FYP REPORT

BATTERY MANAGEMENT SYSTEM FOR LOW EARTH ORBIT SATELLITES

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CERTIFICATE

It is certified that the contents and form of thesis entitled **"BATTERY MANAGEMENT SYSTEM FOR LEO SATELLITES"** submitted by Muhammad Osama Nusrat (2017-NUST-SEECS-BE-EE-09 have been found satisfactory for the requirement of the degree.

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DEDICATION

To ALLAH ALMIGHTY

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To our Parents and Faculty

ACKNOWLEDGEMENT

I sincerely thank my advisor Sir Habeel Ahmed for supporting my challenging idea and then refining it. He was my ultimate source of guidance and help. My Co-advisor Dr. Mansoor Asif for his tremendous help throughout the project especially in DC-DC converters without which we would not have been able to complete the project. My family and friends deserve a special mention for their support.

ABSTRACT

Battery power management is a critical area for satellite systems. Algorithms are being developed to ensure maximum life of battery's installed on satellites. This project aims to develop a cost effective and simple battery management system for LEO satellites.

The Power module handles all the power requirements of the satellite with solar panels and battery bank. Solar panels are mounted on the surface of the satellite and they charge the battery, which provides power to all of the modules.

I have developed a battery charging system using solar panels and I have developed a load management system to ensure minimum consumption of battery during eclipse time.

This project was a source of learning for me as I had to study about the satellites, there subsystems, the power requirements and the current trends in battery management in satellites. Similarly I studied about dc-dc converters, maximum power point tracking.

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CHAPTER 1

PROBLEM OVERVIEW

Satellites need some source of power for operating. The satellites use solar panels to convert solar energy into electrical energy .The major source of power is Sun. The Leo satellites complete their one revolution around earth in 90 minutes. For approx. 60 minutes, they are under sun but for 30 minutes, they are under eclipse so we need some additional source to give power to satellite subsystems for that purpose, rechargeable batteries are used on board. However, in most of cases the battery life is just one to two years, which is not enough. As the satellites are very expensive, there is a continuous work going on development of noble algorithms to enhance the battery life. To enhance battery life it's charging and discharging cycle has to be optimized.

PROBLEM SOLUTION

I have used Lithium ion batteries as they are commonly used in satellites to implement my system and used efficient battery charging and discharging algorithms so that battery life is increased. I tested various algorithms and finally decided to use modified incremental conductance algorithm for Maximum Power Point Tracking and Constant Current Constant Voltage algorithm for charging and discharging of batteries so that I can use Arduino Uno, which uses a cheap microcontroller ATMEGA 328. In this way, I will also improve cost analysis problem.

ORIENTATION OF REPORT

The report is divided into 8 chapter's altogether. Chapter 2 discusses MPPT and its different algorithms and the most efficient algorithm, which I have used. Chapter 3 about power generation and distribution in Leo satellites. Chapter 4 tells us about need for battery in satellites and battery charging and protection. Further in chapter 5 I discussed about Battery Management System topologies. In chapter 6 dc-dc converters were brought into discussion and their simulation in LT Spice. Chapter 7 contains future results and conclusion and chapter 8 contains future prospects and references.

CHAPTER 2

POWER MODULE

LITERATURE REVIEW

The function of Electrical Power System module is to provide the power to all the subsystems of satellite.

The only available source of power is solar radiation. The PV arrays when exposed to solar radiation collect solar power. The EPS module employs Maximum Power Point Tracking (MPPT) in order to extract maximum power from the photovoltaic array. The intended orbit of satellite is LEO with time period of about 90 minutes. So in that 90 minutes for 60 minutes it is exposed to sunlight but for 30 minutes it is under eclipse. So we have to use a battery bank to provide electrical power to satellite subsystems.

Similarly, in daylight, some operations like attitude control require more power than the power generated by solar panels. So for that purpose we also need a battery bank. Battery Charging and management is also a function of EPS module.

Raw power from Solar Panels and Battery Banks needs to be conditioned and regulated to suitable voltage levels.

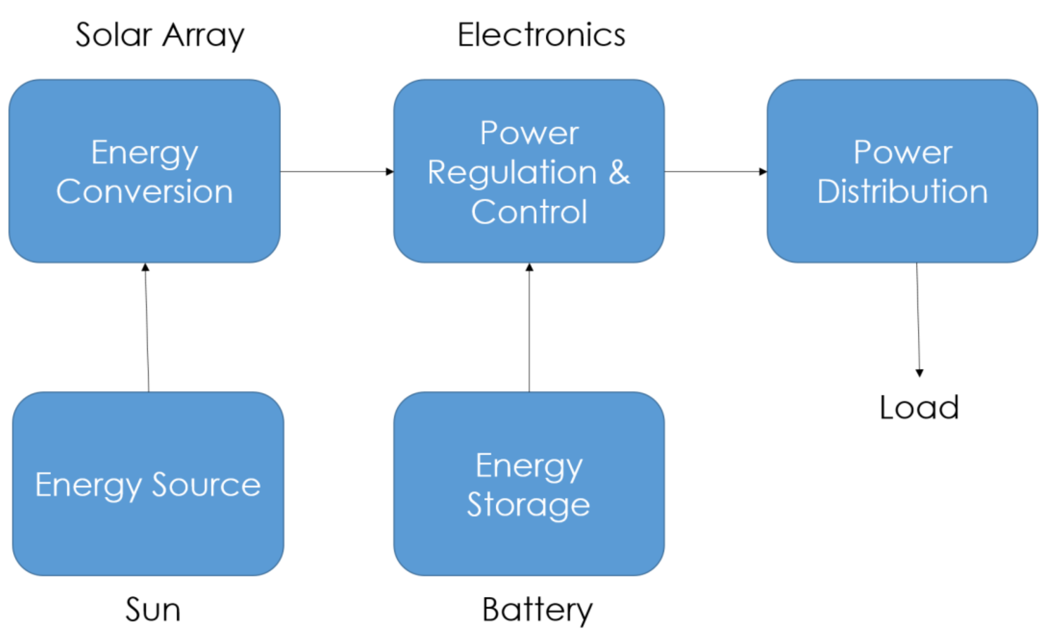


Figure 1 Power regulation and control

METHODOLOGY

We can break our EPS module in individual submodules. Each submodule perform different function. The submodules include DC-DC converters for MPPT, switching regulator submodule for charging of battery, charge controller and main regulator submodule. These four modules merge into EPS system.

MPPT

Sun is the major source of energy. We need a PV cell to convert solar energy to electrical energy. We need to have an MPPT controller to get maximum power from PV module.

It is not easy to increase efficiency of PV panel because it needs advanced components and it requires improvement in manufacturing (i.e. replace old hardware and install new hardware parts). Once installed the PV panels cannot be easily replaced on satellites however their output can be optimized by the use of efficient MPPT algorithms.

We can increase MPPT controller efficiency if we use a new algorithm or update the previous algorithm, which is relatively easy and less costly. The output power, which is generated, will also be increased.

MPPT is used so that we can get maximum power from the PV array.

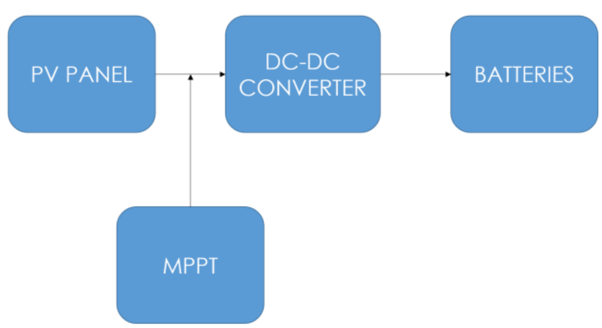


Figure 2 Block diagram of basic MPPT

The above figure 2 shows how system works by using MPPT method. A DC-DC converter is required if we want to deliver maximum power to the load. If we want that, the load receives maximum power its impedance (load) should always be same as the impedance of source(Z_L=Z^*_{th}). We have to control the switching frequency of dc-dc converters so we use a duty cycle value to control switching frequency. The MPPT algorithm detects the best value of D so that load impedance is equal to source impedance. In this way maximum power is transferred from PV array to load.

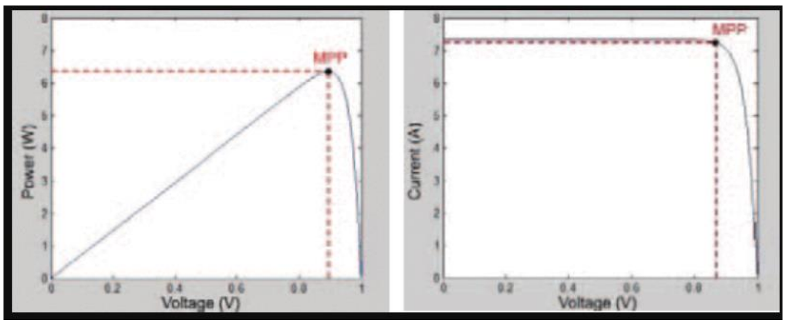


Figure 3 MPP on PV-IV curves

In Fig 3, we can see PV and IV curves. We can see that if we want to reach MPPT the PV system should be operated at specific voltage and current. With changing orientation of the solar panel with respect to sun and variation in irradiance of the Sun the MPPT point shift. I have also plotted PV and IV curves in Matlab as shown below.

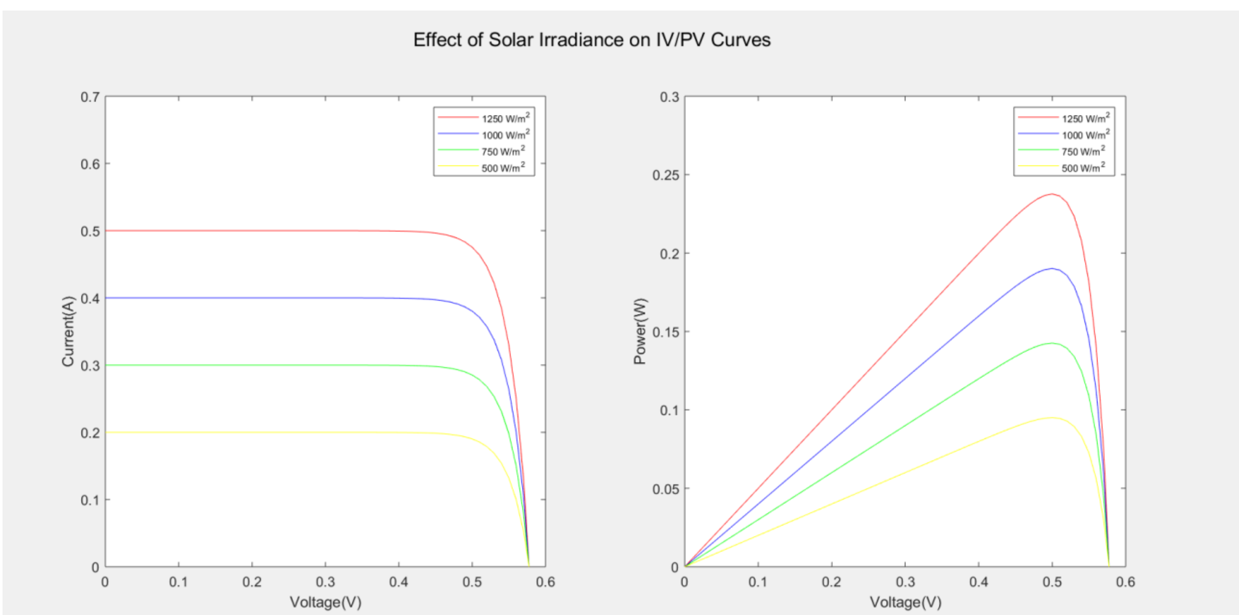


Figure 4 PV-IV curves under different irradiance on MATLAB

PHOTOVOLTAIC CELL

Photovoltaic cell converts light energy into electrical energy. Fig 3 shows model of a PV cell.

Output voltage of solar cell depends almost entirely on current through the diode and follows the Shockley Diode Equation:

$$Id=Ioe\char`^(qVd/kT)-1$$

Hence the output voltage of a solar panel varies with load current, as does the impedance. Changing the impedance by changing the operating point of the Solar Cell is the basis of MPPT.

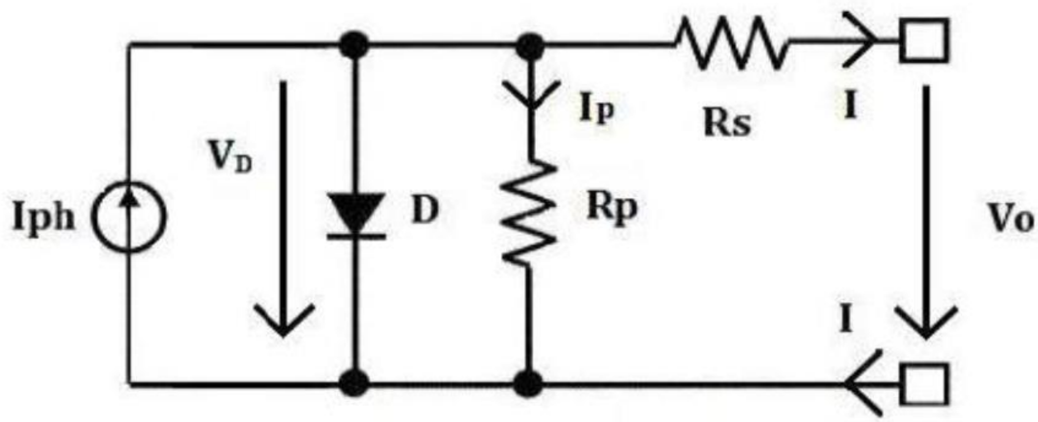


Figure 5 Solar cell model

Characteristic curve of a typical solar panel is given below in Fig 6

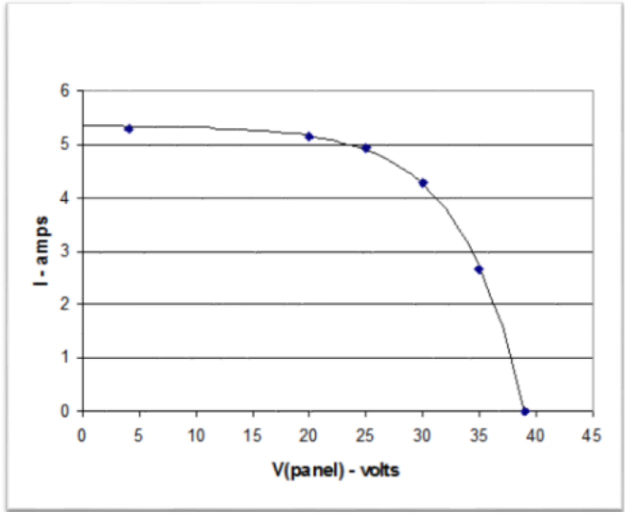


Figure 6 I-V curve of solar panel

From the figure, the MPPT point is the knee of the curve as shown below.

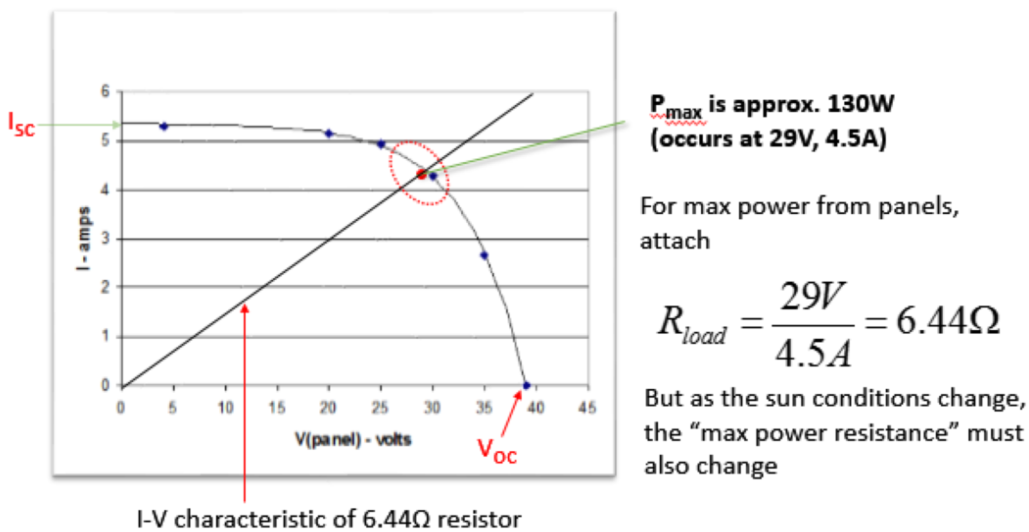


Figure 7 I-V characteristic of 6.44ohm resistor

As an example, if we connect a 100ohm load directly to the cell, much of power is lost.

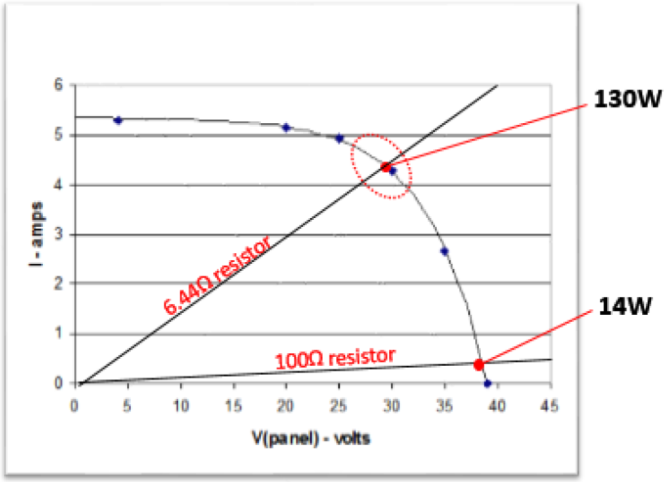


Figure 8 How to extract maximum power with any load

To extract maximum power (130W), connect a boost converter between the panel and the load resistor, and use D to modify the equivalent load resistance seen by the source so that maximum power is transferred

$$R_{equiv} = (1-D)^2 R_{load}, D = 1 - \sqrt{\frac{R_{equiv}}{R_{load}}} = 1 - \sqrt{\frac{6.44}{100}} = 0.75$$

MPPT ALGORITHMS

INTRODUCTION

If we want to extract maximum power from the solar array we use several mppt algorithms. Following is the list of several mppt algorithms.

- Perturb and Observe Algorithm
- Incremental Conductance Algorithm
- Constant Voltage Method

We will discuss only first two of them.

Perturb and Observe Algorithm

In this algorithm MPPT increments the instantaneous voltage and monitors the output power of solar panel. If by incrementing voltage the output power increases the next perturbation will be in positive direction. However, if by increasing voltage the power decreases the next perturbation will be in negative direction. In this way, we can find the maximum power point.

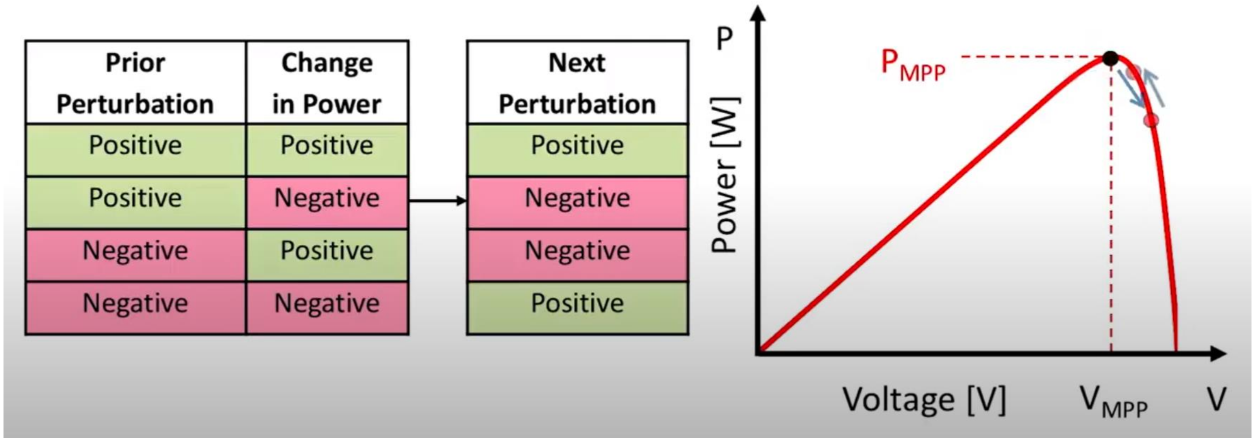


Figure 9 Perturb and observe algorithm

The first perturbation will be random so let us assume it is positive we will monitor the output power. If the change in power is positive, the next perturbation will be positive. If the prior perturbation is positive and change in power is negative, next perturbation will be negative as shown in fig 7. Similarly, if the change in power is positive but the prior perturbation is negative the next perturbation will also be negative.

Lastly, if the both prior perturbation and change in power is negative the next perturbation will be positive.

POTENTIAL DRAW BACK OF P&O METHOD

Let us take an example. If for first perturbation, increase in voltage increases the power the next perturbation should be positive but suddenly due to change in weather (clouds etc.) the irradiance decreases. The PV curve changes so as the maximum power point on the curve as shown in fig below. The system has no knowledge about this, so in next perturbation it will increase voltage, which in turns power decreases. Now the system will assume that the MPPT point is on the left side, eventually it will correct itself. These changes in irradiance are frequent enough that it can result in a PV system operating far from a maximum power point for a significant amount of time.

However, even with this drawback the perturb and observe method works better than the other techniques.

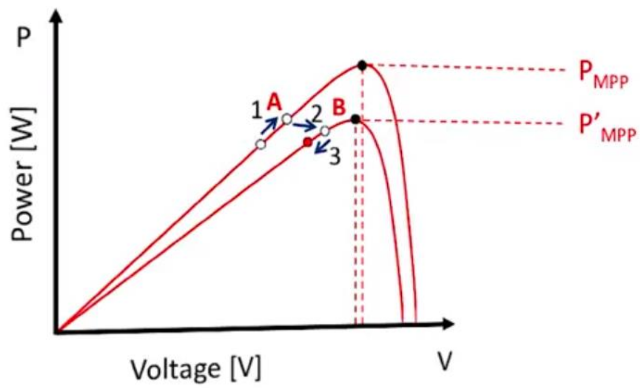


Figure 10 Drawback of perturb and observe

FLOWCHART OF P&O METHOD

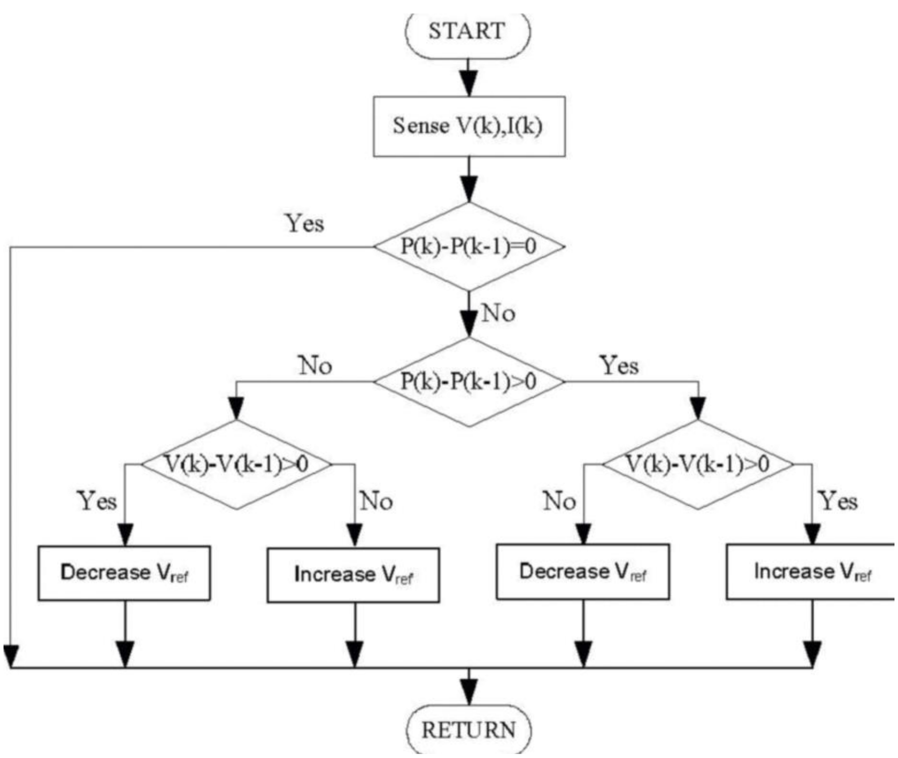


Figure 11 P&O flowchart

Incremental Conductance (INC) Method

Incremental conductance is not as simple as the perturb and observe technique let's get into how it works here we have our normal solar panel IV and PV curves when maximum power point tracking directly there are three regions of interest there is the maximum power point itself and there is also a region to the left of the maximum power point which is in blue here if we are in The region we need to increase the voltage to get to the maximum power point finally there is the region to the right of the maximum power point, which is shown in light green region if we are in this Region we know that we have to reduce the voltage in order to reach the maximum power point so those are the three regions of interest one thing that is unique about these three regions is the derivative of the power with respect to the voltage or DP / DV at the maximum power point DP / DV is zero in the white region to the left of the maximum power point DP/ DV is positive finally to the right of the maximum power point DP/ DV is negative.

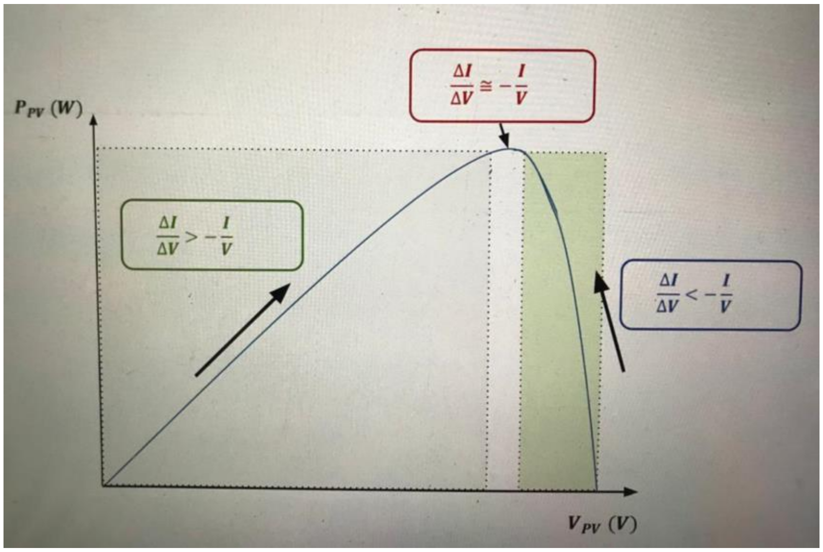


Figure 12 PV diagram INC

FLOW CHART OF INC METHOD

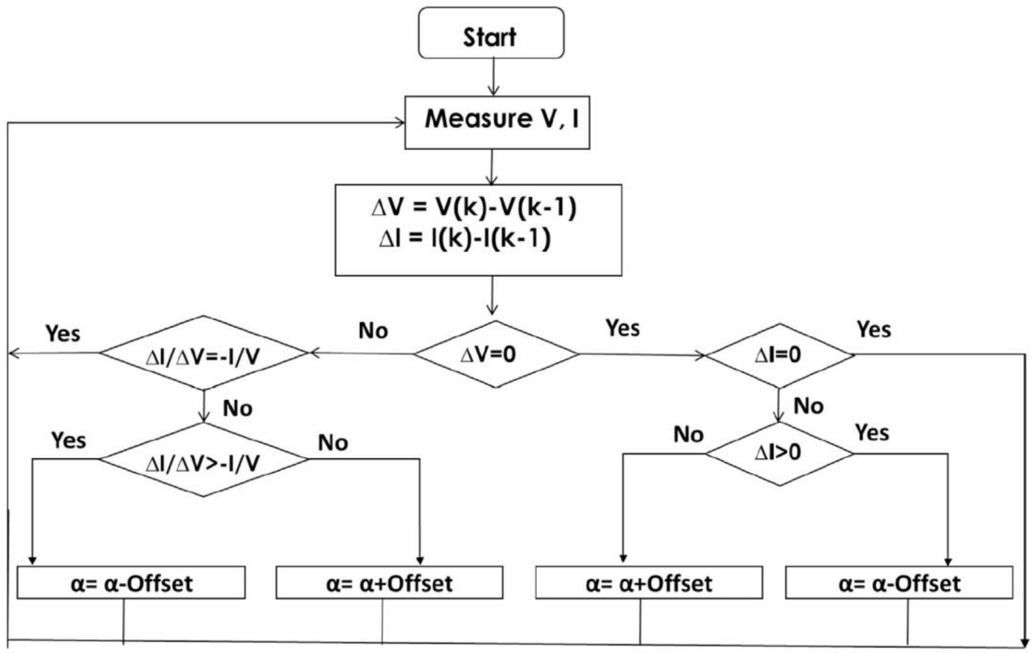


Figure 13 INC algorithm flowchart

Drawbacks

- Its calculation is tedious so it is hard to implement.
- Its decision-making under sudden change in irradiance is not good.
- We have to use expensive microcontroller to implement this algorithm.

MODIFIED INC ALGORITHM

To overcome the drawbacks of INC algorithm due to its complex mathematical calculations and to avoid using expensive microcontrollers, we can use modified inc algorithm. Following is the flowchart of modified inc algorithm.

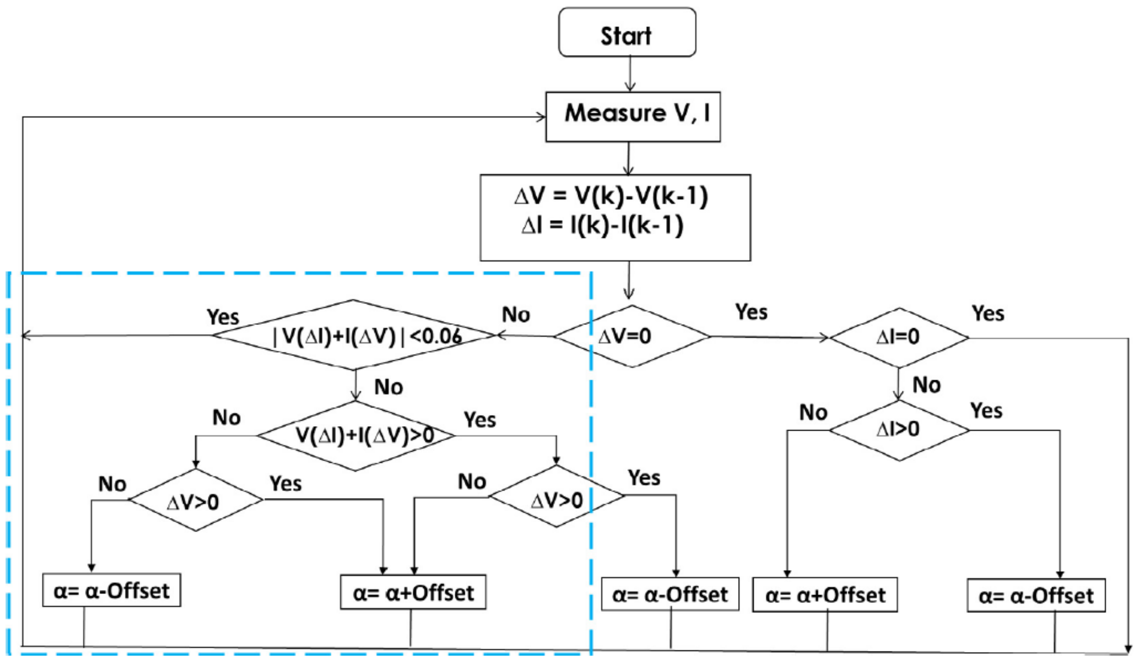


Figure 14 Modified INC algorithm

By using modified inc algorithm we can use Arduino which consist of ATMEGA 328 microcontroller to burn our code.

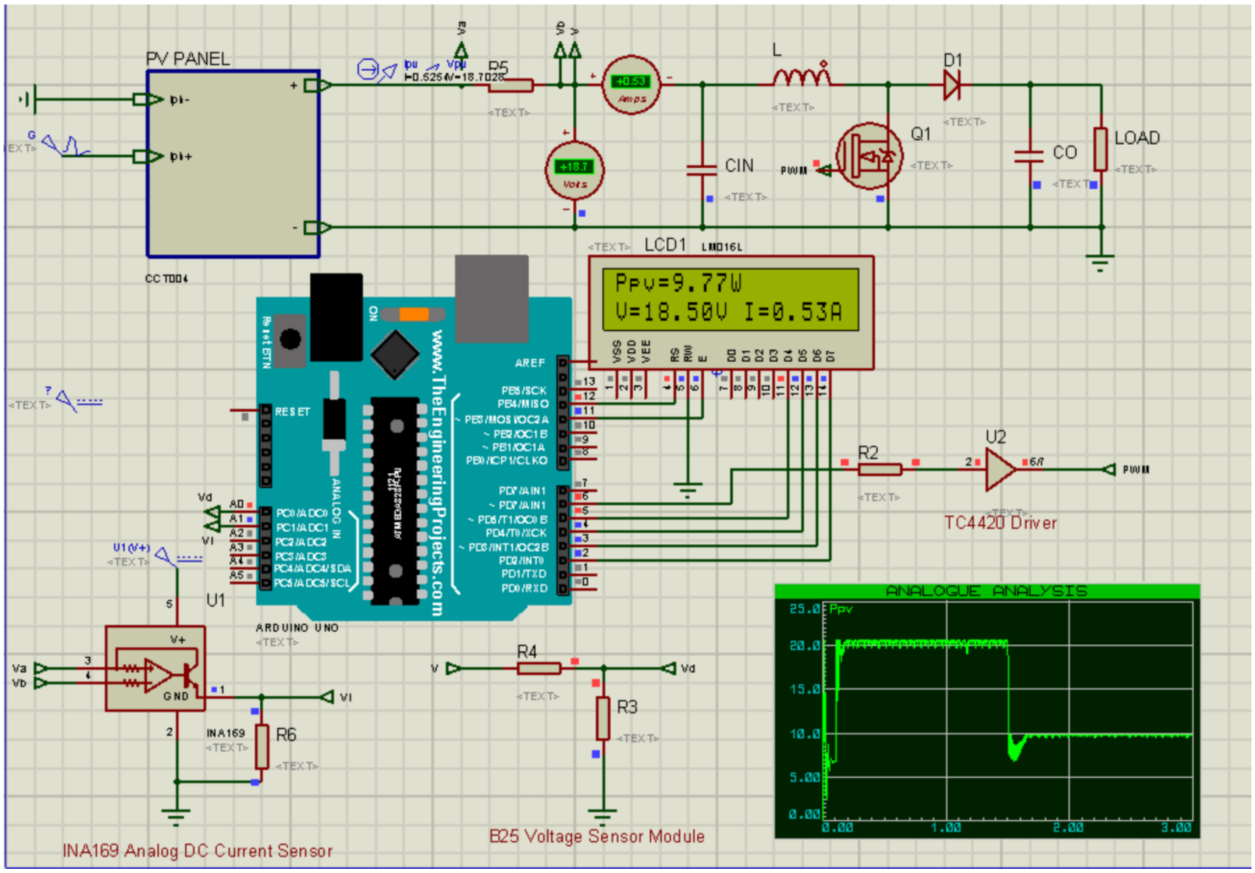


Figure 15 Charge controller

Above is the proteus schematic of our mppt charge controller. Following is the list of components used and their function and purpose in our circuit.

SOLAR PANEL

A solar panel converts solar energy into electrical energy directly. The solar panel consists of semiconducting material which is responsible for photovoltaic effect. Below is Solar panel equivalent circuit.

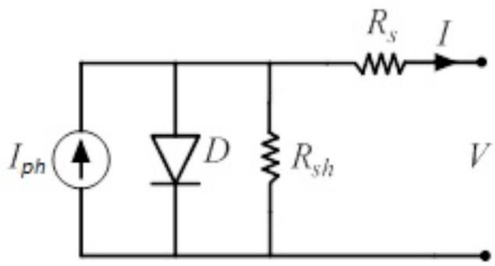


Figure 16 Solar cell circuit

It consists of a current source, diode, shunt resistor and a series resistor. Below is the equation for current generated using Solar panel.

$$I = I_{ph} - \mathrm{I}_0 \left(\exp \frac{\mathrm{q}(\mathrm{V} + R_s \mathrm{I})}{\mathrm{aKTN}_s} - 1 \right) - \frac{(V + IR_s)}{R_{sh}}$$

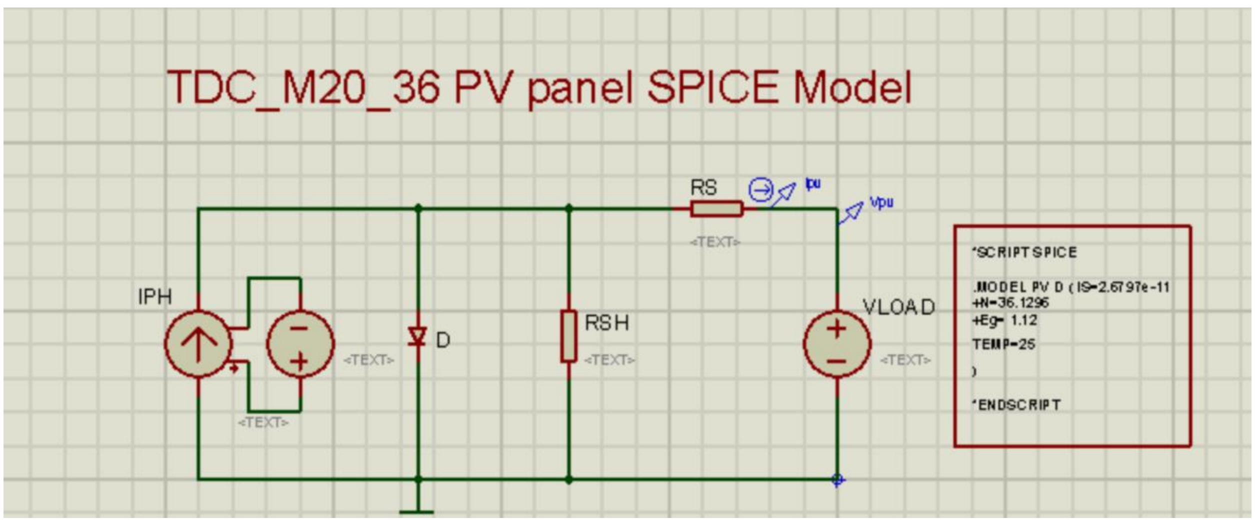


Figure 17 PV panel spice model

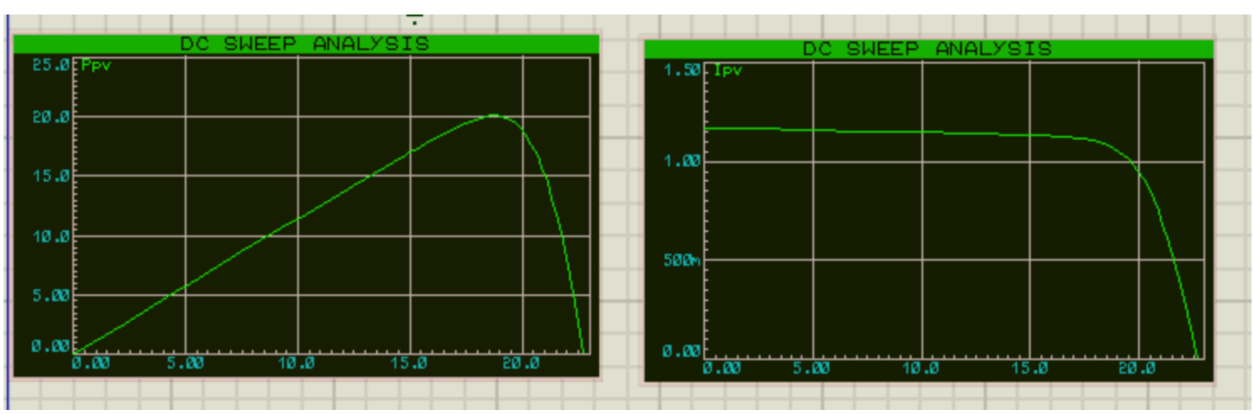


Figure 18 PV/IV curves

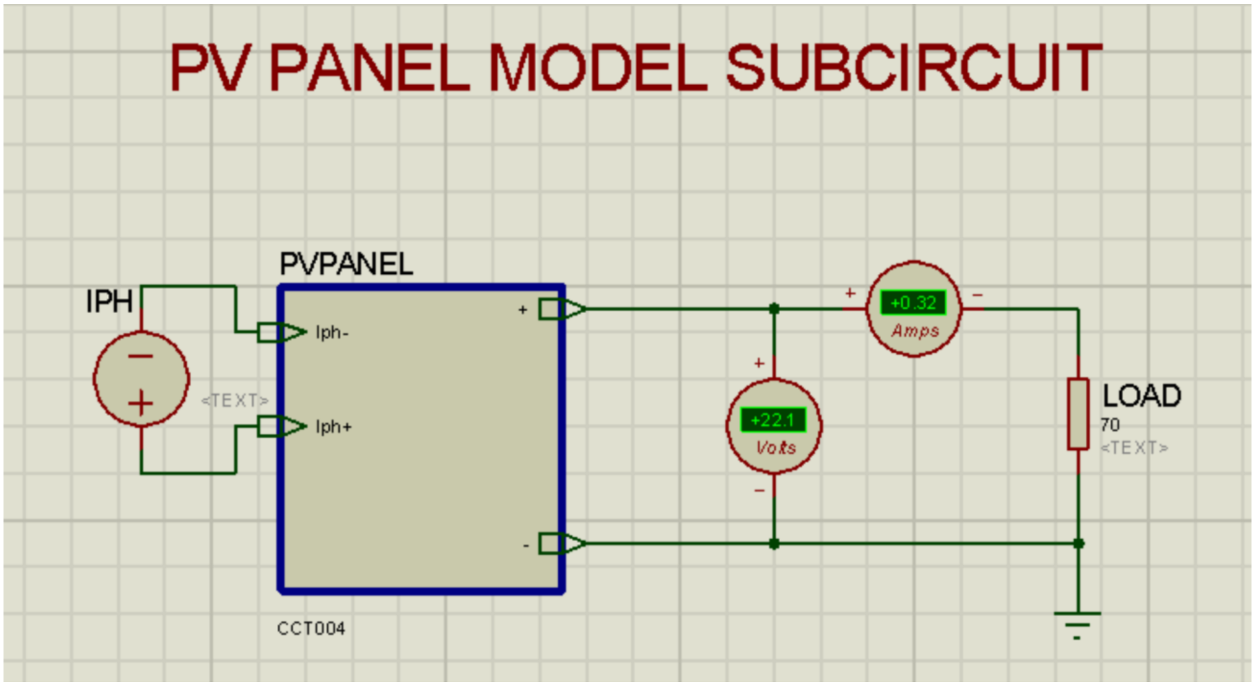


Figure 19 PV panel sub circuit

The advantage of doing simulation in proteus is that the results are almost same when we implement in hardware.

Components Used and Their Use

Arduino Uno

I am using Arduino because it is cheap. I used modified INC so that I could use Arduino to burn my code. Arduino uses At mega 328 microcontroller.

B-25 Voltage Sensor

The voltage, which is coming from our solar panel, is relatively high. The analog input pin of our Arduino cannot read more than 5volts, so to decrease PV voltage to 0- 5V we will use B-25 voltage sensor.

INA-169 Current Sensor

It is used to measure the current coming from solar panel (photovoltaic current). INA-169 is an analog dc current sensor module. The current, which passes through R5(1ohm), is the PV current. R5 is present between solar panel and variable load resistor (70ohm). The subtractor circuit of operational amplifier in INA -169 calculates the voltage across R5 and it is given to Arduino so that we get to know the photovoltaic current value.

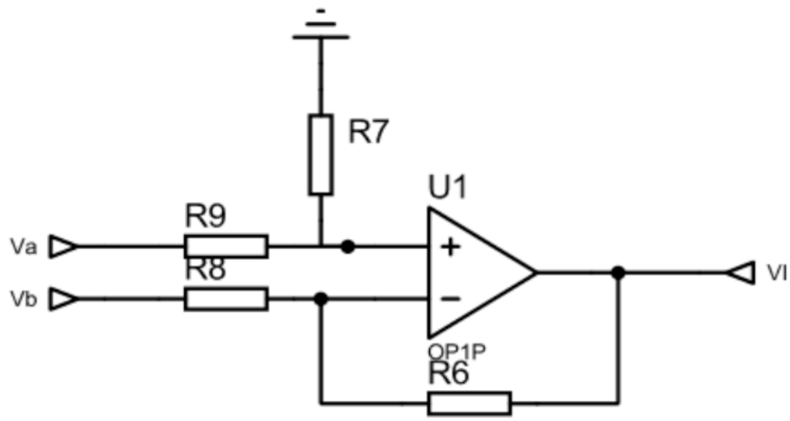


Figure 20 Subtractor circuit in operational amplifier

Boost Converter

I have used a dc-dc converter to transfer maximum power from our solar panel to the load. In this case I will use boost converter. I have used boost converter so that the mismatch is minimized between pv panel and our load resistor, also so that it operates at maximum power point.

Mosfet

Mosfet is used as a switch.it generates pwm waves. I have used IRFP250N Mosfet. A mosfet is also used for switching purpose and also to amplify the input signal. It has 3 parts which are gate, source and drain.

TC4420 Driver

In order to control MOSFET we use gate driver ICs. I have used TC4420 in this project. We basically use it to turn on and off your igbts and mosfets by applying signals at base. Our microcontroller cannot achieve it due to its lower signal strength and that’s why I used an intermediate stage (gate driver) which boosts this gate signal so that switching is achieved.

Diode

A diode allows current to flow in only direction. I have used a schlocky diode because it has very low forward voltage (it is the voltage required to allow current flow across diode) and it also increases the efficiency of our dc-dc converter. I have used 1n4007 diode.

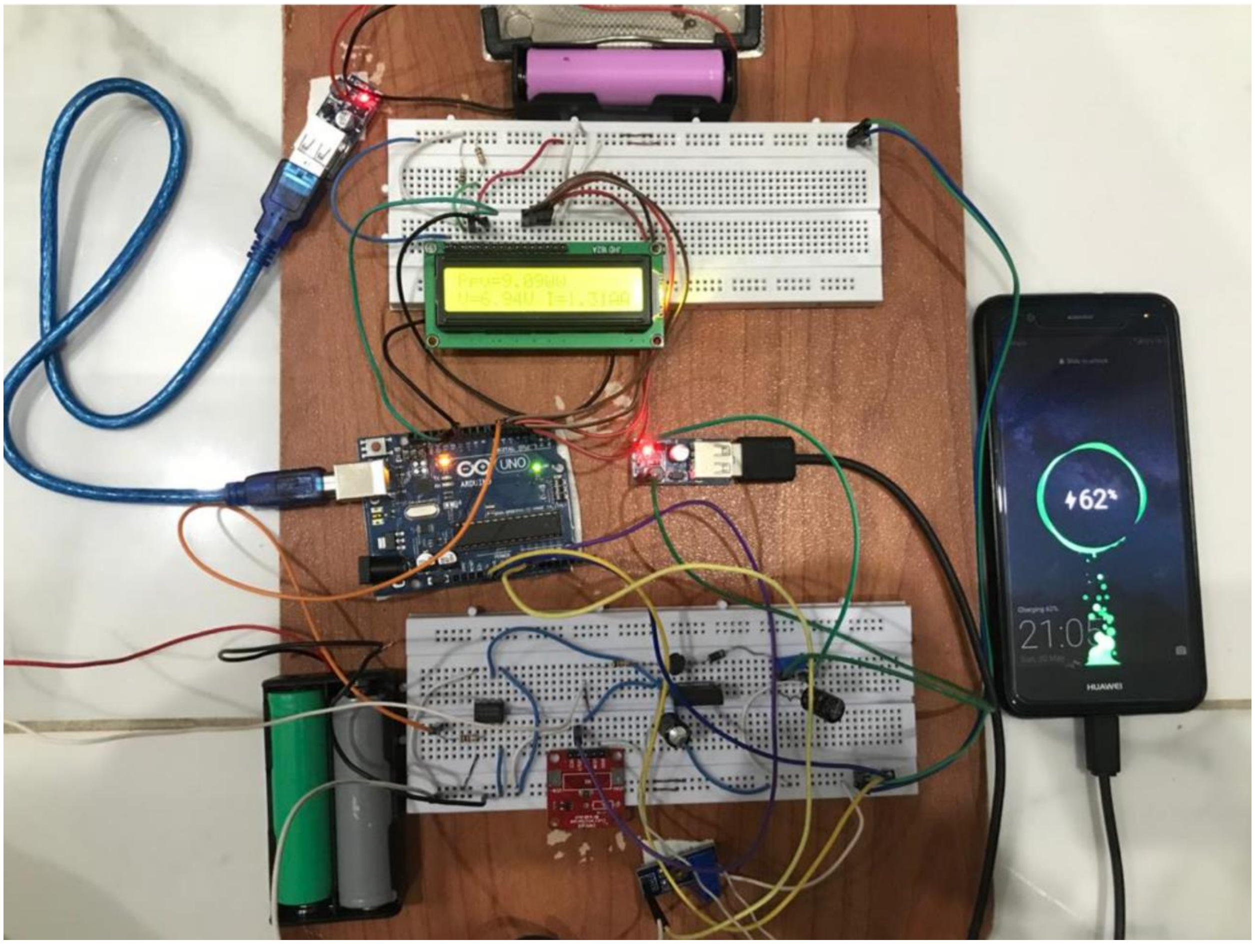


Figure 21 Power distribution hardware

Figure 22 Output of power distribution on lcd

CHAPTER 3

POWER GENERATION AND DISTRIBUTION IN LEO SATELLITES

INTRODUCTION

As we know that we have to give power to the satellites. For that purpose our primary source of power is Sun. the satellite completes its one rotation around earth in 90 min so in one day it completes 16 rotation around earth. In first 60 minutes it is exposed to sunlight. Solar panels are mounted on sunlight so they will provide energy to the load. The remaining 30 minutes it will be under eclipse so we have to provide power through battery banks. We use Lithium ion batteries for this purpose.

POWER GENERATION

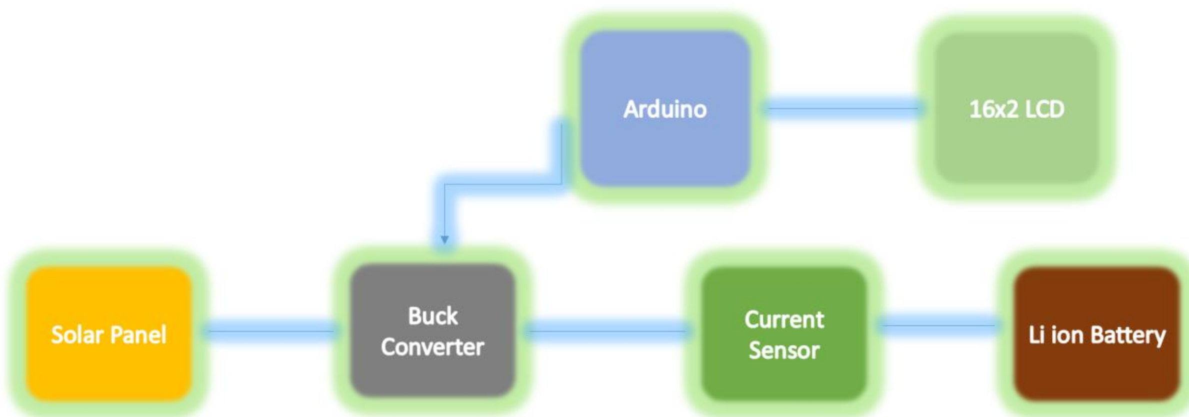


Figure 23 Power generation

In fig 23, I have used Constant current Constant voltage buck converter to charge the battery. It decreases the output voltage. The buck converter module which I used is XL-4015. I used 5A ACS-712 current sensor to measure the charging current of battery. I have used ATMEGA 328 as my microcontroller with Arduino as a microcontroller board. In satellites 28V lithium ion battery is used but for a prototype I have used 3.7V lithium ion cell. I have used 16x2 lcd to display my output that my battery is charging and to show that which mode my battery is charging (constant current or constant voltage) mode.

POWER DISTRIBUTION

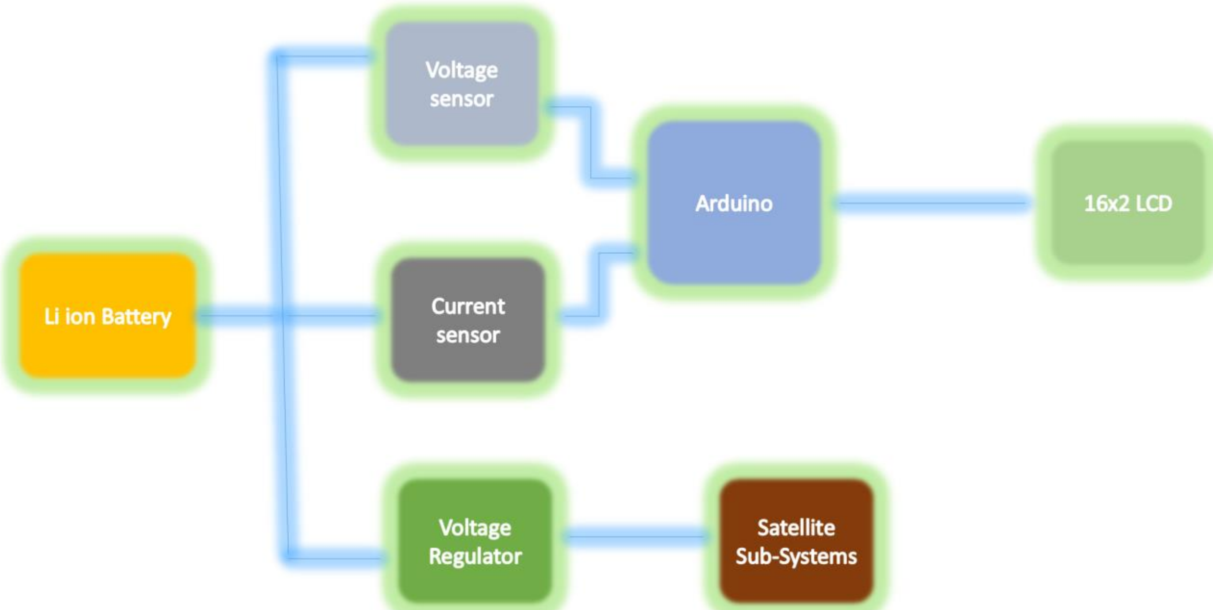


Figure 24 Power distribution

Fig 24 shows a power distribution module. In this module the batteries are providing power to the satellite sub-systems in the eclipse period. I have used voltage sensor to convert high voltage of battery Arduino analog input voltage because Arduino cannot read voltage more than 5V. I have used a voltage regulator which is a boost converter.

CHAPTER 4

BATTERY CHARGING AND PROTECTION

INTRODUCTION

The storage of energy is a major need in renewable energy system especially batteries. But we do not take proper care of batteries when we charge or discharge them. We generally leave the batteries for long time than the actual time they need for charging which causes the battery to be aged and expands them which results in reduction of battery life.

Need For Battery Protection

To increase battery life

Save our expenses

Maintenance is not possible in space so that's why we need to increase battery life.

Charging Algorithm

Different charging and discharging algorithms are used to increase battery life and efficiency. It includes

- Constant current method
- Constant voltage
- Fuzzy logic method

I will discuss the first two methods here.

Constant Current Method

In this method the current is kept constant until the battery gets charged. During charging when voltage is increased then a variable resistor is connected in series. Many batteries are connected in series due to this method and the main supply of current is kept constant.

Potential Drawback

By using this method it will take longer to charge battery and the battery charger should have high voltage rating according to the number of batteries we are connecting.

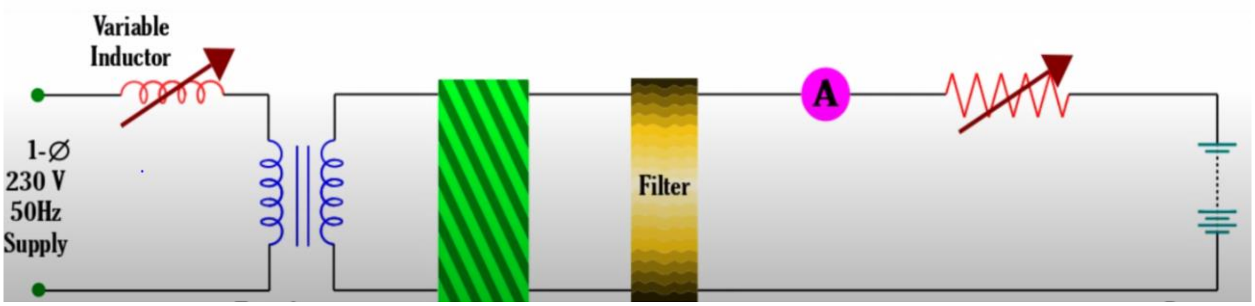


Figure 23 Constant Current method

Constant Voltage Method

In this method the voltage is kept constant when battery is charging. Initially charging current is greater and this current decreases when voltage increases.

The batteries whose voltage is same are connected in parallel and then we charge them.

By using this method the battery charges quickly as compared to constant current method.

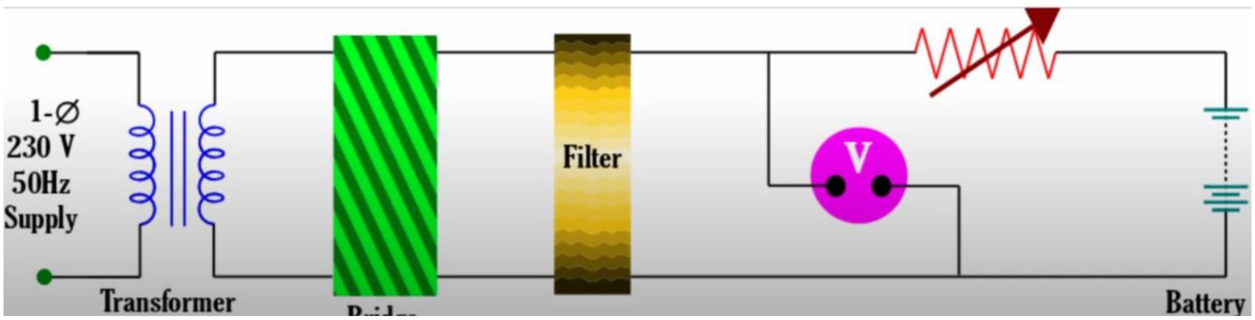


Figure 24 Constant Voltage method

FLOW CHART OF CC/CV METHOD

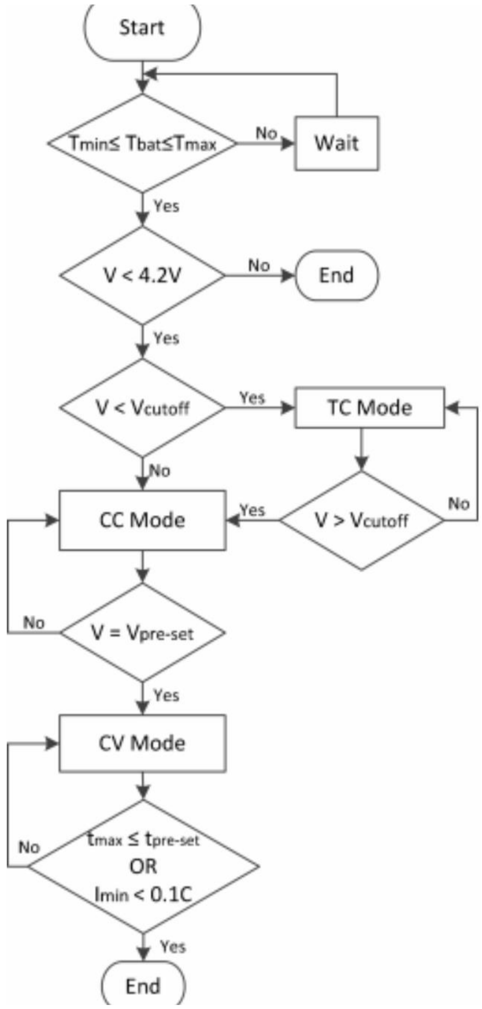


Figure 25 CC/CV flow chart

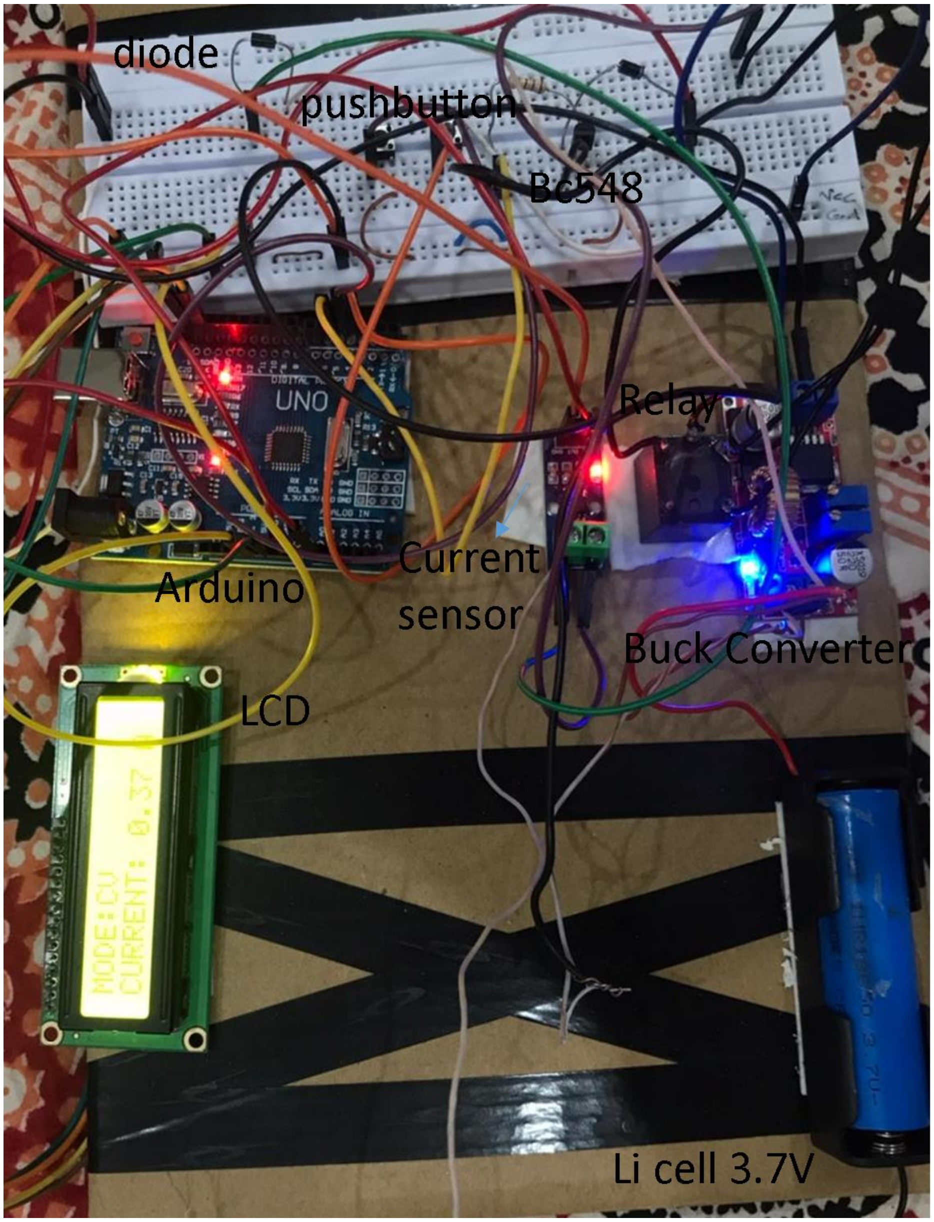


Figure 26 Experimental setup

INTRODUCTION

As we need a secondary source in case of eclipse to give power to satellites we will use lithium ion batteries for that purpose? I have made a prototype for that purpose. I have taken a 18650 2200mAh, 3.7volt lithium ion cell which can charge up to 4.2volt. It will charge in two modes, which are constant current CC and constant voltage CV. Its charging current is 2.2A

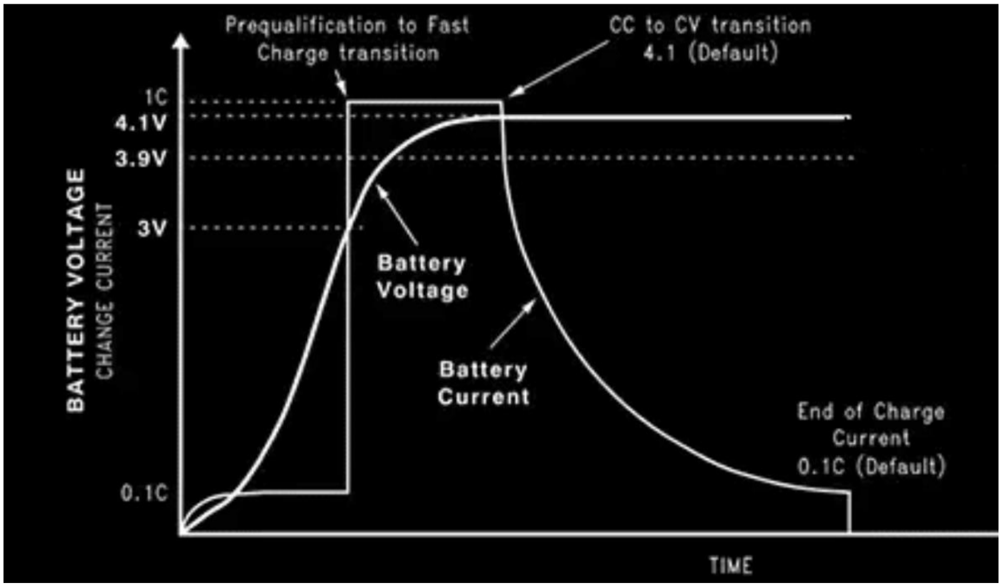


Figure 27 Graphical analysis of constant current constant voltage method

Constant Current and Constant Voltage mode

If I connect a fully discharged cell to a battery charger it will consume current, its voltage will gradually increase but its current will remain constant so this is cc mode, the maximum cell charging capacity is 4.2volt once it has reached its maximum capacity, the current will decrease and the voltage will remain constant this is cv mode, after cv mode has completed our battery will be completely charged.

Following are the components I used and their purpose

CC/CV Buck Converter

I have used XL4015 buck converter module. It can regulate voltage as well it has an additional feature of regulating current also.it has two potentiometers we can change voltage and current with the help of screwdriver. I will set the output voltage to 4.2volt and current 2.2Amps.

Current Sensor

I have used ACS-712 5Amps current sensor. Its function is to measure the charging current of Li ion cell.

LCD with I2C adapter

A 16x2 lcd is used to display the output. I have used i2c module in order to decrease wiring of the circuit and make it look neat and clean.

Transistor

I have used BC548 npn transistor. It is used to turn on our relay.

Resistor

A 1.8kohm resistor is used at base of npn transistor so that it limits the current if high current pass through transistor it will damage the transistor that’s why resistor is used.

JQC3F Relay

I have used 5pin 12-volt relay. A transistor activates the relay. In this case, I used bc548 transistor.

Push Buttons

I have used two push buttons. First button asks us to enter the battery capacity you can increment it by 100. Once it reaches to 5000 it resets to 1000. The second push button starts the charging of our cell.

Diode

I have connected diode in parallel with relay so that it stops flow of reverse current.

BATTERY CHARGING THROUGH SOLAR PANEL

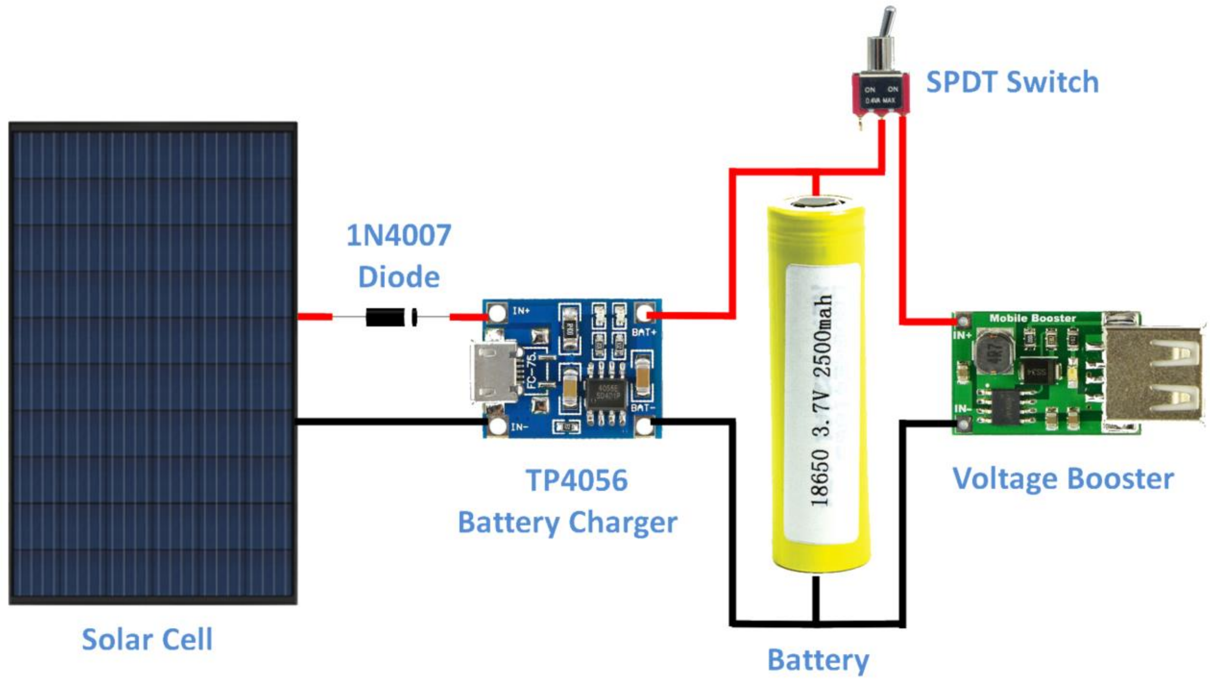


Figure 28 Schematic of solar li ion charger

TP4056

This is a cheap constant current constant voltage lithium battery charging module. It has two leds red and blue. When our load i.e cell is charging its red led is on. When our lithium ion cell is charged completely its blue led is on. We can also directly charge our battery by a charger that's here we use micro usb port.

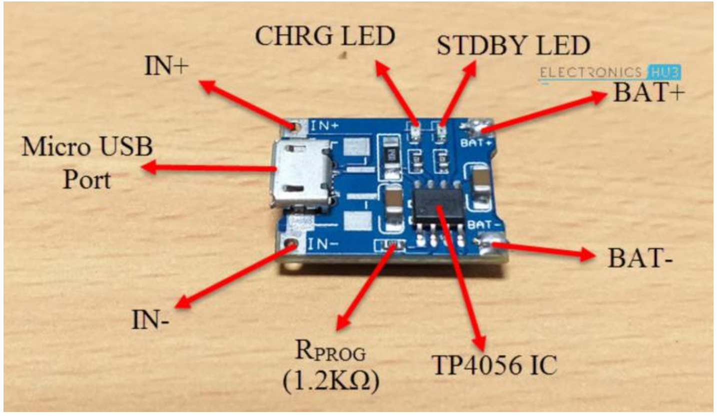


Figure 29 TP-4056 charging module

Voltage Booster

As the output voltage of 18650 li ion cell is 3.7volt so I want to get 5volts at output that's why I have connected a boost converter. This boost converter input is between 1-5volt and output is 5volt. We can connect a load for e.g. a mobile phone and it will charge our mobile phone. We can also use it to power our Arduino Uno etc.

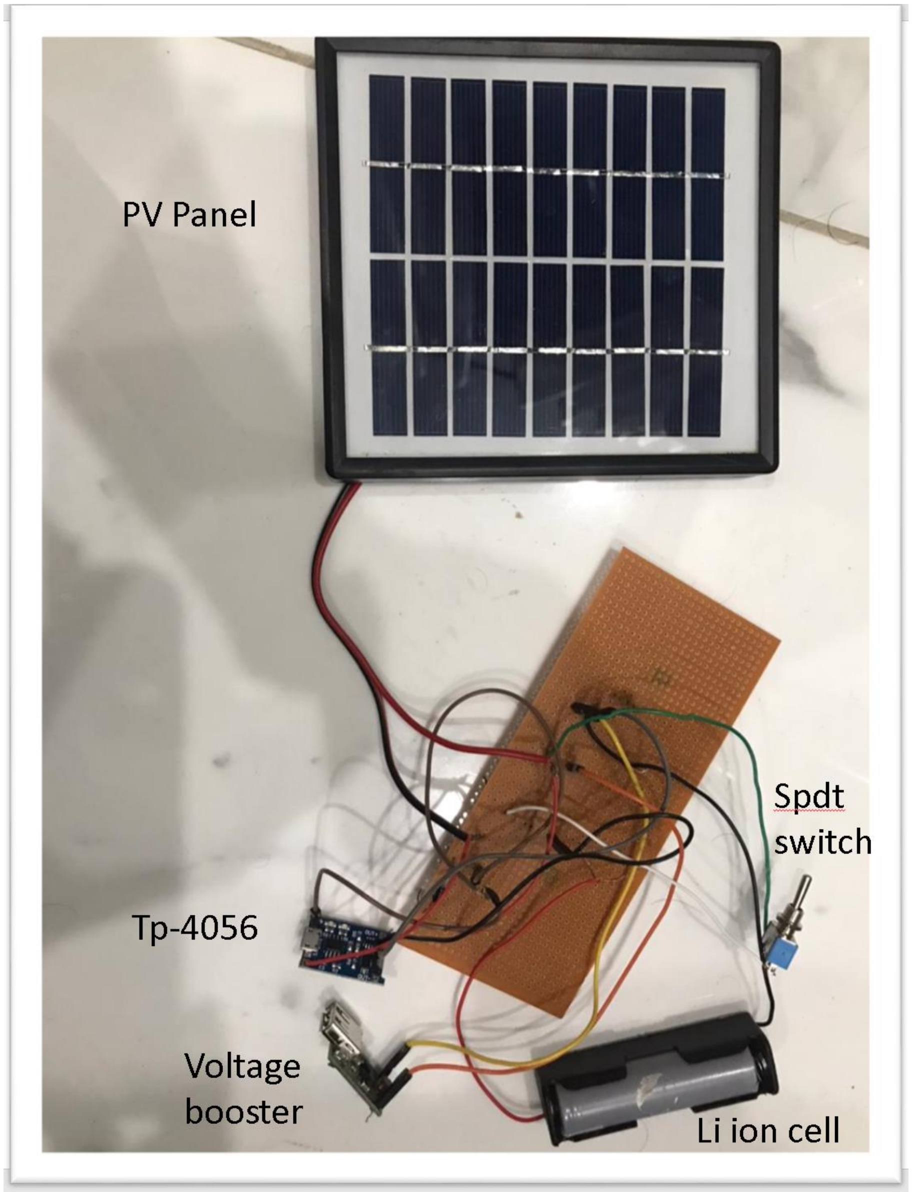


Figure 30 Experimental setup of Solar battery charger

CHAPTER 5

BMS TOPOLOGIES

There are 3 types of BMS topologies.

- Centralized
- Distributed
- Modular

We will discuss them one by one.

Centralized:

In this topology a centralized master control unit is connected to each cell of battery pack. The controller unit protects and balance all the cells.

Advantage & Disadvantage:

It reduces the hardware but excess heat can be generated because the only source for cell balancing is the controller. Moreover cells are distributed between several locations of the satellite which requires a lot of wiring.

Distributed:

In this topology there are small voltage & discharge monitor sockets which communicate with master controller of BMS.

Advantage & Disadvantage:

It is simple and reliable but it requires large no of small PCB's and become difficult to mount on every type of cell.

Modular:

Multiple slave BMS controllers are used to fetch the data and forward it to master controller so no special PCB is necessary to connect individual cell.

In BMS for LEO Satellites, distributed type of topology is used. Below is flowchart of Distributed topology.

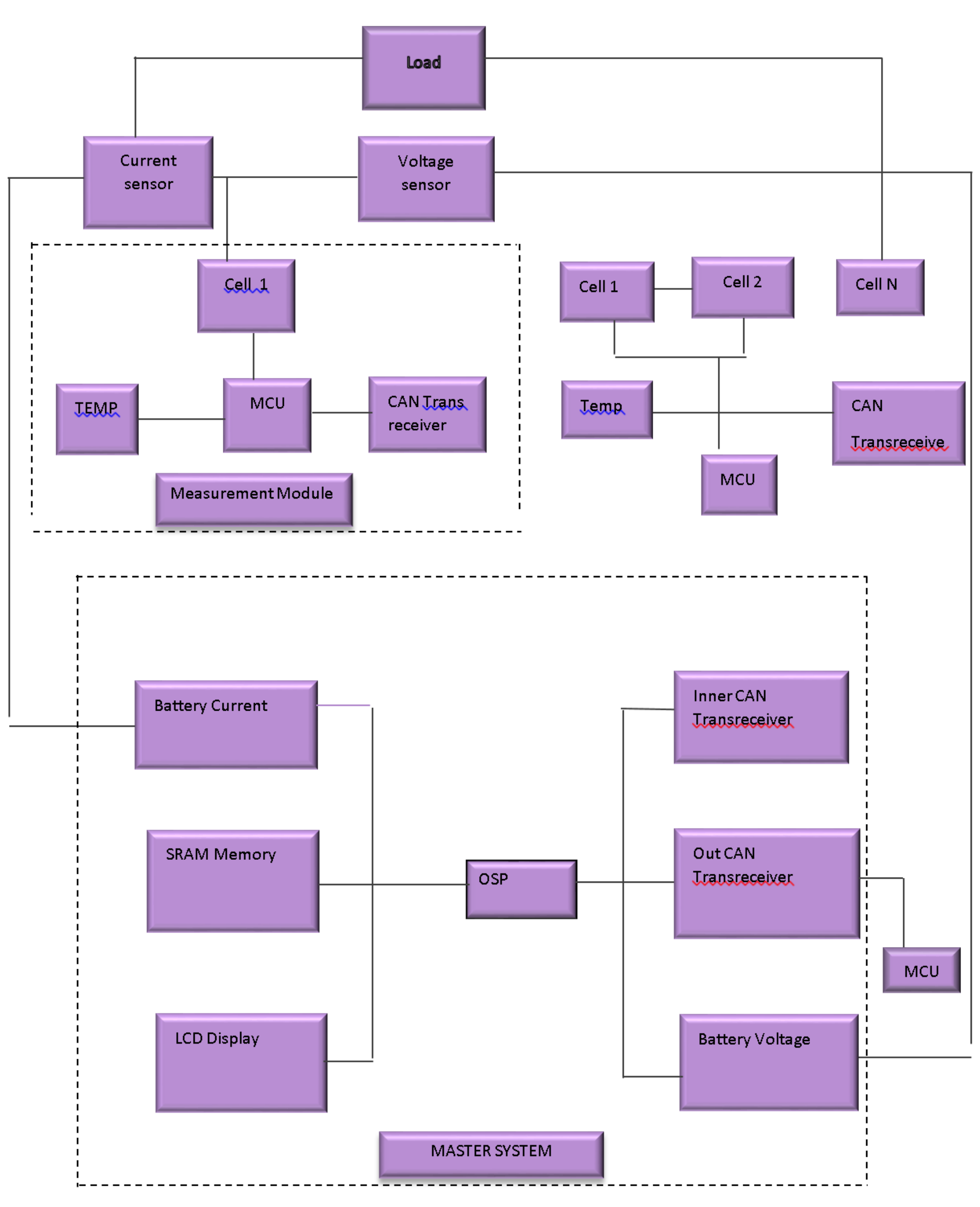


Figure 31 Battery management system topologies flowchart

CHAPTER 6

DC-DC CONVERTERS

BUCK CONVERTER

At the beginning, S is open (not conducting). No current flows and voltage across the load is zero.

S is closed (begins conducting). Current flowing through inductor starts to increase and inductor responds to this change by producing voltage of the opposite polarity, so the v the load voltage is equal to the difference of input voltage and voltage produced by the inductor because of change in current - therefore, it’s smaller than supply voltage. Diode is not conducting at this moment. We are also ignoring the voltage drop across the switch for simplicity.

S is open (stops conducting). The current (from the source, that’s important) rapidly drops to zero, but there’s still magnetic field accumulated in the inductor that has to go somewhere. Remember that the inductor responds to change of current by generating a voltage. This voltage will have opposite polarity from the voltage generated when the current was increasing (the minus will be on the left, the plus on the right). Diode starts conducting and now the inductor powers the load through the diode with a decreasing current. Note that the input source is now disconnected and current flows only from the inductor, through the diode, to the load. Because of that, the current flowing in the load is greater than the current drawn from the source.

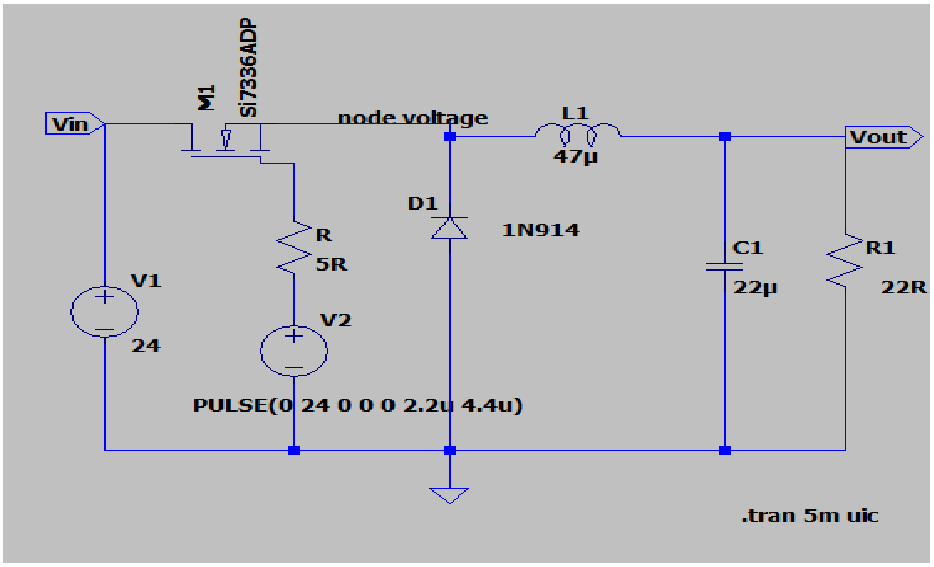


Figure 32 Schematic of buck converter

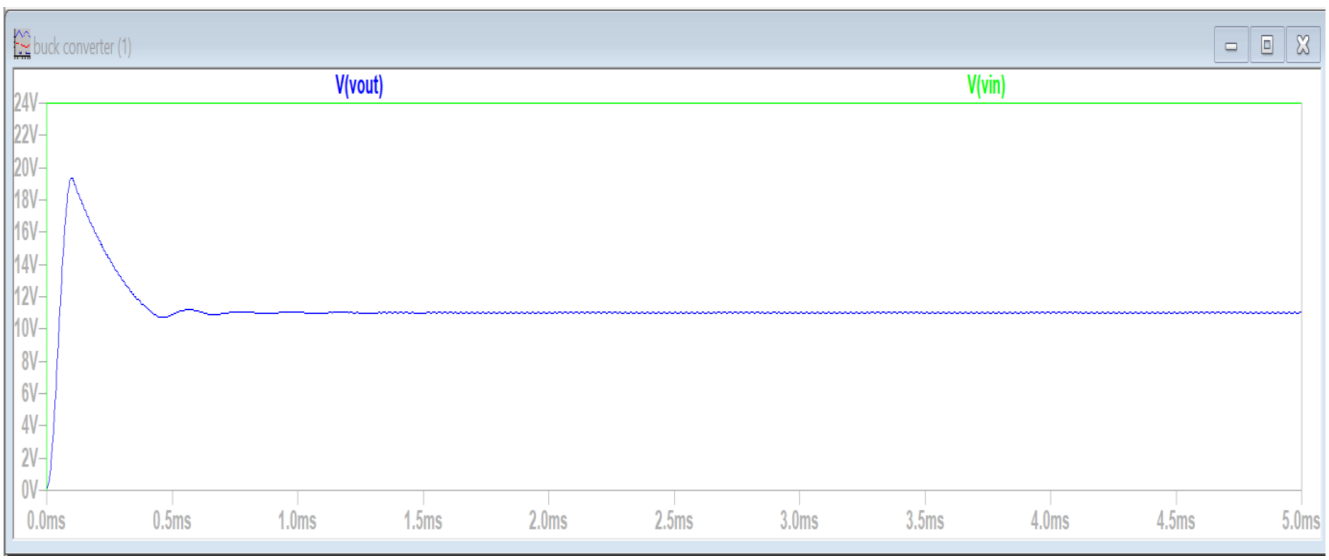


Figure 33 Buck converter output voltage waveform

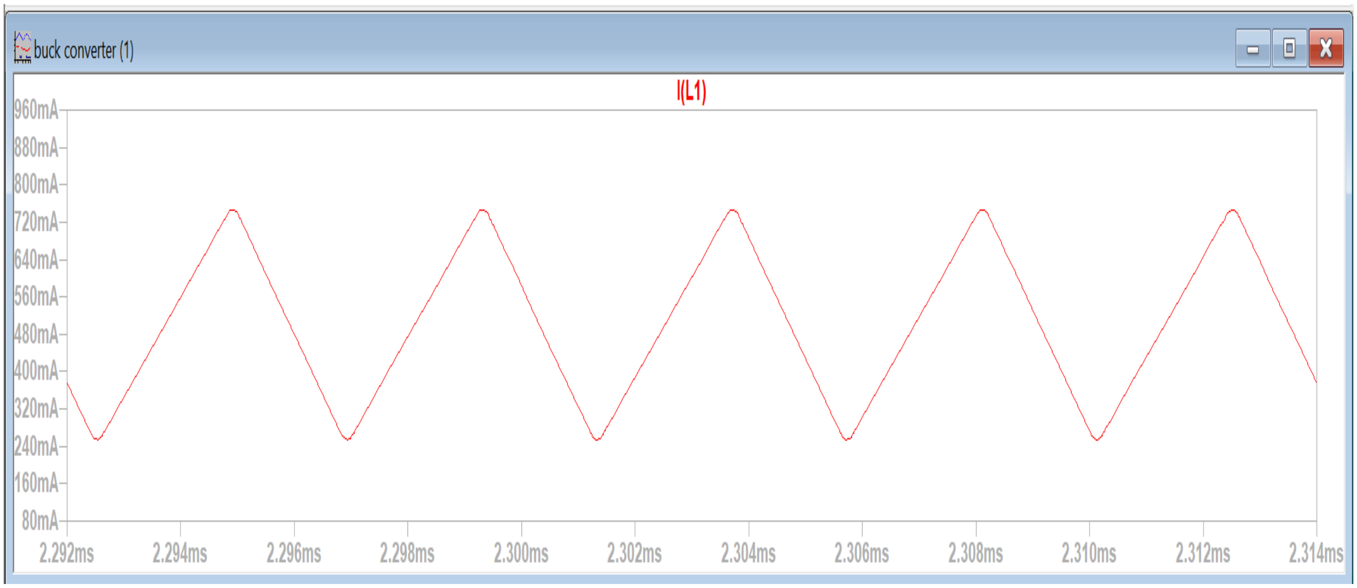


Figure 34 Inductor current waveform

INDUCTOR CURRENT WAVEFORM: There is an inductor current ripple of delta IL = 745.52 – 253.48 =492.04mA

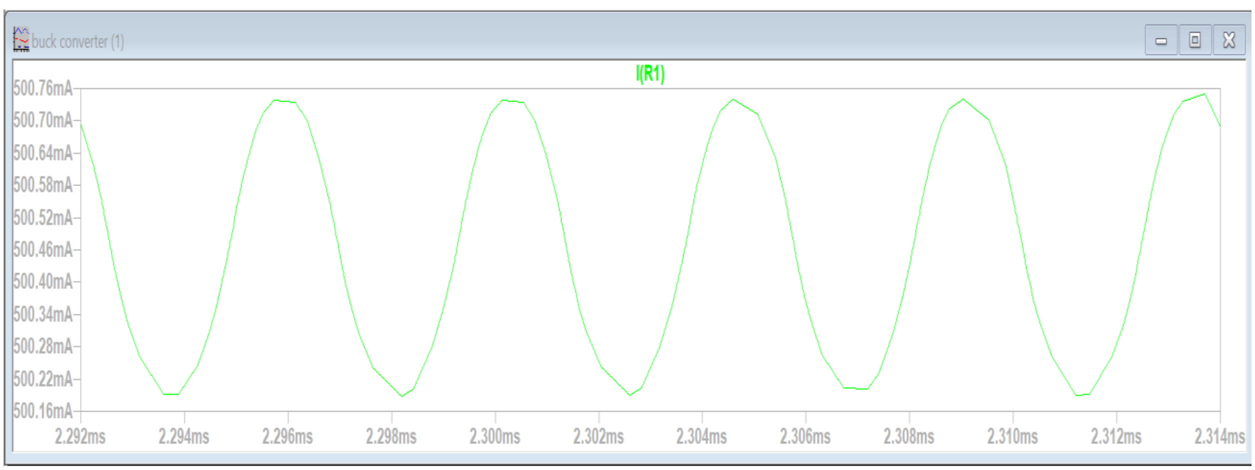


Figure 35 Output current waveform

OUTPUT CURRENT WAVEFORM: There is a current ripple of 500.30 – 499.73 = 0.57mA

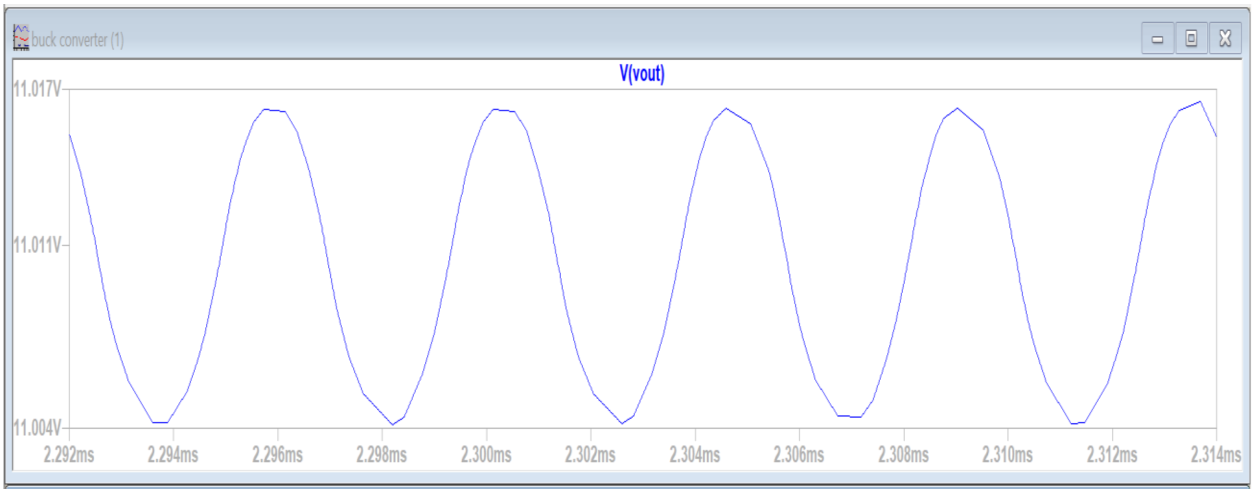


Figure 36 Voltage waveform of buck converter

OUTPUT VOLTAGE WAVEFORM: 11 – 10.995 = 5mV ripple in output voltage

BOOST CONVERTER

A boost converter steps up a lower voltage at input to a higher voltage at output. As the output voltage increases the current decreases.

On state: When we close the switch the current start to flow through the inductor to the switch. In this case the inductor gets charged and it stores energy..

Off-state: The diode becomes forward biased and the inductor releases all the energy which is stored in it when we will open the switch.

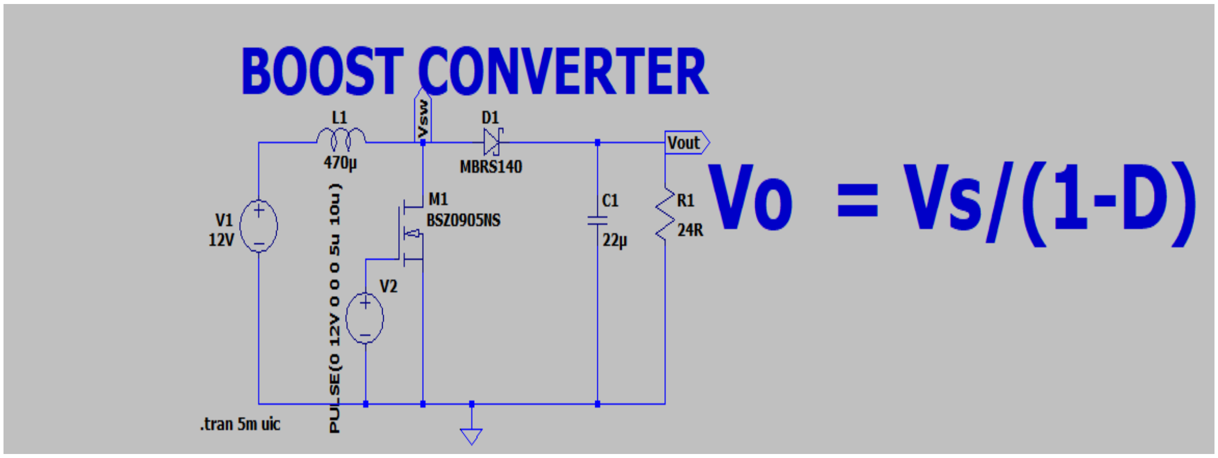


Figure 37 Boost converter schematic

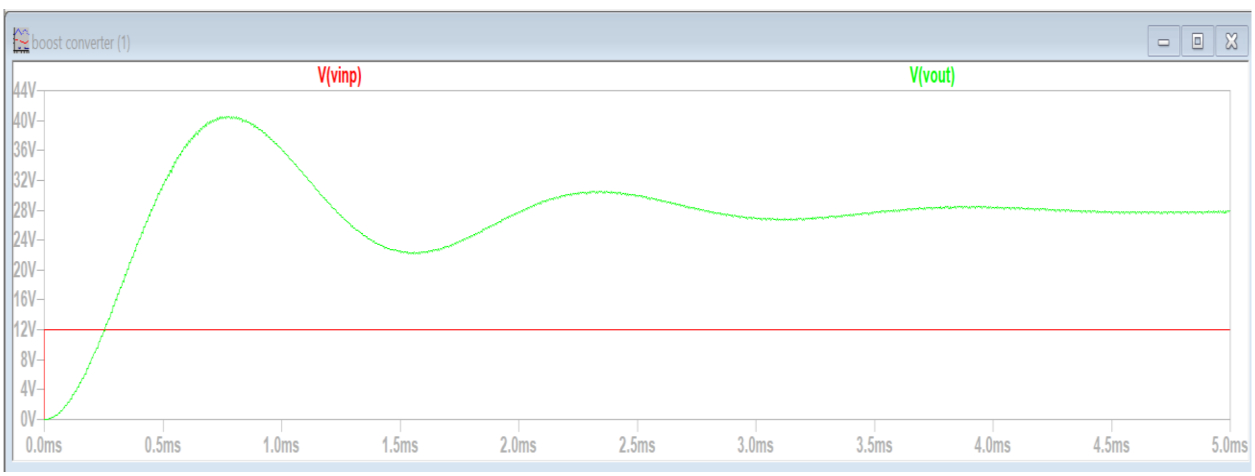


Figure 38 Output voltage waveform of boost converter

IL1

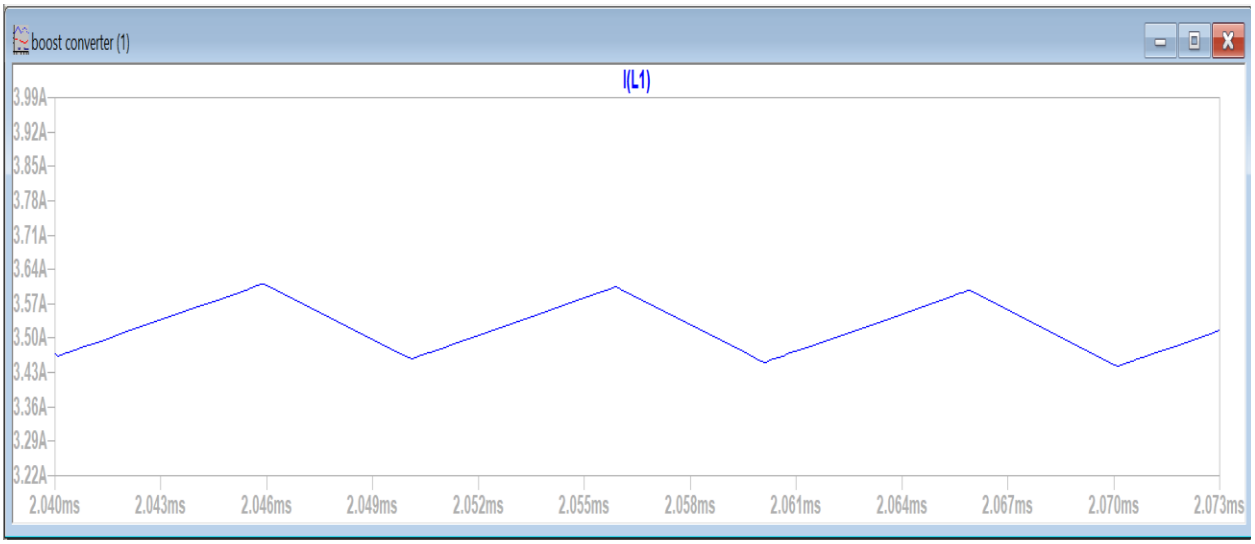


Figure 39 Inductor Current IL1

INDUCTOR CURRENT RIPPLE: 3.59-3.44 =0.15A

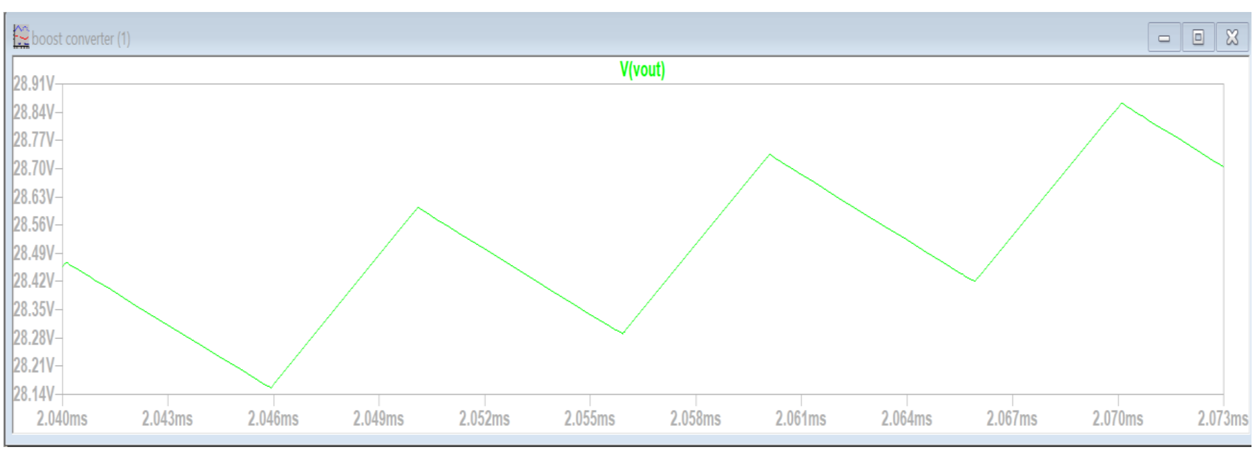


Figure 40 Inductor Current Ripple

OUTPUT VOLTAGE RIPPLE: 28.73-28.41=0.32V

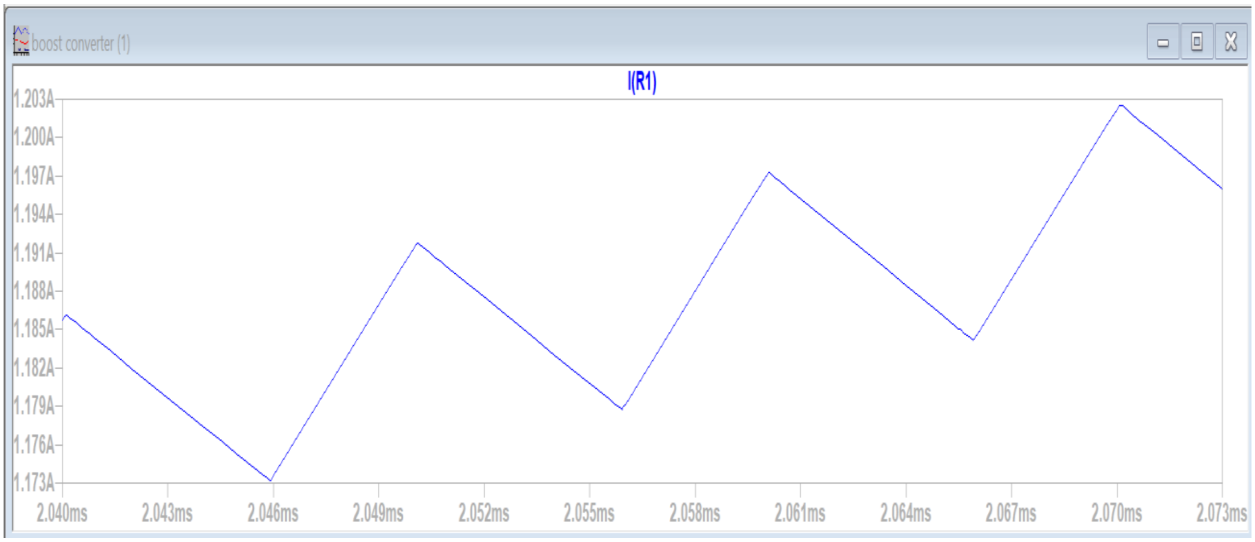


Figure 41 Output Current Ripple

OUTPUT CURRENT RIPPLE: 1.19716-1.18417 = 12.99mA

BUCK BOOST CONVERTER

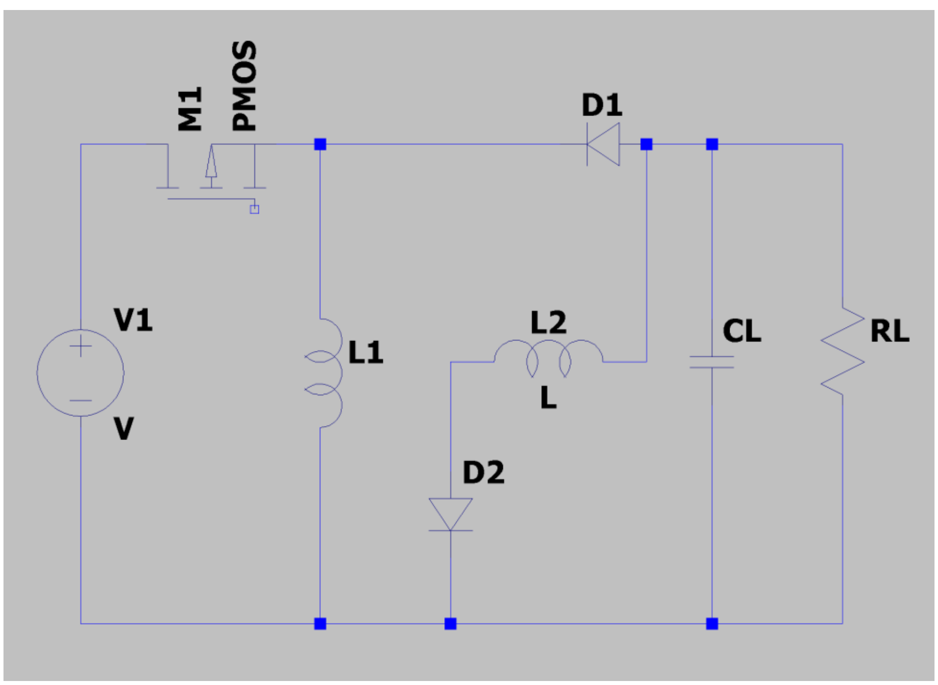


Figure 42 LT Spice Buck Boost converter

A Buck-Boost converter can act both as a buck converter and a boost converter.it can step up as well as step down the input voltage at the output. It can also reverse the input voltage at output.

On State

When the switch is on the diode D1 and D2 become open circuit due to reverse bias. The current will pass through the inductor and it will store energy. Similarly the capacitor will release the store energy and the current will pass through the load resistor RL.

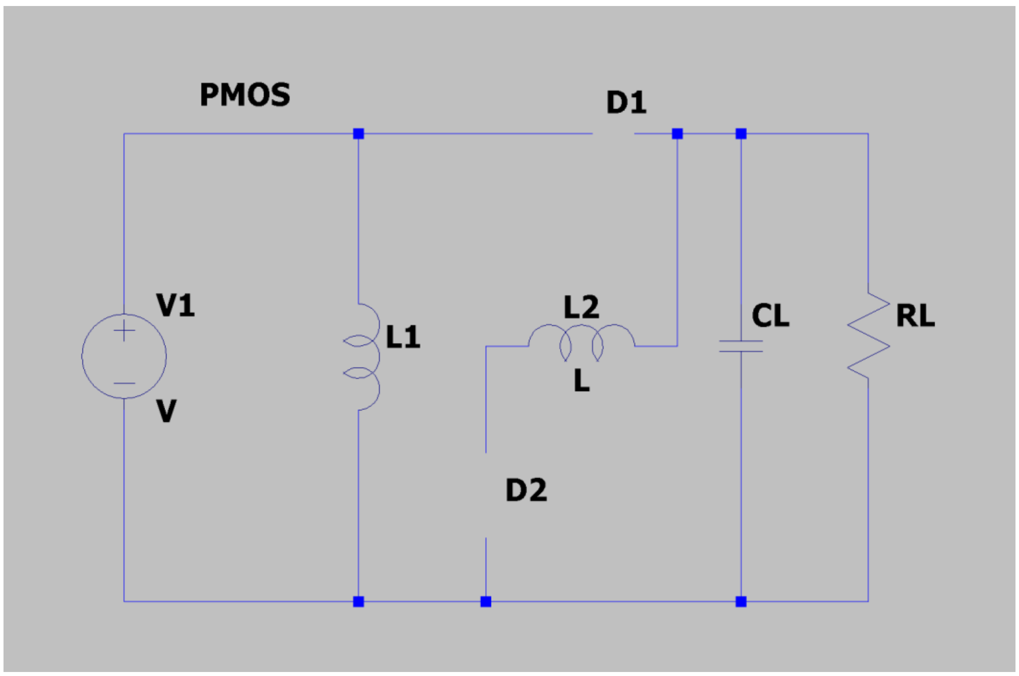


Figure 43 Buck Boost converter on state schematic

Off State

When the switch is open, the diode D1 becomes forward biased and diode D2 becomes open due to reverse bias.

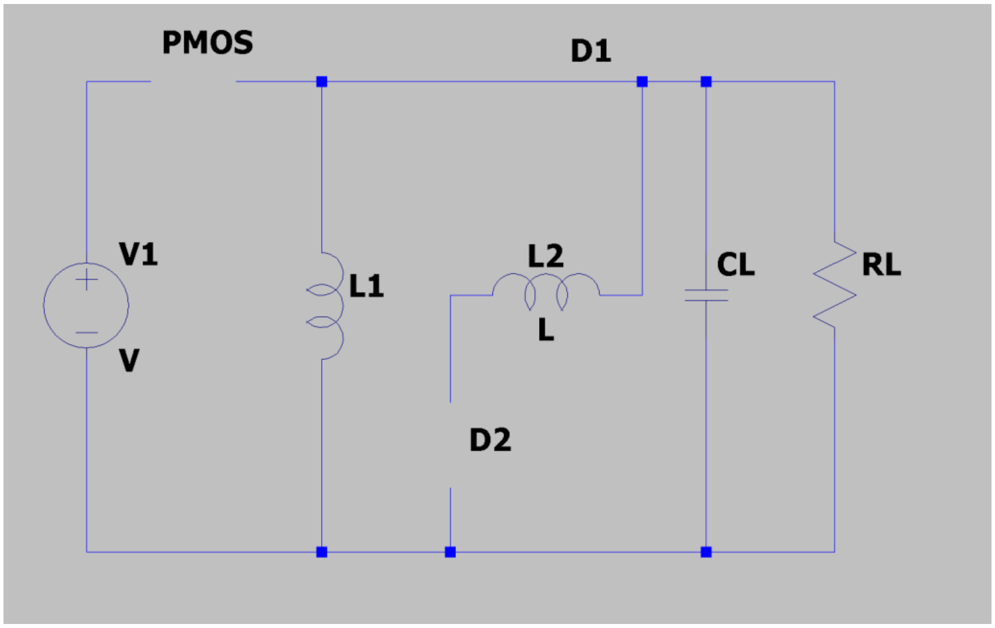


Figure 44 Buck Boost converter off state schematic

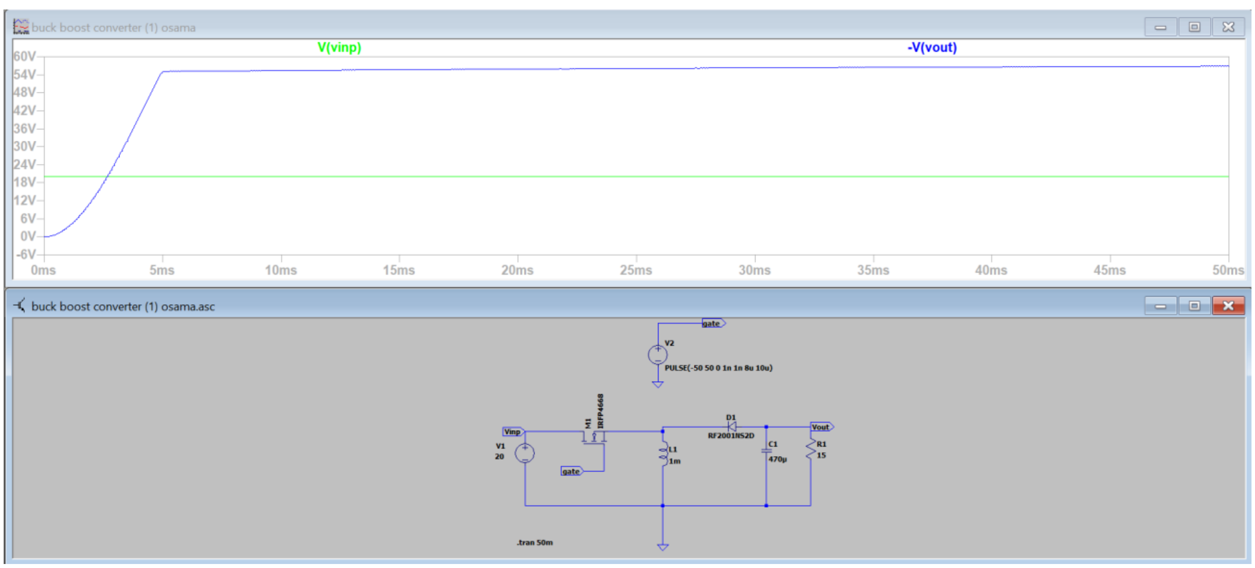


Figure 45 Buck Boost converter output voltage waveform

now i/p is increased to 168 V from 20 V but o/p is 56 V

by changing Duty cycle of nmos:

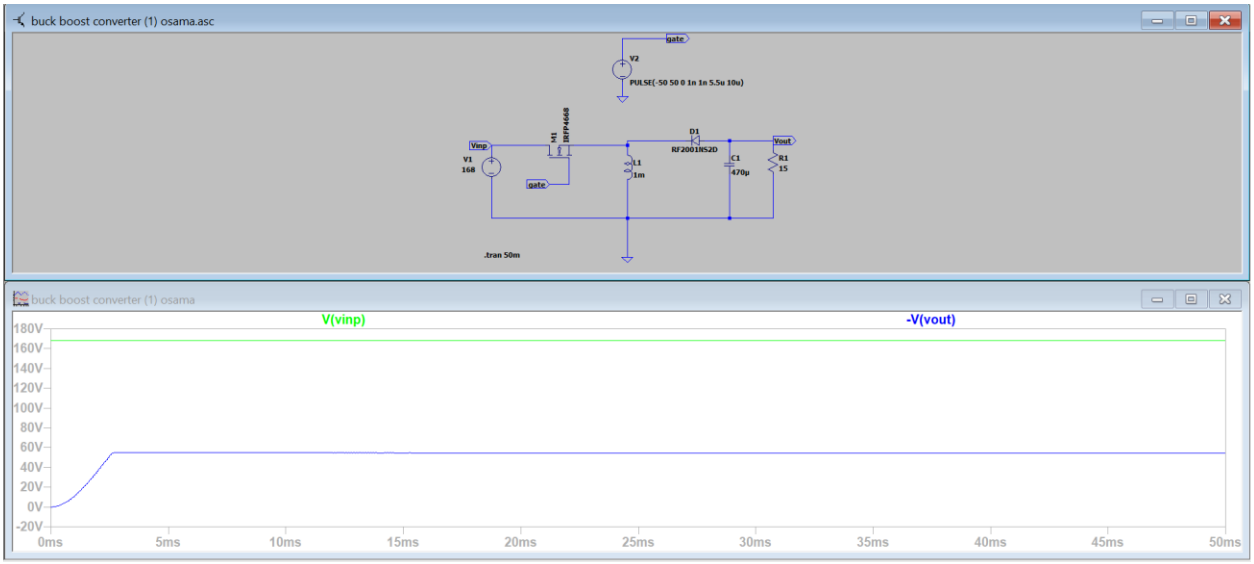


Figure 46 Constant output voltage of Buck Boost converter by changing duty cycle

now i/p is 100 v but o/pstill 56V

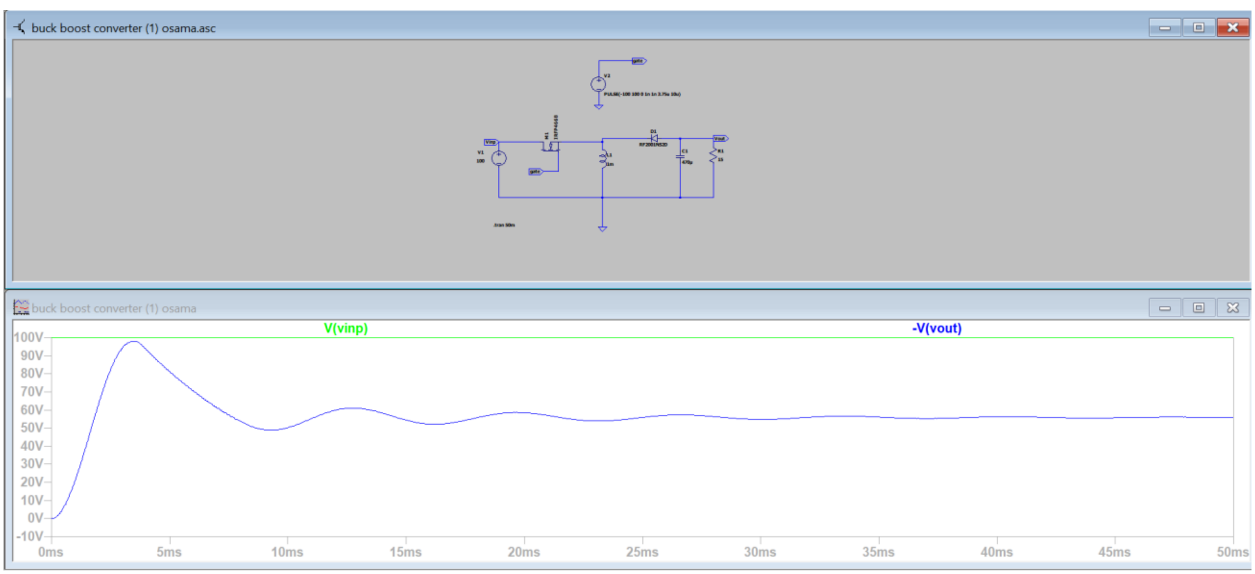


Figure 47 Buck Boost Converter fixed output voltage

BUCK BOOST CONVERTER WITH VARIABLE VOLTAGE SOURCE BUT FIXED OUTPUT

SIMULINK

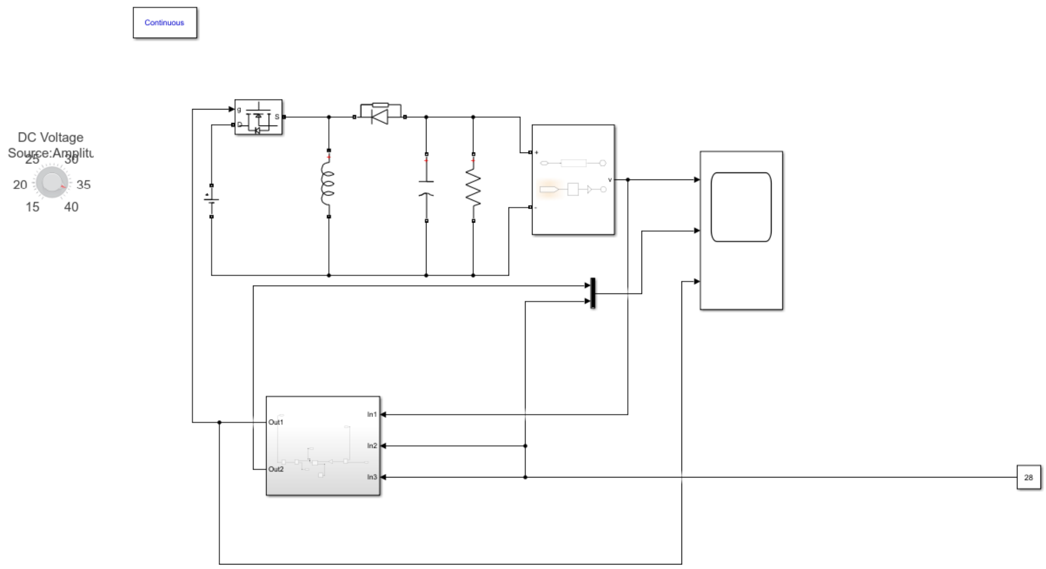


Figure 48 Simulink Model of Buck Boost Converter

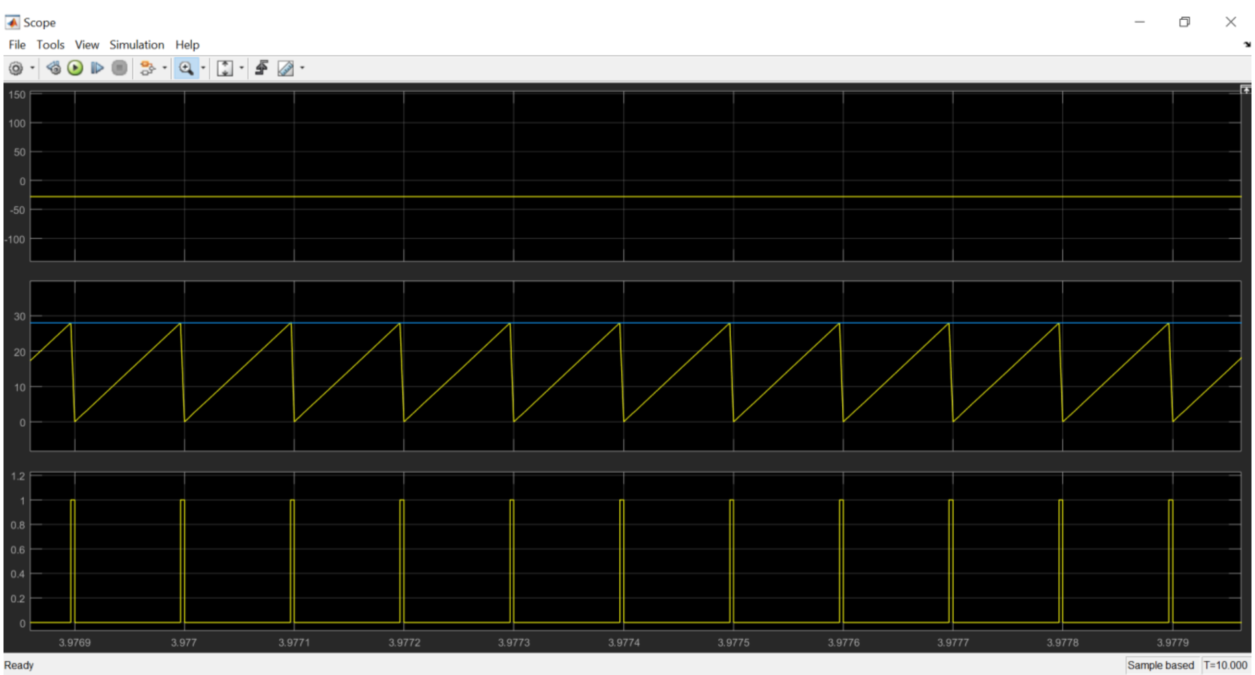


Figure 49 Output result of buck boost converter

28V is the desired output which is needed as shown in the above graph.

CHAPTER 7

RESULTS AND CONCLUSION

The following fig53 and fig54 shows the execution time of simple incremental conductance algorithm and modified incremental conductance algorithm. Fig 53 shows that the execution time of simple incremental conductance algorithm is 480us but the execution time of modified incremental conductance algorithm in fig 54 is 393us. This shows the benefit of eliminating long tedious calculations in incremental conductance algorithm.

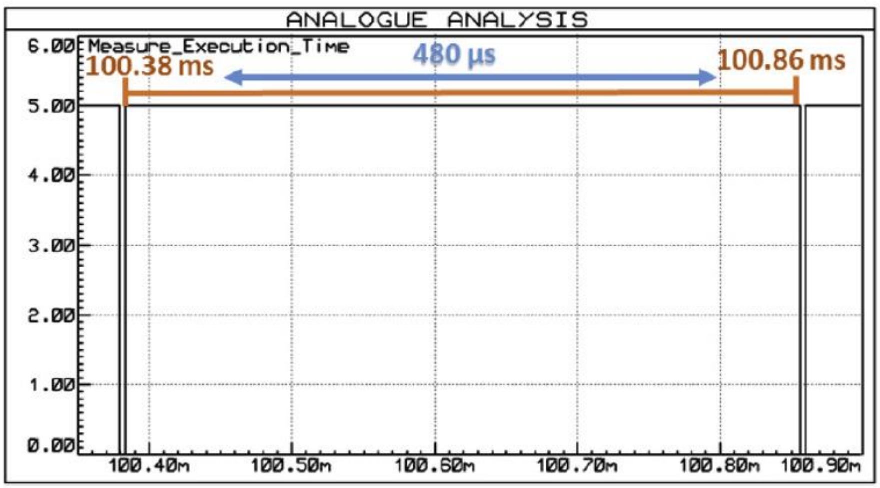


Fig 50 Execution time of INC algorithm

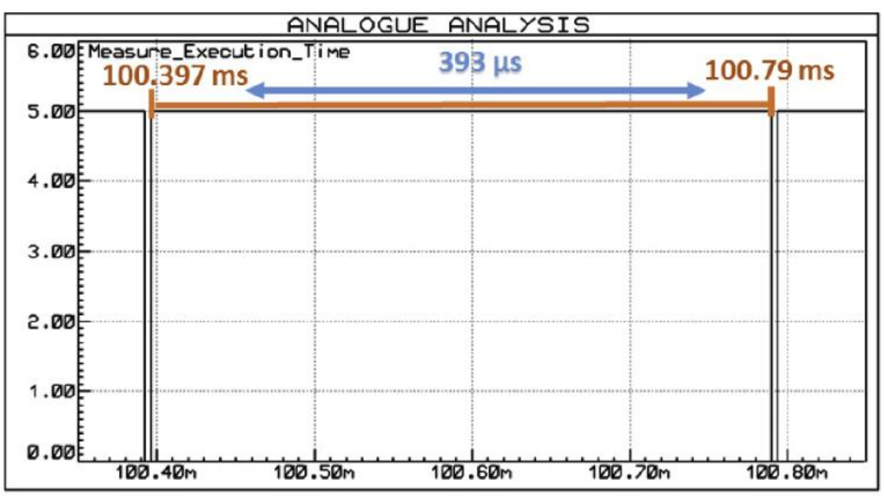


Fig 51 Execution time of modified INC algorithm

Fig55 and 56 shows that when the irradiance is changed from 1000W/m^2 to 500W/m^2 at t=1.5sec the response time of simple INC algorithm is 0.37sec and the response time of modified INC is just 0.1 sec. Moreover we can see in fig 56 that the steady state oscillations decreases by using modified INC algorithm.

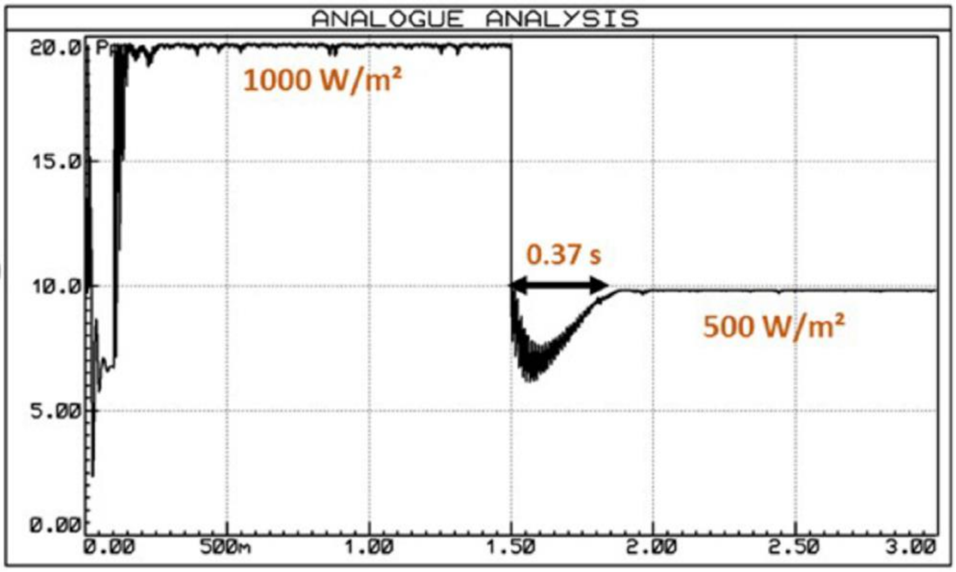


Fig 52 Response time of conventional INC algorithm

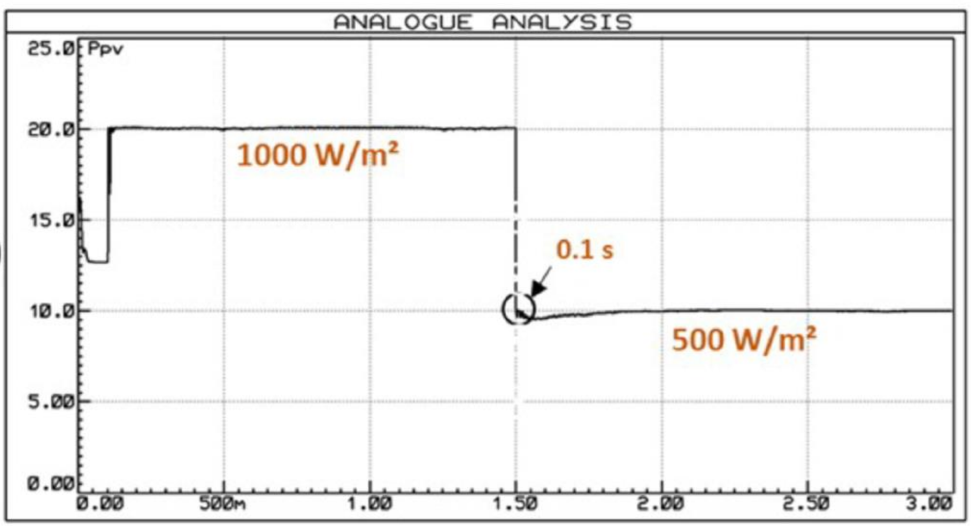
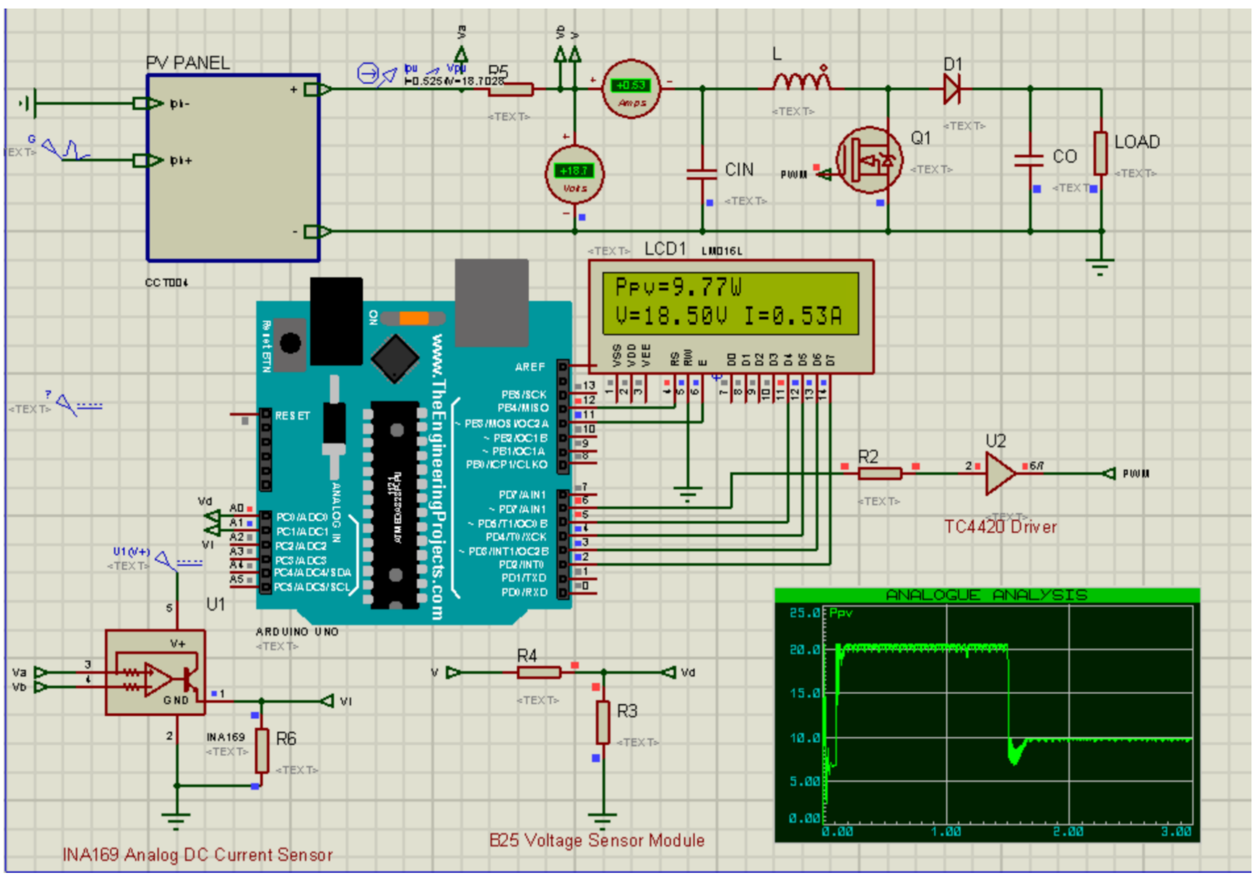


Fig 53 Response time of modified INC algorithm

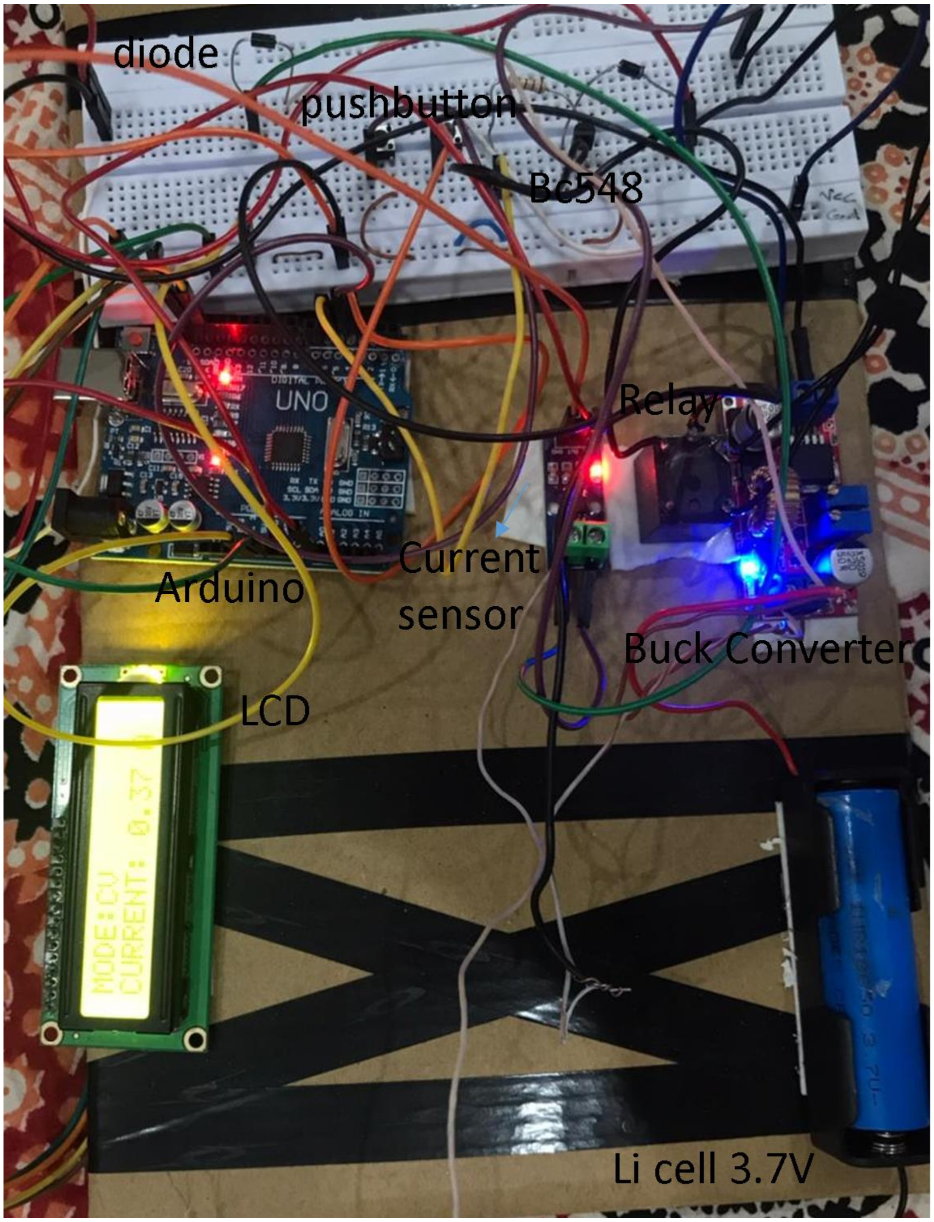
Publication year, Paper	PV Power at STC	MPPT algorithm	Embedded Controller	Power ripples	Efficiency	Response time	Cost of controller	Conditions of test
(Chavoshian et al., 2014)	80 W	Modified INC	FPGA (Xilinx XC3S400)	2.7 W	98.8%	2.5 ms	38.5 $	500 and 900 W/m^2, 38 °C
(Rahim et al., 2014)	210 W	Adaptive P&O-fuzzy MPPT	DSP TMS320F28335	1 W	95.2%	20 ms	21.17 $	200 and 1000 W/m^2
(Mishra and Sekhar, 2014)	40 W	TS fuzzy-based INC	dsPIC33fJ128MC802	1 W	97.5%	2 s	4.46 $	500 and 1000 W/m^2
(Soon and Mekhilef, 2015)	87 W	Modified INC	Microcontroller PIC18f410	1.3 W	99%	0.275 s	4.26 $	400 and 1000 W/m^2, 25 °C
(Boukenoui et al., 2017)	10 W	FLC MPPT	dSPACE-1103	0.9 W	97.295%	0.264 s	38 $	(858 W/m^2 26 °C) and (493 W/m^2 19 °C)
(Boukenoui et al., 2017)	10 W	Improved INC	dSPACE-1103	1 W	91.93%	0.254 s	38 $	858 W/m^2 26 °C) and (493 W/m^2 19 °C)
Proposed	20 W	Modified INC	Atmega 328	0.5 W	98.5%	0.1 s	2 $	500 and 1000 W/m^2, 25 °C

The above table shows that our proposed MPPT algorithm is the most efficient and cheap.

MPPT CHARGE CONTROLLER SIMULATION IN PROTEUS



SCREENSHOTS OF HARDWARE OF LI BATTERY CHARGING

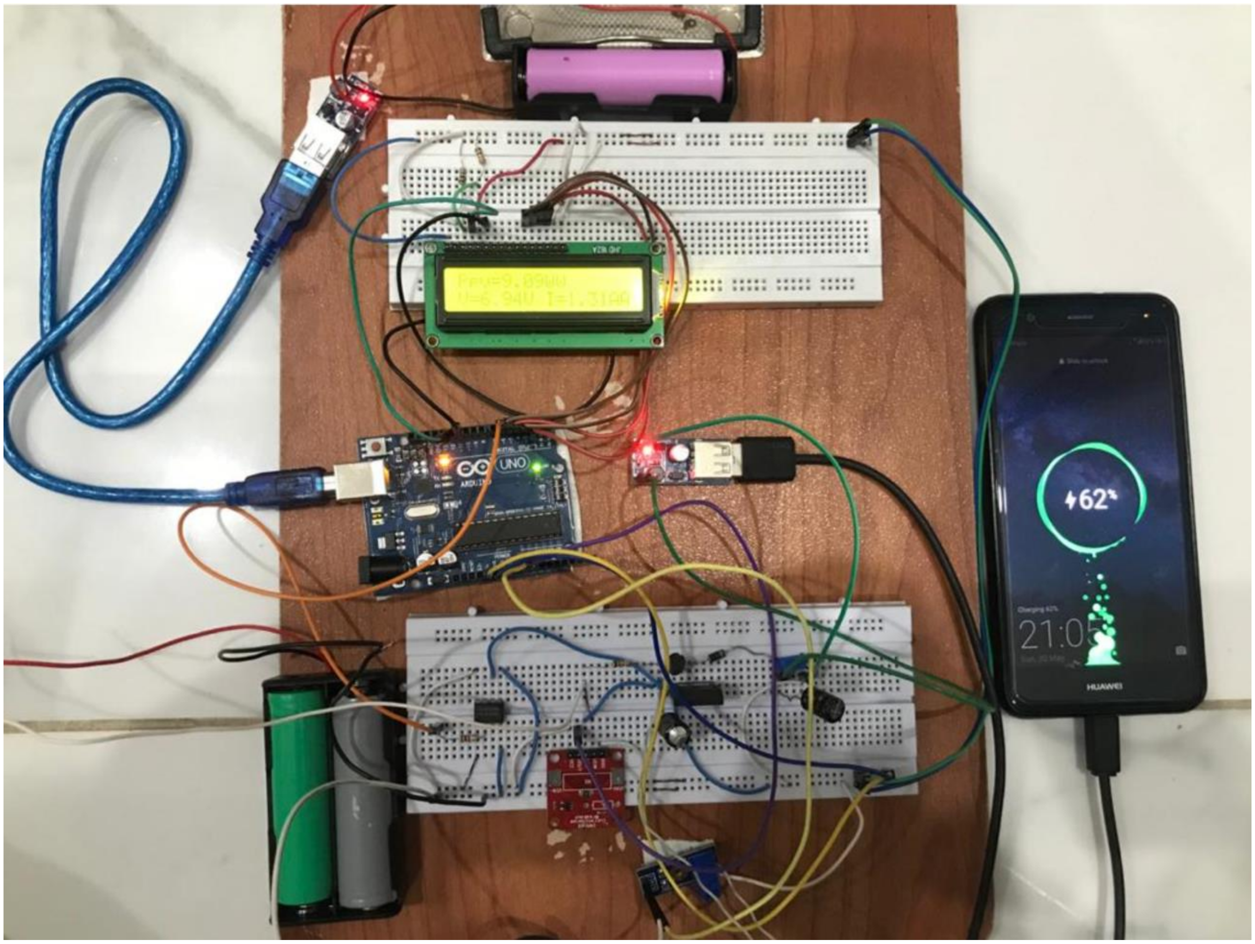


The lithium ion battery charges in 2 steps. Firstly it charges in constant current mode. The battery voltage increases but the current remains constant.

In the second step the battery charges in constant voltage mode. In this mode the current decreases and the voltage remains constant.

After the constant current and constant voltage mode the battery is finally charged.

POWER DISTRIBUTION MODULE HARDWARE



CONCLUSION

To conclude I want to say that I have implemented many power electronics concepts. I have understood buck converter, boost converter, buck boost converter. I have implemented these concepts in LT-Spice software. I have also researched on maximum power point tracking (MPPT), the various algorithms used in MPPT. After spending ample time in research and testing various algorithms, I came to a conclusion that Modified INC is the most efficient MPPT algorithm. I also studied and implemented a charge controller. I used lithium ion batteries as a secondary source to give power to satellites in eclipse period. My main goal was to increase battery life so for that purpose I again put a lot of effort in researching various battery charging discharging algorithms and after testing various battery charging discharging algorithms, I came to a conclusion that constant current constant voltage algorithm is the most efficient algorithm.

CHAPTER 8

FUTURE PROSPECTS AND REFERENCES

Battery management system for low earth orbit satellites is a long-term project. My contributions are just a starting point.

I have used lithium ion batteries to give power in case of eclipse to my satellites. A better and advanced approach is to use super capacitors. Super capacitors are more efficient.

A mock-up of LEO Satellite may be developed at SEECS for design and development of various satellite subsystem as it is an emerging area.

My work may be extended in terms of power generation and battery backup to Increase its capacity.

Use of AI in battery management system may be explored to enhance the battery life.

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