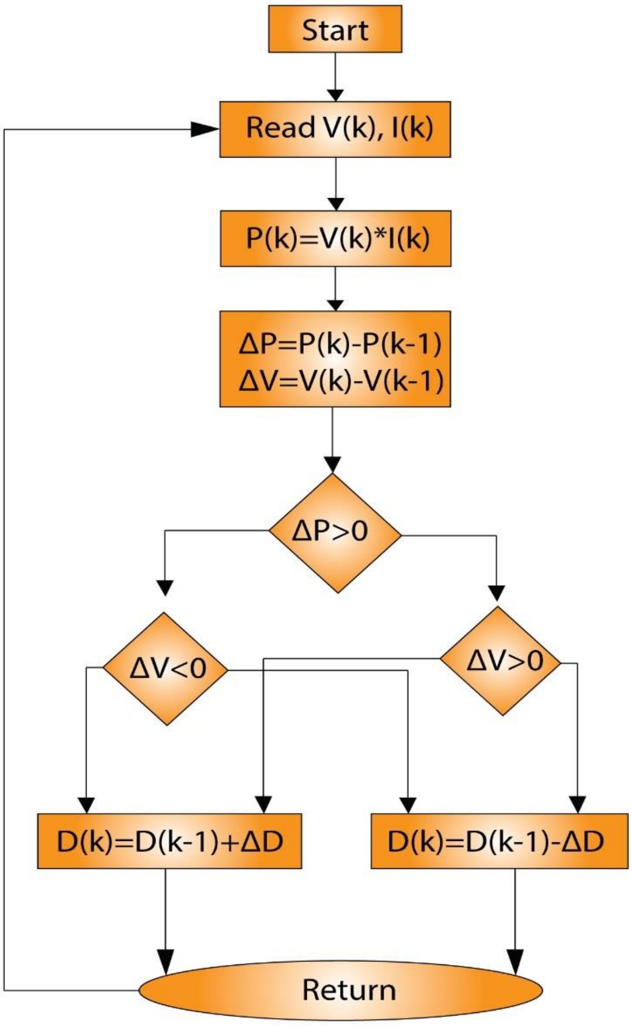


Figure 3.2.2(a)

By using this principle, an MPPT circuit is constructed by using memory block for delay and transistor switches for switching as given in figure 3.2.2(b). The output of this circuit will be given to PWM which generates a PWM signal used by the DC-DC buck converter to generate a stable input to battery.

MPPT subsystem

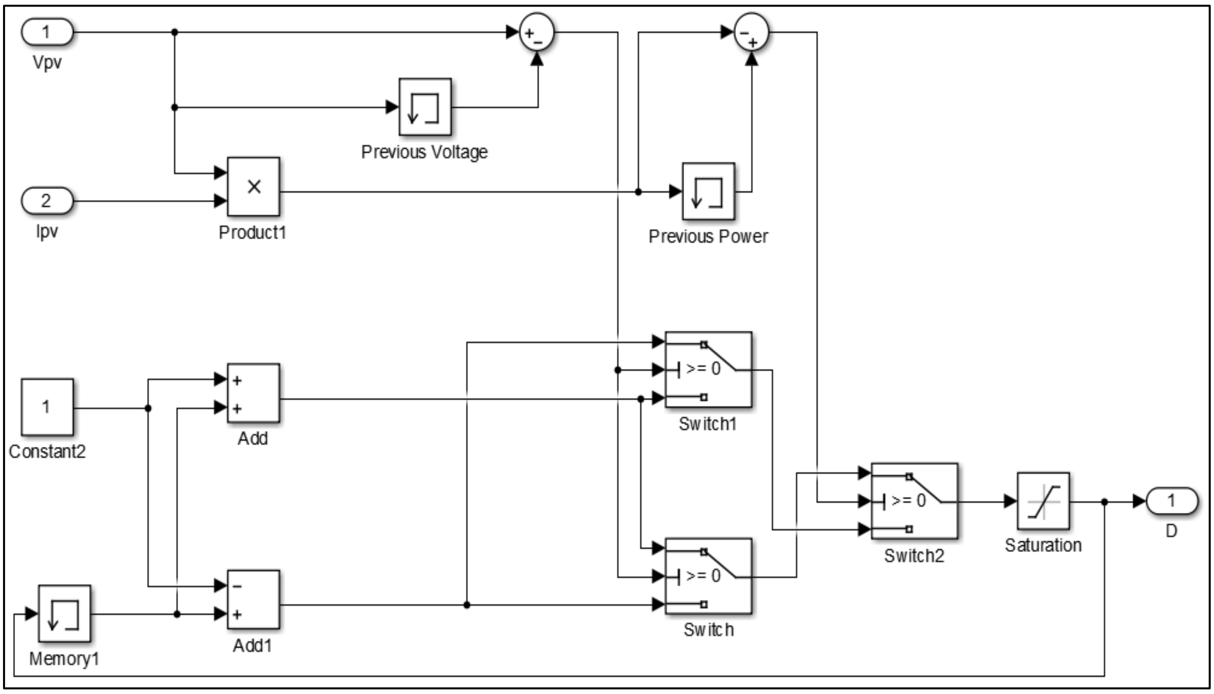


Figure 3.2.2(b)

3.2.3 Simulation Model:

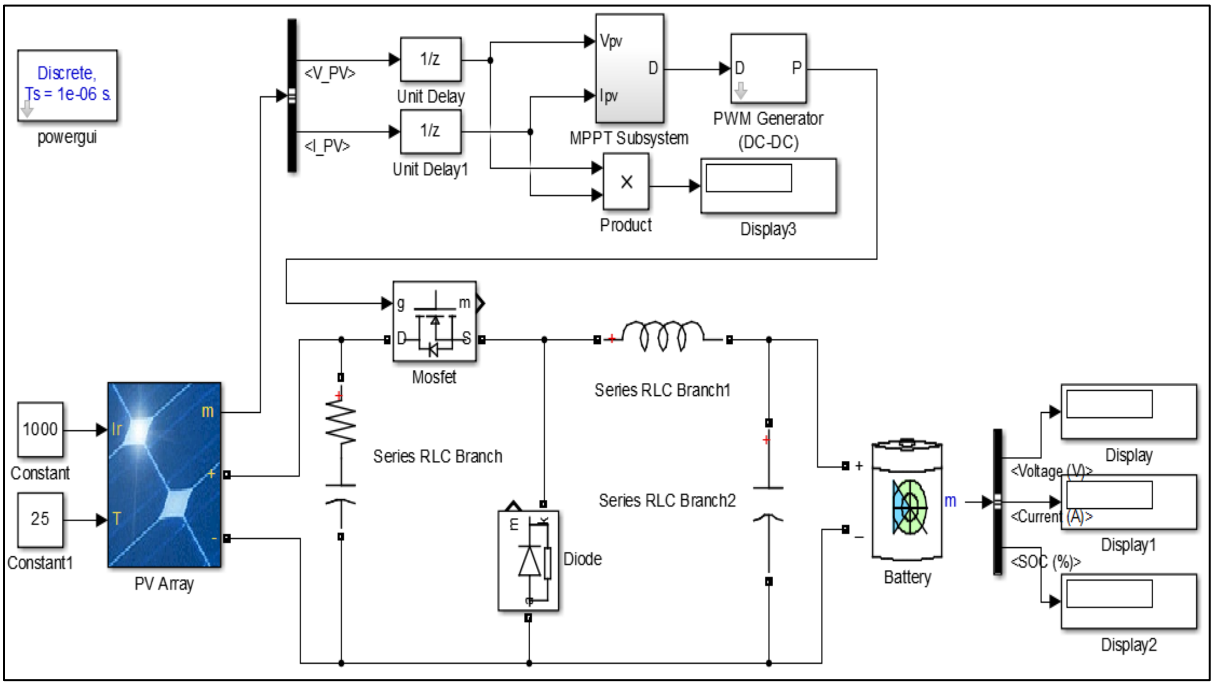


Figure 3.2.3

The pulse width modulated signal is generated by using the given input reference signal and a sawtooth signal. The output pulse signal is generated by comparing the input reference signal and sawtooth signal [1]. The frequency of the sawtooth signal can be varied according to the requirements by the user. The input reference signal will decide the duty cycle of the output signal. The input for this block is given by the output of the MPPT. The output of PWM will decide when the MOSFET is to be ON and OFF. This ultimately serves as a DC-DC converter.

<u>Solar Array Specification</u>

Rated Power-210W

Vinput=28-36V

Voutput = 12V

Fsw=5kHz

Iripple=10%

Vripple=1%

Output Current = 17.5A

Current Ripple = 10% of 17.5 = 1.75A

Voltage Ripple = 1% of 12 = 0.12V

<u>Calculation Of Inductance and Capacitance</u>

Inductance, L = $\frac{V_{op}(V_{ip}-V_{op})}{f_{sw}*I_{ripple}*V_{ip}}$

= 0.783mH

Capacitance, C = $\frac{I_{ripple}}{8*f_{sw}*V_{ripple}}$

= 364μF

Battery Characteristics	Specific Values
Battery Type	Lithium Ion
Nominal Voltage	12V
Initial SOC	50%
Fully Charged Voltage	12.6V

The characteristics of PV Array used in the model are given in the figure below.

At Irradiance = 1000W/m^2

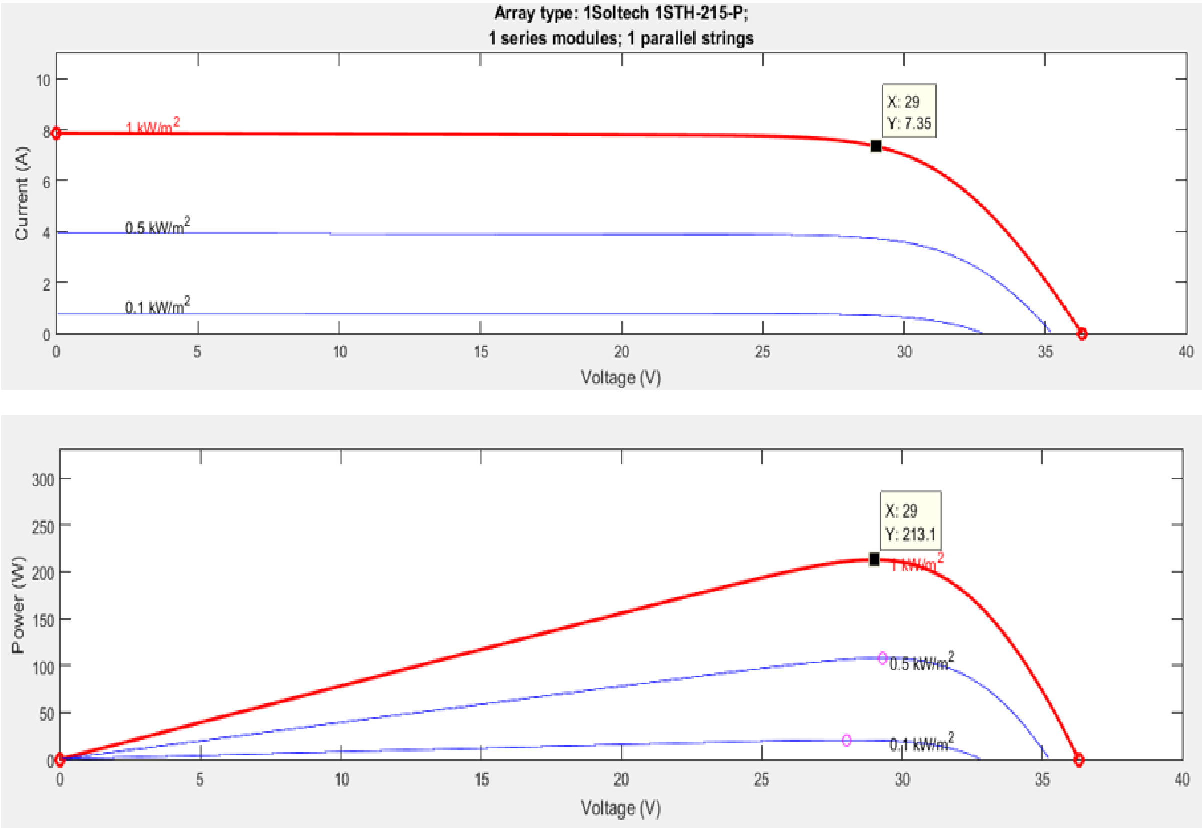


Figure 3.2.4(a) & (b)

Maximum Voltage (V_m) = 29V

Maximum Current (I_m) = 7.35A

Maximum Power at MPP = 213.1W

At Irradiance = 500W/m^2, the Maximum Power at MPP = 108W

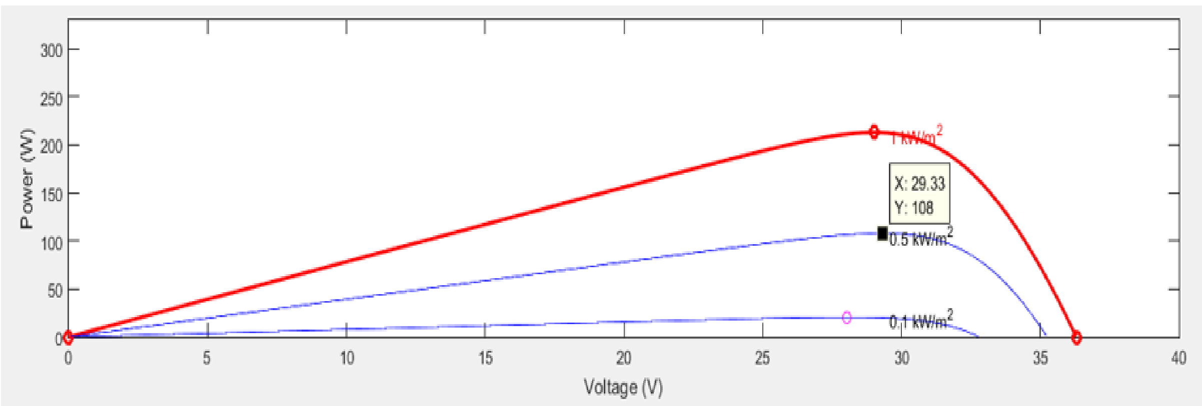


Figure 3.2.4(c)

3.2.4 Results and Observations

<u>Result 1:</u>

At Irradiance = 1000W/m^2, Temperature = 25°C & initial SOC (%) = 50%

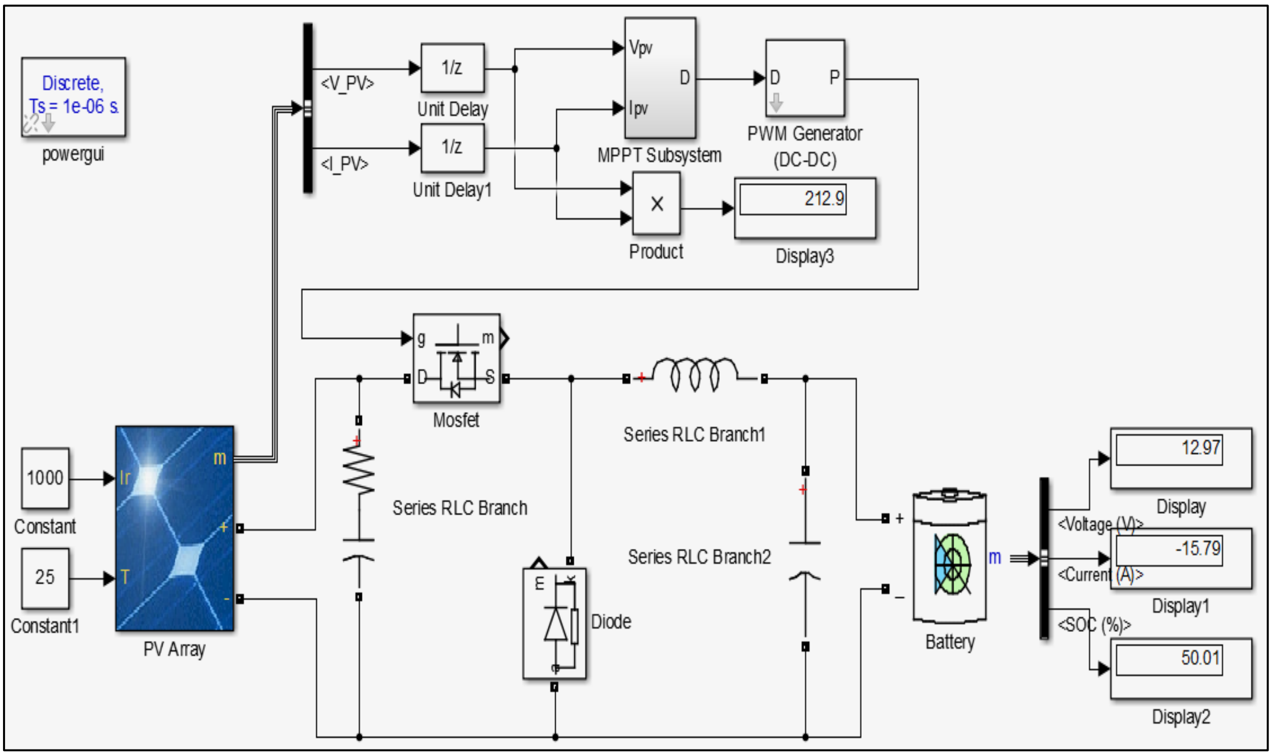


Figure 3.2.5(a)

<u>Observation 1:</u>

- We see that the power obtained at Display3 reaches 212.9W≈213W.
- When the simulation is run for a longer time, the rise in SOC (%) at Display2 is observed which indicates that the battery is charging as shown in figure 3.2.5(a), (b) & (c) respectively.

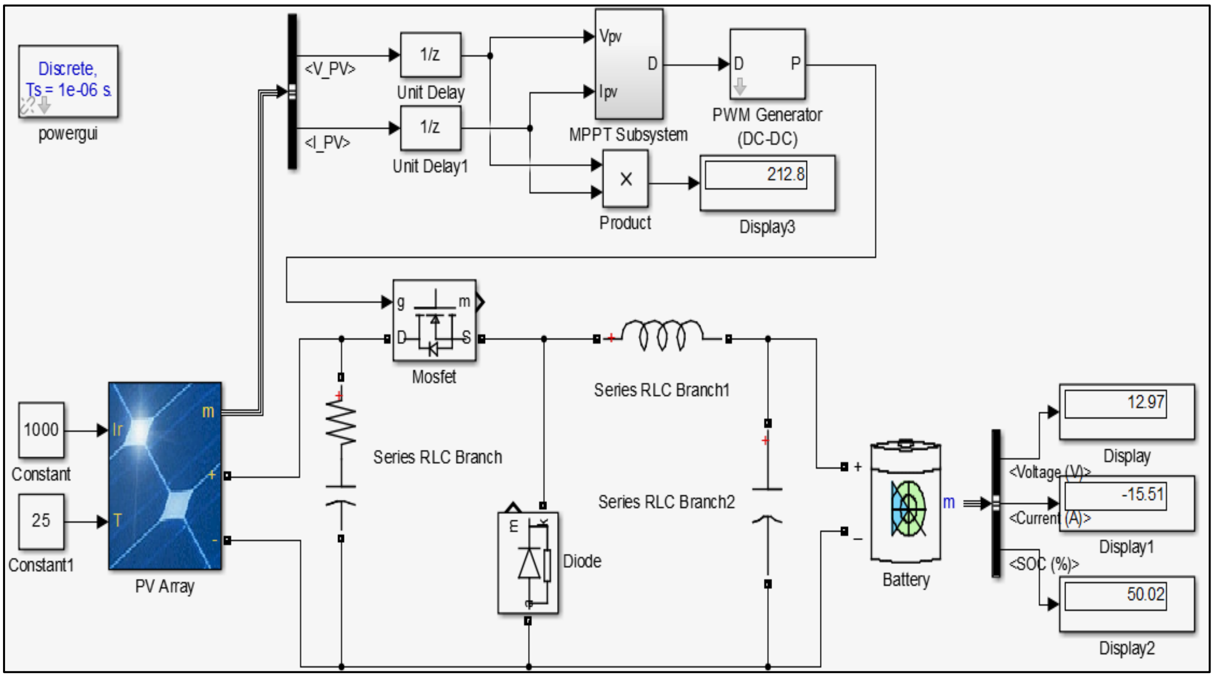


Figure 3.2.5(b)

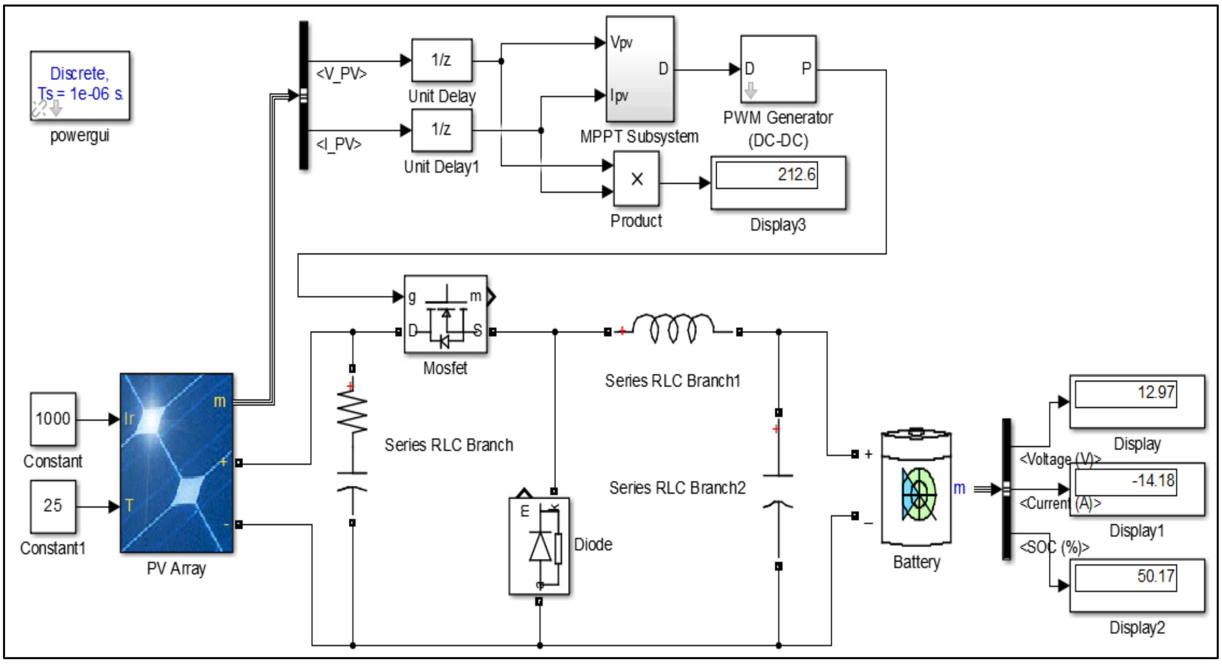


Figure 3.2.5(c)

<u>Result 2:</u>

At Irradiance = 500W/m^2, Temperature = 25℃ & initial SOC (%) = 50.02%

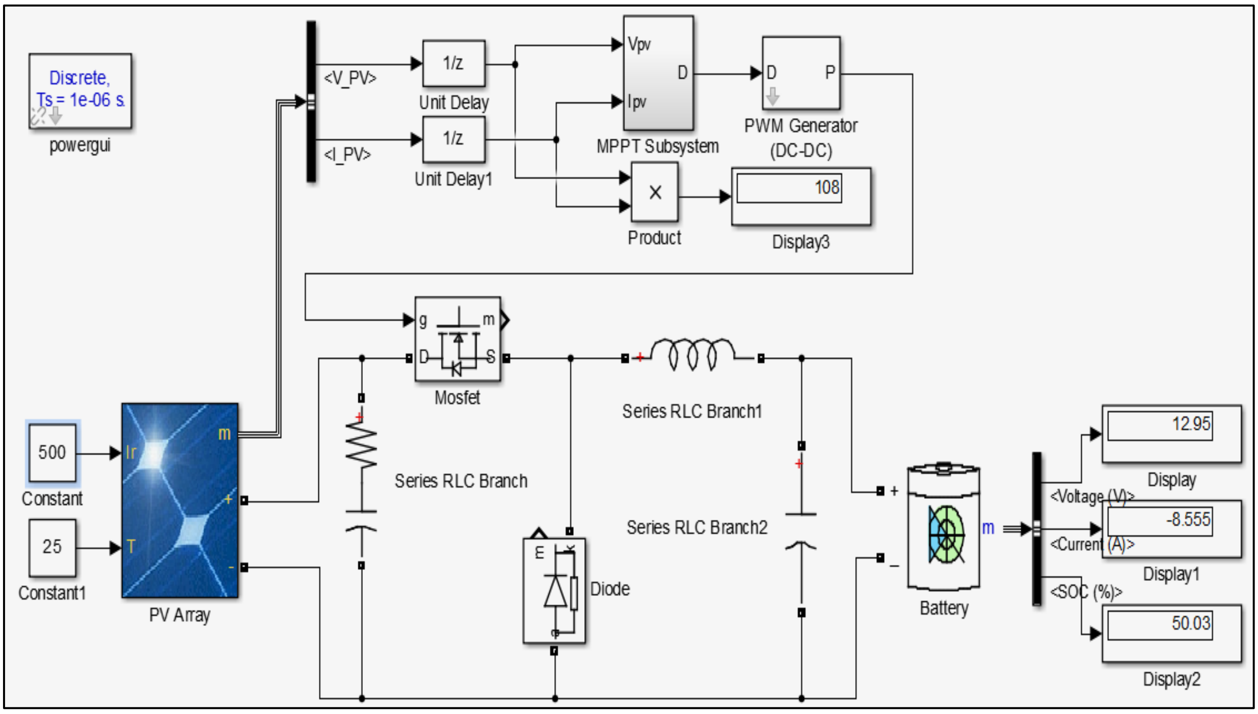


Figure 3.2.6

Observation 2:

With the change in irradiance from 1000W/m^2 to 500W/m^2, the change in maximum power point tracking output is observed. Power output at display3 reaches 108W which was previously reaching 213W approximately. This shows that the model responds to the variation in the irradiance. The power at MPP at 500W/m^2 was seen to be 108W previously as per the PV Array characteristics given in figure 3.2.4(c).

Chapter 4:

Solar Powered portable Power Bank System Design

CHAPTER 4

SOLAR POWERED PORTABLE POWER BANK SYSTEM DESIGN

4.1 Description and Specification

The proposed system is a 2000mAh 5V/12V output power bank device which utilizes the solar power to get charged. An additional dc port facility is built to provide multiple charging option to the system. The system effectively provides control of solar charge and protects the battery bank from unfavourable conditions that may arise due to inconsistency of solar radiation.

Specification:

Charging I/P voltage = 12V

Discharging O/P voltage = 5V(USB) & 12V (dc port)

4.2 Engineering solution

The proposed system meets the following requirements:

- It is a compact, portable and lightweight solution to resource conservation
- Provides effective protection to the battery pack therefore increasing the lifetime
- Easy to recycle, reuse, dismantle
- Minimizes the dependency on exhaustible resources
- User-friendly and takes care of hazardous chemical substances

4.3 Device Architecture

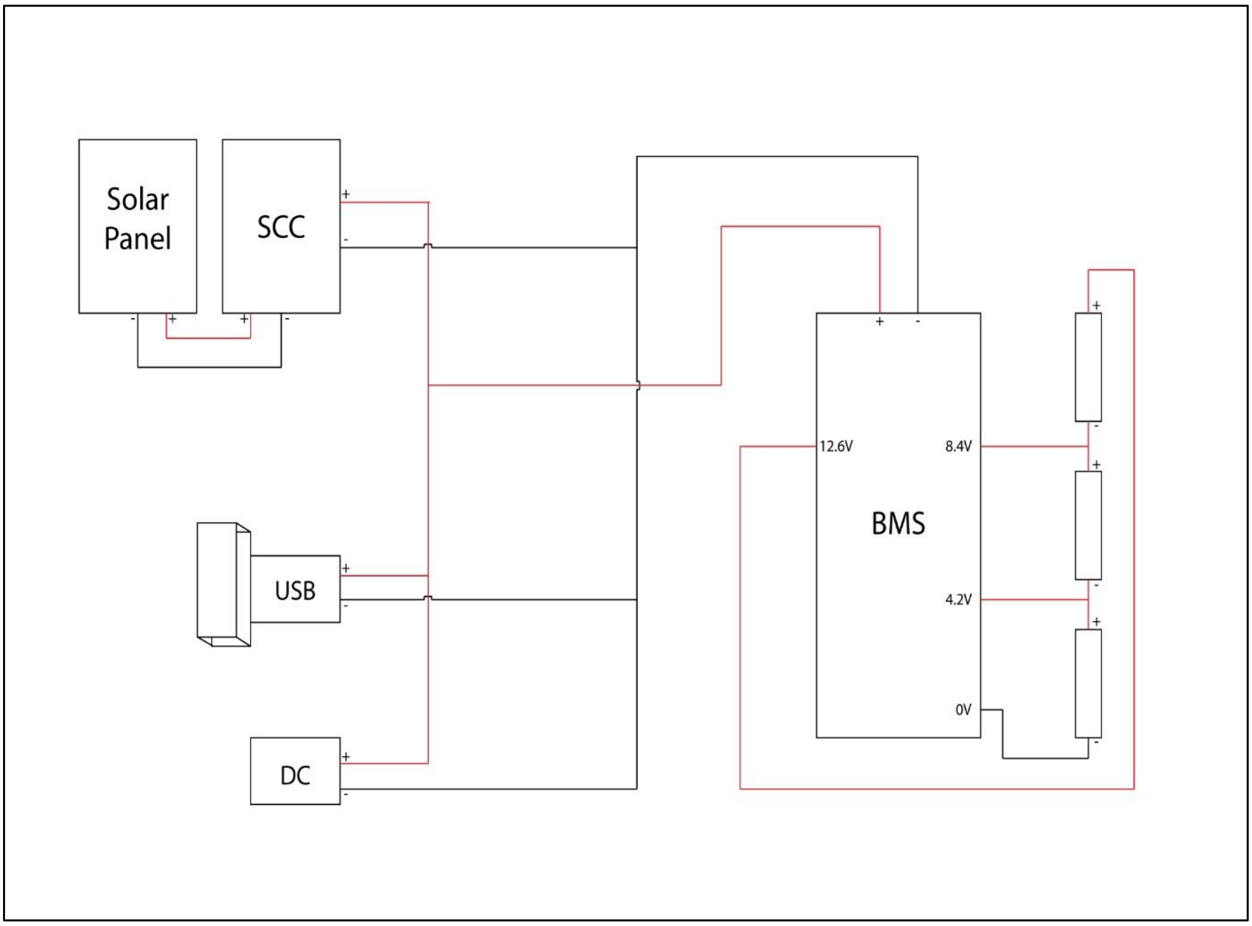


Figure 4.1: Device Architecture of the Power Bank System

In the above diagram,

SCC → Solar panel Charge Controller

BMS → Battery Management System

4.4 Technical Functionality

4.4.1 Solar Panel/ Photovoltaic Module

Solar Panels are available in various sizes and shapes and it is required to choose the type of solar panels as per the requirement. Keeping in mind the portability of the system, the solar panel used is having a specification of 6V operating voltage and 60mA working current and of the dimensions 80x40mm. It is rectangular in shape and four such panels are connected in series to make it suitable for 3s configuration.

Figure 4.2

4.4.2 Solar Panel Charge Controller

Solar Panel Charge Controllers are those electronic devices which are used to manage the power entering into the battery bank from the solar panel. They ensure the charging conditions of the batteries and prevent the deep cycle batteries from being overcharged during the day. They are also required to ensure that the power doesn't flow back to the solar panels overnight and drain the batteries. There are charge controllers available with additional capabilities but managing the power flow is their primary job.

12V MPPT CN3722 3S Lithium Li-ion 18650 Battery Charge Controller Module

The system consists of CN3722 which is a PWM switch-mode battery charger controller which is powered by photovoltaic cell with maximum point tracking function. It is specially designed for charging 1 or multi cell lithium-ion batteries. It is a constant current, constant voltage battery charger controller. In constant voltage mode, the regulation voltage is set by the external resistor divider. The constant charging current is programmable with a single current sense resistor [13]. Here the regulation voltage is set for 3s battery configuration.

Deeply discharged batteries are automatically trickle charged at 15% of the programmed constant charging current until the cell voltage exceeds 66.7% of the regulation voltage. In constant voltage mode, the charging current decreases gradually, the charge cycle will be terminated when the charging current drops to 9.5% of the full-scale current, and a new charge cycle automatically restarts if the battery voltage falls below 95.8% of the regulation voltage in constant voltage mode. CN3722 will automatically enter sleep mode when input voltage is lower than battery voltage.

Features:

Wide input Voltage: 7.5V to 28V

Charge Current up to 5A

2 status indication

Battery overvoltage protection

Operating Ambient temperature -－40℃ to ＋85℃

Battery Temperature Monitoring

Typical Application Circuit of CN3722:

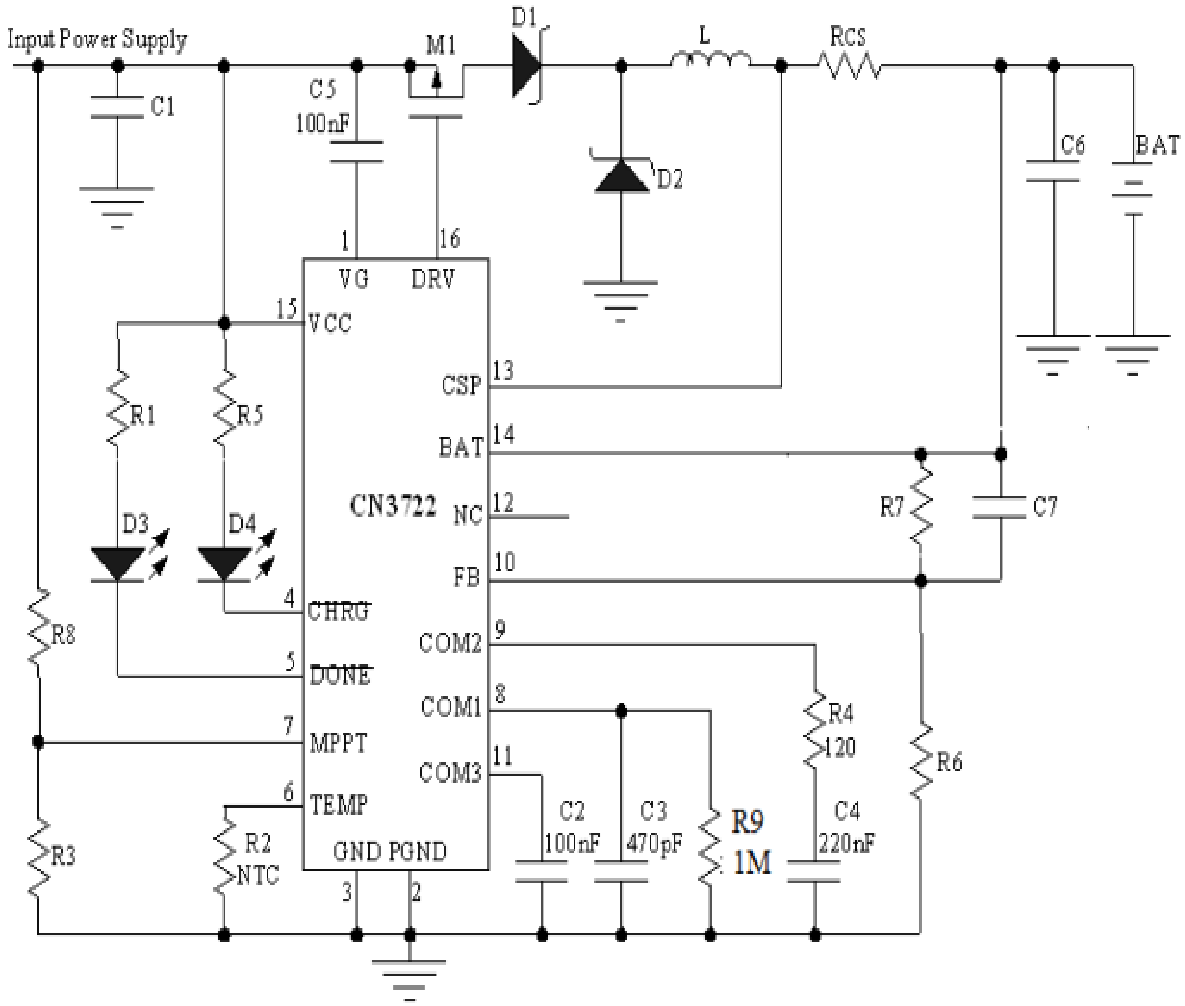


Figure4.3: Typical Application Circuit

A charge cycle begins when the following 3 conditions are met:

(1) The voltage at VCC pin rises above the UVLO level

(2) The voltage at VCC pin is greater than the battery voltage by sleep mode release threshold VSLPR

(3) The voltage at VCC pin is no less than the maximum power point voltage set by the external resistors

At the beginning of the charge cycle, if the battery voltage is less than 66.7%×VREG, the charger goes into trickle charge mode. The trickle charge current is internally set to 15%(Typical) of the full-scale current. When the battery voltage exceeds 66.7%×VREG, the charger goes into the full-scale constant current charge mode [13].

The charger current starts to decrease when the voltage of the battery approaches the regulation voltage and the charger is moves into constant voltage mode. The current will start to decrease at this time. In constant voltage mode, the charge cycle will be terminated once the charge current decreases to 9.5% of the full-scale current.

During the charge termination status, the DRV pin is pulled up to VCC, and an internal comparator turns off the internal pull-down N-channel MOSFET at the pin, another internal pull-down N-channel MOSFET at the pin is turned on to indicate the termination status [13].

In order to restart the charge cycle, it is required to remove and then apply the input voltage again. Also, if the battery voltage drops below the recharge threshold voltage of 95.8%×VREG, a new charge cycle automatically begins. When the input voltage is not present, the charger goes into sleep mode.

An overvoltage comparator guards against voltage transient overshoots (>8% of regulation voltage). In this case, P-channel MOSFET are turned off until the overvoltage condition is cleared. This feature is useful for battery load dump or sudden removal of battery.

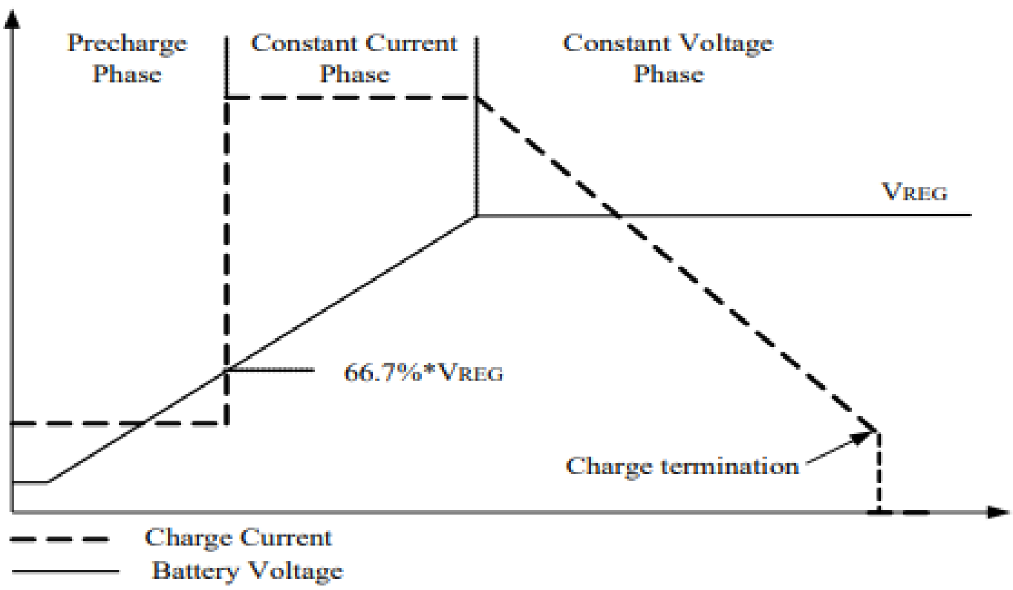


Figure4.4: The Charging Profile

The Module used in the system is given below:

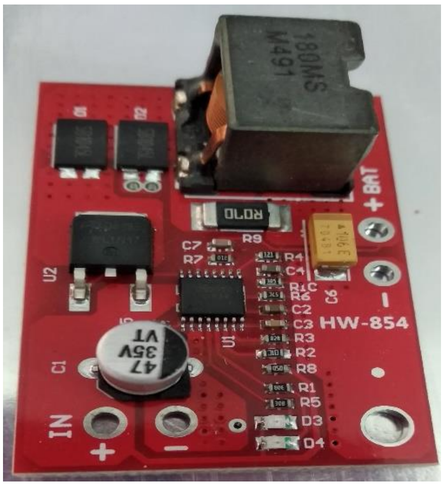


Figure4.5: 12V MPPT Solar Panel Controller CN3722 3S Lithium Li-ion 18650 Battery Charge Controller Module

Regulation Voltage in Constant Voltage Mode Setting

Here the regulation voltage in constant Voltage mode is set via the resistor divider comprising of R6 and R7.

The regulation voltage in constant voltage mode is determined by the equation:

$VBAT = 2.416 \times (1 + R7 / R6) + IB \times R7$

From the above equation, we can see that an error is introduced due to the existence of bias current IB, the error is IB×R7. If R7＝500KΩ, then the error is about 25mV. So the error should be taken into account while designing the resistor divider.

The regulation voltage range that can be set is from 3V to 25V.

Here, the regulation voltage set is around 12.6V.

Charge Current Setting

The full-scale charge current commonly known as the charge current in constant mode is decided by

ICH= 200mV/RCS

Where ICH is the full-scale charge current

RCS is the resistor between the CSP pin and BAT pin.

Here the Maximum Constant Current is set at 3A.

Maximum Power Point Tracking

CN3722 adopts the constant voltage method to track the photovoltaic cell's maximum power point. From I-V curve of photovoltaic cell, under a given temperature, the photovoltaic cell's voltages at the maximum power point are nearly constant regardless of the different irradiances. So, the maximum power point can be tracked if the photovoltaic cell's output voltage is regulated to a constant voltage.

But the maximum power point voltage has a temperature coefficient of about －0.4%／℃. At 25℃, CN3722's MPPT pin's voltage is regulated to 1.04V with a temperature coefficient of －0.4%／℃ to track the maximum power point working with the off-chip resistor divider (R3 and R8).

At 25℃, the maximum power point voltage is decided by the following equation:

$$VMPPT = 1.04 \times (1 + R8 / R3)$$

Trickle Charge Mode

At the beginning of a charge cycle, if the battery voltage is below 66.7%×VREG, the charger goes into trickle charge mode with the charge current reduced to 15% of the full-scale current.

Charge Termination

In constant voltage mode, the charge cycle will be terminated once the charge current decreases to 9.5% of the full-scale current.

Battery Temperature Monitoring

A negative temperature coefficient (NTC) thermistor located close to the battery pack can be used to monitor battery temperature and will not allow charging unless the battery temperature is within an acceptable range. Connect a 10kΩ thermistor from the TEMP pin to ground. Internally, for hot temperature, the low voltage threshold is set at 175mV which is equal to 50℃(RNTC≈3.2kΩ). For cold temperature, the high voltage threshold is set at 1.61V which is equal to 0℃(RNTC≈28kΩ) with 50uA of pull-up current. Once the temperature is outside the window, the charge cycle will be suspended, and the charge cycle resumes if the temperature is back to the acceptable range.

The TEMP pin's pull up current is about 55uA, so the NTC thermistor's resistance should be 10kΩ at 25℃, about 3.2kΩ at hot temperature threshold, and about 28kΩ at cold temperature threshold. The NTC thermistor such as TH11-3H103F, MF52(10 kΩ), QWX-103 and NCP18XH103F03RB can work well with CN3722. The above-mentioned part numbers are for reference only, the right NTC thermistor part number can be selected based on the requirements.

If the thermistor with negative temperature coefficient is tightly bonded to the battery pack and connected to the TEMP pin of CN3722 through the connector, the circuit shown in Figure 3 should be used to avoid damage to the chip when plugging and unplugging the battery.

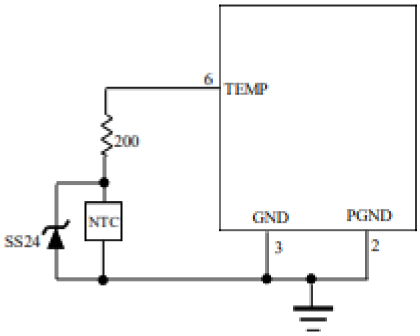


Figure 4.6: Battery Temperature Monitoring Function

Status Indication

The module has 2 status outputs: $\overline{\text{CHRG}}$ and $\overline{\text{DONE}}$.

$\overline{\text{CHRG}}$ is pulled low that is the Red LED glows when it is charging the Li-ion battery and thus shows the charging status, otherwise it becomes high impedance. $\overline{\text{DONE}}$ is pulled low if the charger reaches the termination status that is the charging is stopped. The Green LED starts to glow then in order to show that the charging is done.

The table [13] below lists the two indicator status and their corresponding charging status. It is supposed that red LED is connected to $\overline{\text{CHRG}}$ pin and green LED is connected to $\overline{\text{DONE}}$ pin.

$\overline{CHRG}$ pin	$\overline{DONE}$ pin	**State Description**
Low(the red LED on)	High Impedance(the green LED off)	Charging
High Impedance(the red LED off)	Low(the green LED on)	Charge termination
Pulse signal	Pulse signal	Battery not connected
High Impedance(the red LED off)	High Impedance(the green LED off)	There are three possible state: ● the voltage at the VCC pin below the UVLO level or ● the voltage at the VCC pin below V_{BAT}, or ● abnormal battery's temp

Table 1 Indication Status

4.4.3 Lithium-ion Battery

Lithium-ion battery is referred to as a battery which is rechargeable. In Li-Ion Batteries the Lithium ions move from the positive electrode (cathode) to the negative electrode (anode) when it is charging and from the negative electrode (anode) to the positive electrode (cathode) when it is discharging.

At the positive electrode, Lithium-ion cells utilises intercalated lithium compound as the material and at the negative electrode, typically graphite is used. These batteries have a high energy density, have no memory element and have low self-discharge.

Charging and Discharging

Discharging:

At the time of discharging, the current within the battery is carried through the non-aqueous electrolyte by the lithium ions from the negative to the positive electrode.

Charging:

An external power source is required to charge the battery which needs to be applied with a higher voltage that it produces and of the same polarity and this forces a charging current to pass through each cell from positive to negative electrode which is the reverse condition from the discharging time. The ions then get migrate to the negative electrode and get embedded in the porous electrode material through the process of intercalation.

The charging methods for single Li-ion cells vary from that of Li-ion batteries. The stages slightly vary for both the cases.

Single Li-ion cell gets charged in two stages:

1) Constant Current (CC)
2) Constant Voltage (CV)

Li-ion Battery gets charged in three stages:

1) Constant Current (CC)
2) Balance (this is only required when cells are not of same capacity and not required when battery is balanced)
3) Constant Voltage (CV)

At the time of Constant current stage, A constant current is applied by the charger to the battery at a steadily increasing voltage and this continues till the voltage limit per cell is reached.

At the time of balance stage, the charging current is reduced by the charger and meanwhile the state of charge of individual cells is brought to the same level by the use of a balancing circuit and this continues till the battery gets balanced. Many times, this stage is skipped by some fast chargers and some ties, the balancing is achieved by charging each cell individually and independently.

At the time of constant voltage stage, a voltage that is equal to the maximum cell voltage times the number of cells in series to the battery is applied by the charger as the current gradually starts to fall towards 0. This is continued until the current is below the set threshold of about 3% of initial constant current.

Figure below depicts the charging profile of a lithium ion.

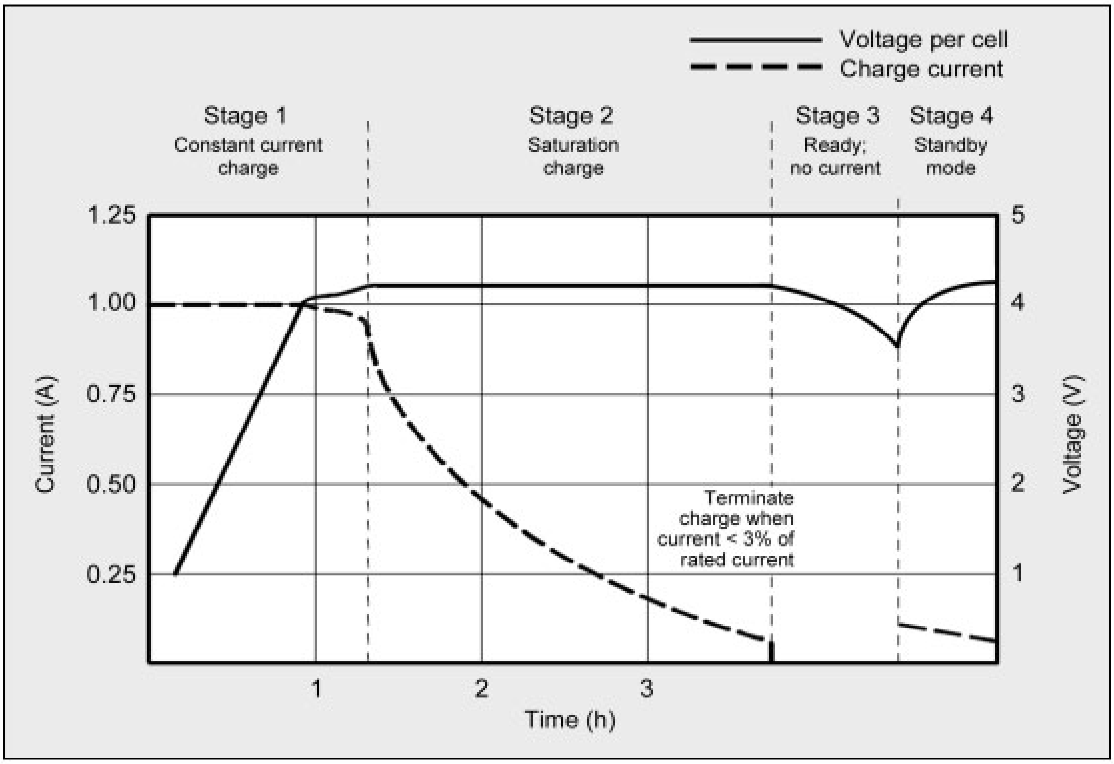


Figure 4.7: Charge stages of lithium ion

Stage 1: Voltage rises at constant current

Stage 2: Voltage peaks, current increases

Stage 3: Charge terminates

Stage 4: Occasional topping charge

They can however pose threat to safety if damaged or incorrectly charged and can lead to explosions and fires. Therefore, it is required to provide protection to these batteries and prevent over charge and over discharge.

4.4.4 Battery Management System (BMS)

Need of Constant Monitoring of Battery

Any battery pack consists of tiny cells connected in series and parallel combination. These tiny cells are highly unstable. The voltage across the cells has to be precisely monitored and balanced. If it is not done then it may end in destroying the battery pack and safety of the whole device may compromise. When a battery is charging, we have to apply the voltage and current to it. If the voltage is more than the specified limit mentioned in the datasheet then it is considered that the battery is charging with overvoltage which will eventually increase the temperature of the battery. Every battery has a specific range of temperature in which the battery works fine and operates safely. So, if this temperature increases which ends up increasing the state of charge, this also increases the internal resistance of a battery and eventually the power loss cross the battery increases. On the other hand, if the voltage applied to the battery is lower then also it will lead to over temperature. Overvoltage and under voltage lead to over temperature which results in degrading the battery life. Due to over temperature the batteries may catch fire as well.

There are always differences in the state of charge, discharge rate, capacity, impedance between two cells if the cells are from the same manufacturer and produced in the same lot. While charging or discharging these cells together, some cells experience more stress in battery pack so they lead to degradation. In order to avoid all these difficulties, the over voltage and under voltage limits of the battery have to be monitored. The efficient and effective way to maintain a close watch on these cells, a fast battery management system has to be used. A BMS can monitor all of these and provide real-time diagnostics.

Battery Management System

A BMS has two primary functions:

- To keep the battery pack safely.
- To keep it operating reliably.

A Battery management system is a system that takes a number of inputs like voltage (cell voltage and pack voltage), temperature, current (charging or discharging) and runs a number of algorithms to generate an accurate estimation of the following outputs – SOC (State of Charge), SOH (State of Health).

Discharge Control

A BMS primarily functions to keep the battery away from operating out of its safety zone. The BMS must protect the cell during discharging.

SOC determination

One of the features of the BMS is to keep the track of SOC of the battery. The SOC indicates the user about current capacity of the battery.

There are several methods to determine SOC. The SOC can be determined through

- Direct voltage measurement
- Coulomb counting
- Combination of coulomb counting and voltage measurement

- Direct voltage measurement

  To measure the SOC directly, a voltmeter can be used simply as the voltage decreases more or less linearly during the discharging cycle of the battery. So if the voltage decreases, the SOC of the battery also decreases.

- Coulomb counting

  In the coulomb counting method, the current coming in or going out of a battery is measured over time to calculate the relative amount of charge. The BMS measures the amount of current going inside the battery and calculates the charge deposited inside the battery over time. When the calculated charge is near to the rated capacity of the battery, then BMS informs that battery is fully charged and while discharging it follows the same process and cut off from over charging or over discharging automatically.

SOH determination

It is the battery's ability to store charge and deliver electrical energy compared with a new battery. Any physical parameter of battery such as internal resistance or conductance changes significantly with age can be used to indicate the SOH of the cell. In practice, the SOH could be estimated from the internal resistance or the cell conductance. As the battery gets older the internal resistance of the battery increases.

Cell Balancing

This is a method of compensating weaker cells by equalizing the charge on all cells in the chain to extend overall battery pack's life. In the whole battery pack, small differences between the cells due to tolerances or operating conditions gives rise to uncertainties. During charging, weaker cells may get over stressed and get even weaker until they eventually fail which may cause the whole pack to fail prematurely. So, to avoid this, BMs has to provide cell balancing. Majorly there are two cell balancing techniques:

1) Active balancing
2) Passive balancing

Log book

A BMS also has to work as a log book because the SOH of a battery is a relative term. It compares the new battery and old battery. So, this measurement should hold a record of the initial conditions of a cell and should be able to compare with the same cell as it gets old. So, the log book function of the BMs would record such important data into the memory.

What is BMS made up of?

A BMS is made up of many hardware and software functional blocks which includes Cut-off MOSFETS, Fuel Gauge/Current monitor, Cell Voltage Monitor, Real-time clock and Temperature monitoring system

<u>Purpose and technology</u>

- Cut-off MOSFETS

-These are basically transistors, mostly MOSFETS are used as controlled switches. These are sued for the connection and isolation of the battery pack between the load and the charger. Micro controller unit of BMs measures the cell voltages, current in real-time and based on that it switches the FETs. Initially both MOSFETs are turned off. When a charger is connected current is not flowing because FETs are off. BMS senses the voltage at the input and then it turns on the CFET which charges the battery. If the voltage at the input pin is not present them BMS determines that load is connected. Then it turns on the DFET.

- Current Monitor

This block keeps the track of the charge coming in and going out of the battery pack. As we know Charge is the product of current and time. For measuring the current a current sense amplifier and a MCU which has an Analog to Digital converter is used. A very low value current sense resistor is connected in series with the battery line. Voltage drop across this resistor is measured by this amplifier and then it amplifies the signal and delivers it to the ADC of the microcontroller. The microcontroller measures that voltage and calculates the charge according to time. The discharging and charging currents are sensed by the direction of current. If the current is going out of the battery, then the current is discharging and if the current is coming inside the battery that implies that the battery is charging. Many times, using a fuel gauge IC adds additional cost to the BMS design and when the load current is changing continuously, using a shunt resistor is can be a better option. This configuration also helps in all current protection. When the current rises above safety level, the fuel gauge circuit senses it and gives the signal to turn off the DFET (discharging FET) or CFET (charging FET).

- *Cell Balancing/Voltage monitoring*

Monitoring the voltage of each cell is very important. The voltage of a Li-ion cell ranges from 2.5V to 4.2V depending on the chemistry. As it is observed before that operating the voltage outside the voltage range significantly reduces the lifetime of the cell. There are always differences in the state of charge, discharge rate, capacity, impedance between two cells if the cells are from the same manufacturer and produced in the same lot. While charging, if the battery pack has a weaker cell than an average cell, this would result in the weaker cell to reach out it’s limit first and rest of the cells are still charging. So, this weaker cell heats up and its lifespan decays. On the other hand, a weaker cell discharges faster than rest of the cells. The weaker cell trips the discharge limit first leaving the cells with some charge remaining inside of them. This can be overcome by cell balancing. The cell balancing can be done by two methods:

1) Passive Cell Balancing

- This is the simplest and cost-effective method. In this a dummy load like a resistor is used to discharge the excess voltage and equalise it with other cells. These resistors are known as bypass resistors.
- Each cell connected in series in a pack will have its own bypass resistor connected through a switch. While charging, the weaker cell charges fast so the MOSFET connected across the weaker cell is turned on. The charge of this cell is removed and dissipated through this resistor. This process minimizes the charging rate of the weaker cell.

- Whenever charge level of the weaker cell tends to go near its full capacity the MOSFET is turned on, so all cells along with weaker cell charge at the same time but this method is not useful while discharging. The weaker cell may reach to its minimum cut off voltage earlier than the other cells.
- However, this balancing technique is inexpensive and technically easy to implement but this method is not very efficient because electrical energy is dissipated as heat in the resistors and FETs and has switching losses.
- Another drawback is that the entire discharge current flows through the MOSFET which is mostly built into the controller IC and hence the discharge current has to be limited to lower value up to the IC's limit which increases the discharging time.

2) Active Cell Balancing

- Unlike Passive balancing, in active balancing the excess charge from one cell is transferred to another cell which has low charge to equalize them. So, this can be done by charge storing components like capacitors and inductors. There are many methods to carry out active cell balancing.
- One such method is the usage of charge shuttles or the flying capacitors which is most commonly used in active balancing.
- In this method, the capacitors are used to transfer the charge from high voltage cell to low voltage cell. The capacitor is connected through SPDT switches. Initially, the switch connects the capacitor to the cell which has high voltage and once the capacitor is charged then the switch connects it to the cell which ha slow voltage and the charge from the capacitor flows into the cell.
- These capacitors are called flying capacitors. This method also has a disadvantage and it is that the charge can be transferred only between the adjacent cells.
- Also, it takes more time as the capacitor has to be charged and then discharged to transfer the charges but still it better than the passive cell balancing.

- *Temperature Monitoring*

Li-ion batteries give out a lot of current while maintaining constant voltage which can lead to a thermal runaway condition that causes the battery to catch fire. The construction of battery is highly volatile. This temperature measurement is not only for safety, it can also suggest if the temperature of the battery is suitable for charging or not. To measure the temperature of the battery, a temperature sensor is used. Generally, thermistors are used as a temperature sensor. The thermistor is basically a temperature dependent resistor. Whenever there is a change in temperature the resistance of the thermistor changes and BMS calculates the temperature rise accordingly.

- *Logbook*

As it is seen earlier that BMS acts as a logbook to calculate the SOH and other parameters of the battery. So, for that purpose the BMS has to take the data according to time, so it should be working even if the load is not on but it might consume the excessive power from the battery pack itself. So, to avoid that a Real-time clock is integrated with the BMS which needs very small power and it does the job.

BMS system

Features =>

Suitable range: Nominal voltage 3.6V 3.7V lithium battery (18650) 3s configuration

Charging voltage: 12.6V

Maximum output current: 20A

Maximum output power/charging power: 252W

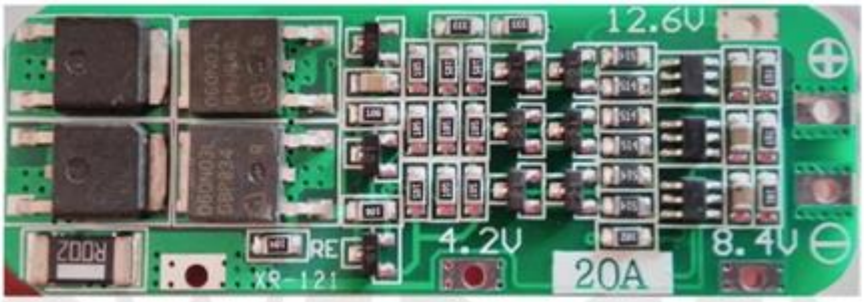


Figure 4.8(a)

Circuit Diagram:

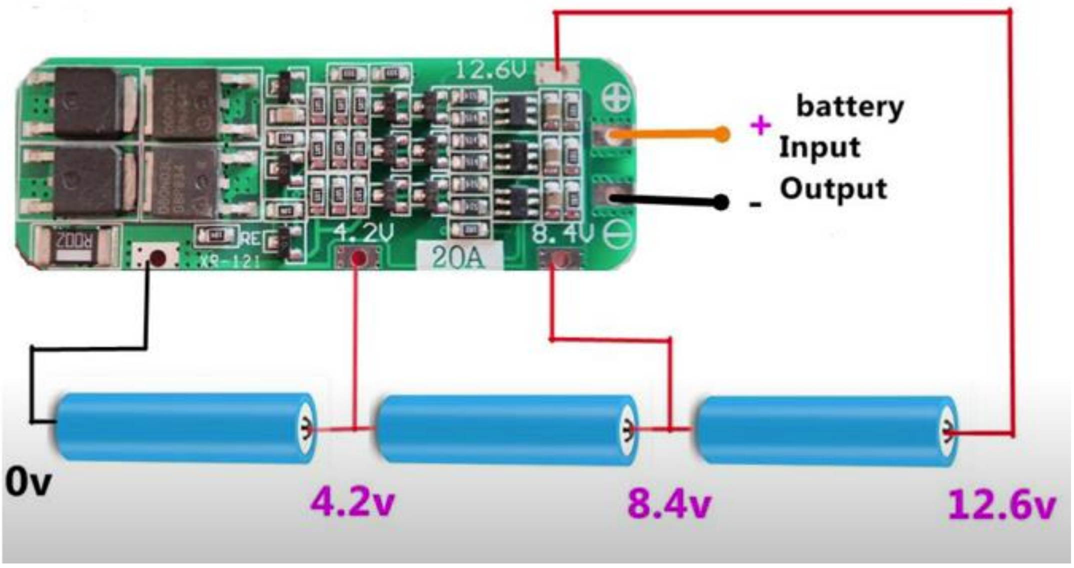


Figure4.8(b): circuit diagram of BMS and 3s battery pack

Electrical parameters:

ITEM	Minimum	Typical	Maximum	Unit
Consumable current	12	18	24	μA
Over charge protection voltage	4.2	4.25	4.3	V
Over charge recovery voltage	4.1	4.16	4.2	V
Over charge delay time	500	1000	1500	ms
Over discharge protection voltage	2.35	2.5	2.7	V
Over discharge recovery voltage	2.9	3.2	3.3	V
Over discharge delay time	50	100	150	ms

Overcurrent protection current	37	40	43	A
Overcurrent delay time	5	10	15	ms
Normal operating current	0	20	20	A
Conduction resistance	10	12	14	mΩ
Transient current(<10ms)	18	20	22	A
Ambient temperature	-40	25	85	℃

4.4.5 DC-DC Buck converter circuit

Any converter works in two distinct modes with respect to the inductor current: the CCM or the continuous current mode and the DCM or the discontinuous conduction mode. When the inductor current is always greater than zero, it is said to be in CCM. When the average inductor current is too low due to the high-load resistance or low-switching frequency, then the converter is in DCM []. The CCM is preferable for high efficiency and efficient use of semiconductor switches and passive components. The DCM requires a special control since the dynamic order of the converter is reduced [14].

The output voltage ripple is expected to be small in an efficient converter. Load is assumed to be resistive and dc component of the output is devoid of any ripples. The analysis is shown in the below figure.

Figure4.9(a): Small ripple approximation

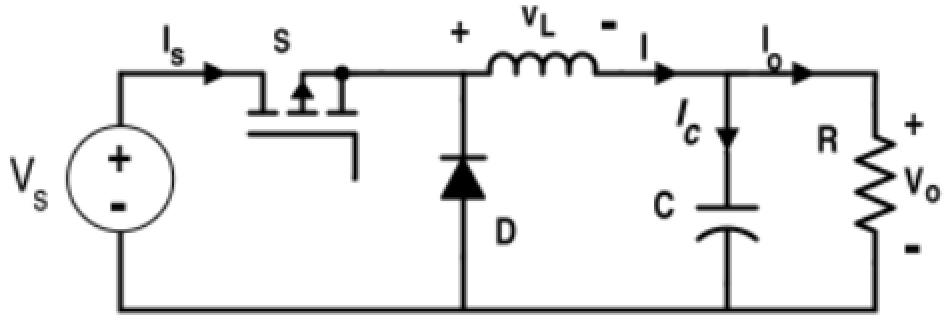


Fig4.9(b): Buck converter circuit diagram

As represented in the above figure, the buck converter consists of a DC supply or a rectified AC output, two switches i.e. D (diode) and S (can be semi-controlled or fully-controlled power electronics switches), two-pole low-pass filter (L and C) and a load. Let the duty ratio of switch S be

$D=T_{ON} / T$

Where $T= T_{ON} + T_{OFF}$

Buck converter is mostly used for DC drives systems e.g. electric vehicles, electric traction and machine tools.

This circuit can be studied in two different modes. The first mode is when the switch S is on while the second mode is when the switch S is off. The circuit diagrams when the switch S is on and off are given in Fig. 4.9(c) and Fig. 4.9(d) respectively.

Voltage across the Inductor = V_L = L dI/dt

Where $I=I_C+I_O$

Load Current = $I_O = V_O/R$

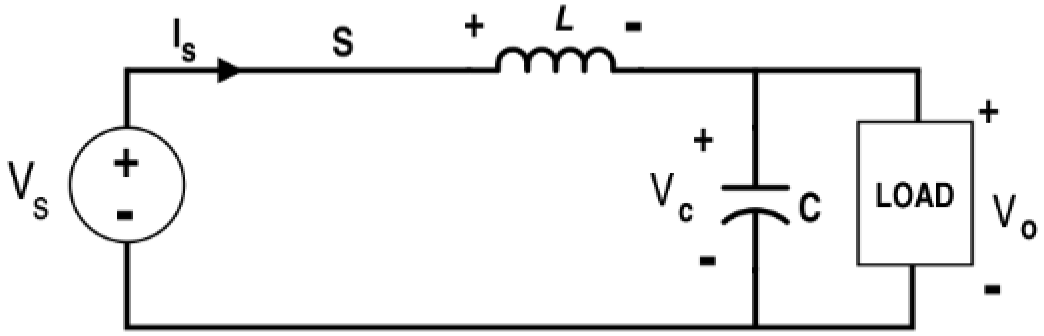


Figure4.9(c): Buck converter circuit when switch S is ON(Mode1)

When the switch S is on and applying the Kirchhoff's voltage law (KVL), it is obtained

$V_S = V_L + V_O$

- ⇨ $V_S = L(di/dt) + V_O$ and $V_O = V_C$

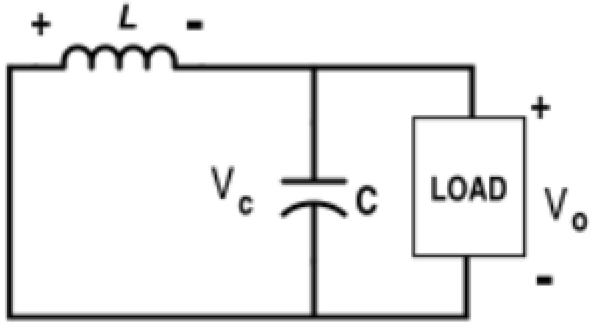


Figure4.9(d): Buck converter circuit when switch S is OFF(Mode2)

When the switch is off, the KVL in fig 4.9(d) gives,

$V_L + V_O = 0$

- ⇨ $V_O = - L(di/dt)$

As the output voltage is assumed to be constant,

- ⇨ L(di/dt) = constant
- ⇨ di/dt = constant
- ⇨ Slope of the inductor current is constant

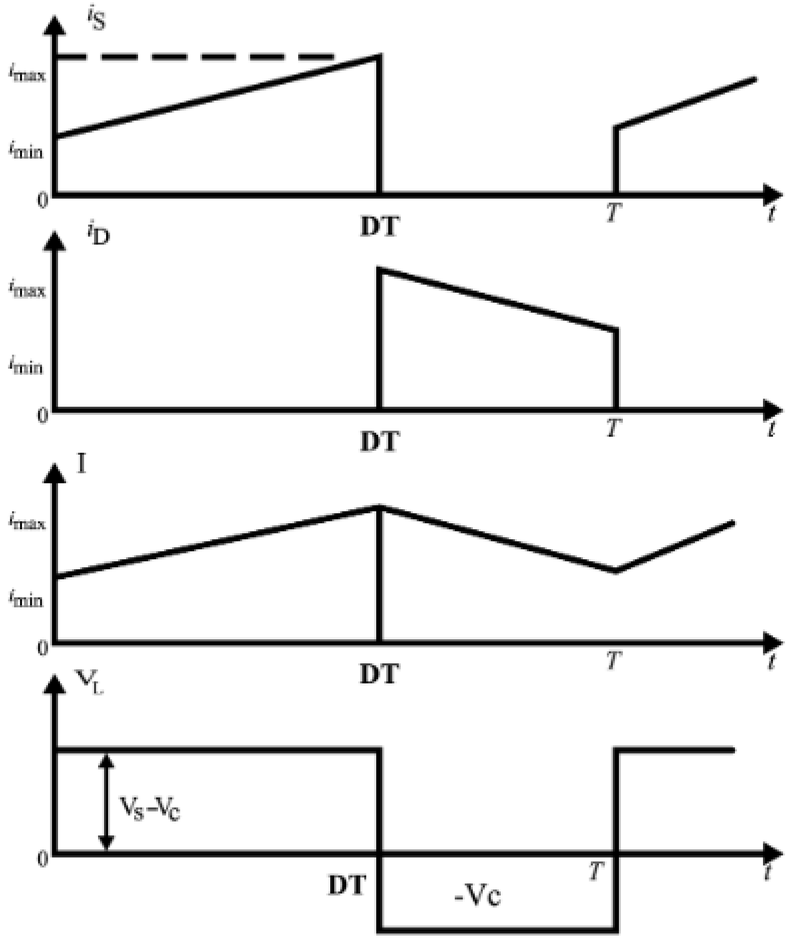


Figure4.9(e): Supply current I_S, diode current I_D, inductor current I and inductor voltage V_L waveforms respectively

Buck converter circuits are most commonly used in DC drive systems like power bank, electric vehicles etc.

The DC-DC step-down voltage converter circuit here supports 6-24V voltage input and 5V 3A output with input polarity reverse protection and output voltage and short circuit protection. On- board female type AUSB port perfectly fits android smartphones and iphone, iPad as well as it can be used to power or recharge any electronic gadget which requires 5V input power up to 3A.

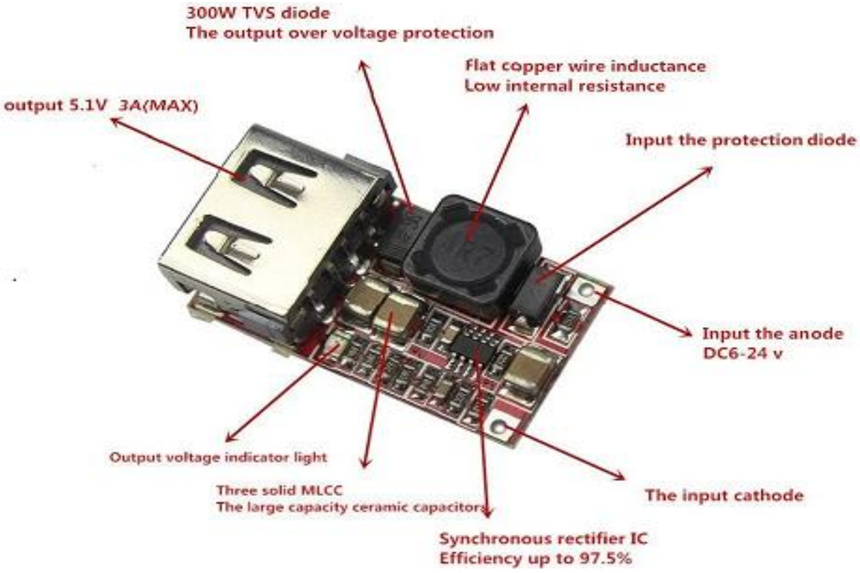


Figure4.9(f): DC-DC step down buck converter module

Specification:

Input voltage = 6-24V(DC)

Input mode = soldering

Output Voltage = 5.1-5.2V

Output mode = USB

Maximum output current = 3A

Output Voltage indicator = LED(Red)

Operating Temperature = -40° to + 85°C

4.5 Physical Prototype & Working Mechanism

The proposed power bank system is based on solar power and solar panels play a vital role in the experiment.

- Here, we have 4 solar panels each of 6v in series to form a single solar panel, in order to receive the energy from the sun. This gives open circuit voltage around 28v under direct sunlight.
- The output from the solar panels is fed to the input ports of the Solar Panel Controller which manages the power entering into the battery and ensures the charging condition of the battery pack. This is designed to output voltage for 3 cells in series configuration and gives around 12.6v when the solar panel is under direct sunlight on a sunny day. This component provides the overcharging protection and tracks the maximum power from the solar panel.
- Then the output from the Solar panel controller is fed to the battery via the BMS. The BMS module is attached to the battery in order to protect the battery pack from both overcharge as well as over discharge.
- The output and input ports of the BMS are the same so it is used for both charging as well as discharging the battery pack. The BMS also provides short circuit protection. In case of short circuit, it cuts off the battery pack and gets deactivated. In order to activate it again, a dc voltage is required to be applied at the common input output ports of the board. This is also same in case of over charge protection and over discharge protection.
- The battery pack used in this system is a combination of three 18650 4.2V(maximum voltage) 2000mAh cells in series which make up a total of 12.6V output. This pack is connected to the BMS inputs (0v, 4.2v, 8.4v, 12.6v) in correct manner so that it can be protected from unsuitable charging and discharging conditions.
- For the output a USB port dc-dc step-down buck converter module is connected which converts the 12V output voltage into 5V suitable for mobile charging. It can also be used for emergency lighting purposes by the usage of 5V USB lights.
- There is an additional dc charging port connected to the BMS output in order to keep a backup charging option through a DC Adapter in absence of sunlight that is during the night. This serves as a common dc input and output port i.e. it can be used for 12V dc output too along with dc charging since it is connected to the common input output port of the BMS of the battery.

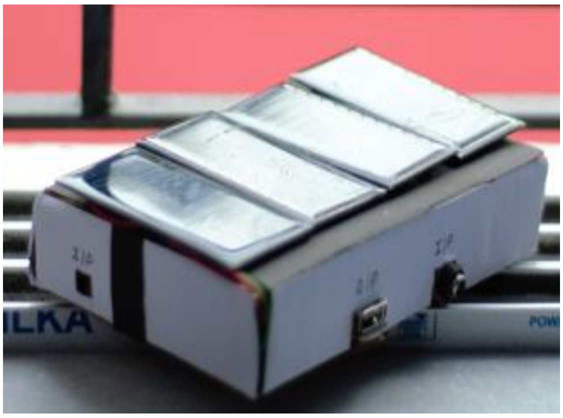


Fig.5a: Solar Charging of Power Bank

Fig.5b: Discharging (mobile charging)

4.6 Result Discussion

- When the solar panels are exposed to the sunlight, the solar panel controller shows the signal of charging depending upon the charge condition of the battery pack. The red LED glows when the solar panel controller is charging the battery.
- The red LED goes high impedance and stops glowing when the charging status terminates. At that very moment the Green LED starts to glow showing that the charging is done. Then the solar panels can be removed from the sun.
- Also, if the solar panels get unexposed to sun due to weather change or any other circumstances and the charging is not yet full then also the red LED stops glowing but, in this case, the green LED does not glow. This is because the solar panel controller charges the battery only when the desired voltage at its input is served.
- Since the input and output ports of the BMS are the same, this does not block the reverse discharge of battery to the solar panel at night. But the solar panel controller present does the job and it blocks the discharge of battery to the solar panel during the night.
- Also, during discharging of the battery, when the minimum discharge voltage is reached, the BMS auto cuts off the discharge and stops charging the mobile phone or any other form of discharge. Thus, the proposed power bank system as a whole provides high level protection to the battery at reasonable cost aiming to provide an appreciable lifetime of the system.

Chapter 5:
Conclusion

CONCLUSION

Energy is a vital issue at the present situation of the world. Uncontrolled use of non-renewable resources will lead to eventually extinction of them due to their exploitation. Therefore, we should expand our research towards solar energy and other renewable sources of energy and depend more on them so that we can come up with alternatives. There is research indicating that if we could store solar energy for a day all over world it will be enough to give electricity for a year but it is very difficult to store the generated energy []. In this project, a cost effective solar powered portable power bank system is designed after studying the characteristics of photovoltaic module by modelling in Simulink and designing a Simulink model for a solar charging of Li-ion battery. If we can charge our power bank and trap energy of the sun, we can save a lot of energy.

In this work, we have designed a power bank system that works on solar power with ample protection to the battery for better lifespan. Solar power banks are available in the market but are not highly efficient as they mostly do not focus on the health of the battery by directly charging under the sun without any over charge protection. This model is designed keeping in mind the health of the battery with adequate over charge, over discharge protection. The Simulink model of solar charging of battery uses a MPPT algorithm to track maximum power and DC-DC buck converter controls the voltage going inside the battery. The Solar panel charge controller does the same job for the hardware 3s configuration and maintains a constant voltage range around 12.6V that goes inside the battery through the BMS protection board.

The conduction of several rounds of experiment led to the conclusion that in order to obtain high-efficient performance of operation, the following points need to be noted:

- Bright and sunny weather is needed for better charging.
- The solar panel should face the sunlight directly i.e. it should be placed under direct sunlight to achieve better efficiency.
- It is required for the solar charge controller to receive adequate amount of solar energy to step down and maintain a constant around 12.6V supply to the power bank battery. Thus, four 6V solar panels are needed to input around 17-18V to the solar charge controller.
- Lastly, it takes a longer time to charge the power bank if it undergoes simultaneous charging and discharging.
- The system costs around an effective amount of 1.5k INR which is less than the market price.

Future Improvements

The Capacity of the pack can be increased by connection of more 3s configuration of Lithium-ion cells in parallel. Currently it is 2000mAh, it can be made into 4000mAh (6 cells) or 6000mAh (9 cells) or even higher.

If the requirement is only 5V output then 1s configuration can be used in place of 3s. In that case, the solar panel controller input voltage needs to be adjusted by adjusting the external resistances and two 6V solar panels in series would be enough.

Also, the charging current of the solar panels can be improved by attaching more solar panels in parallel.

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