Power Distribution System for a CubeSat

Project report
submitted to the APJ Abdul Kalam Technological University
in partial fulfillment of the requirements
for the degree of

Bachelor of Technology in Electrical and Electronics Engineering

by

Ansaf Niyaz **TRV19EE016**	**Govind Murali** **TRV19EE025**
Jijesh J. Kumar **TRV19EE029**	**Naveen A.B.** **TRV19EE038**

ELECTRICAL AND ELECTRONICS ENGINEERING

GOVERNMENT ENGINEERING COLLEGE, BARTON HILL

JANUARY, 2023

DECLARATION

Project Title	Power Distribution System for a CubeSat
Authors	*Ansaf Niyaz*, *Govind Murali* , *Jijesh J. Kumar* and *Naveen A.B.*
Student IDs	TRV19EE016, TRV19EE025, TRV19EE029, and TRV19EE038

We, the undersigned, hereby declare that the mini project report titled *Power Distribution System for a CubeSat* , submitted for partial fulfillment of the requirements for the award of degree of Bachelor of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by us under the supervision of Dr. Dinesh Gopinath, Department of Electrical and Electronics Engineering, Government Engineering College, Barton Hill. This submission represents our ideas in our own words and ideas and words of others have been included, we have adequately and accurately cited and referenced the original sources. We also declare that we have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or sources in submission. We understand that any violation of the above will be a case for disciplinary action by the institute and/or the University can also evoke penal action from the sources which have thus not been properly cited or from whom proper permisssion has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other university

Place: TVM
Date: March 6, 2023

Ansaf Niyaz TRV19EE016
Govind Murali TRV19EE025
Jijesh J. Kumar TRV19EE029
Naveen A.B. TRV19EE038

Department of Electrical and Electronics Engineering
Government Engineering College,
Barton Hill

DEPT. OF ELECTRICAL & ELECTRONICS ENGINEERING
GEC BARTON HILL TRIVANDRUM
2019-23

CERTIFICATE

This is to certify that the report titled **Power Distribution System for a CubeSat** submitted by **Ansaf Niyaz, Govind Murali, Jijesh J. Kumar, Naveen A.B.** of the **Department of Electrical and Electronics Engineering** to the APJ Abdul Kalam University in partial fulfillment of the requirements for the award of the Degree of *Bachelor of Technology in Electrical and Electronics Engineering* is a bonafide record of the project work carried out by them under my guidance and supervision. This report in any form has been submitted to any other university or institute for any purpose.

Dr. Dinesh Gopinath
(Project Guide)
Electrical and Electronics Engineering
GEC Barton Hill
Thiruvananthapuram

Anjana K.R.
(Project Coordinator)
Electrical and Electronics Engineering
GEC Barton Hill
Thiruvananthapuram

Francis M. Fernandez
(Head of Department)
Electrical and Electronics Engineering
GEC
Barton Hill, Thiruvananthapuram

ACKNOWLEDGEMENTS

We would love to express our sincere gratitude to **Dr. Bijulal D**, Principal, Government Engineering College, Barton Hill for giving us the opportunity to do the project work.

We owe a great deal of gratitude towards **Dr. Francis M. Fernandez**, Head of the Department of Electrical and Electronics Engineering, Government Engineering College, Barton Hill, for his whole hearted support for this project.

We express our sincere thanks and deep sense of gratitude to our project guide **Dr. Dinesh Gopinath**, Department of Electrical and Electronics Engineering, for his encouragement and support throughout our preparations.

We would like to extend our sincere gratitude to **Prof. Anjana K.R.**, Electrical and Electronics Engineering, Government Engineering College, Barton Hill, Trivandrum for her support and co-operation.

We also thank our colleagues who have helped us in partial completion of the project.

Ansaf Niyaz, **Govind Murali** , **Jijesh J. Kumar** and **Naveen A.B.**

Government Engineering College, Barton Hill

Date: March 6, 2023

ABSTRACT

CubeSats are miniature versions of satellites that offer hands-on experience to engineering students in designing, developing, testing and operating a real spacecraft system. A 1U CubeSat is a cube shaped satellite with dimensions of 10 cm x 10 cm x 10 cm and maximum mass of 1.33 kilograms. CubeSats are traditionally built from COTS-components (Commercial Off-the-Shelf) with low resources. Typically, CubeSat have limited mission time and short development and testing time.

One of the most critical aspects of the CubeSat is the Electrical Power System (EPS) since the electrical power is necessary for a CubeSat to operate. The EPS of the CubeSat consists mainly of solar cells, batteries, voltage converters and protection circuits. The EPS is responsible of providing stable power to the CubeSat subsystems.

The purpose of this project is to design and implement an EPS for a CubeSat. The EPS must be able to power all subsystem components including telemetry, on-board computer, attitude determination and control system , thermal system as well as the payload while also protecting the subsystems from the over-current and over-voltage issues associated with the device failure. The system will be designed to provide power for the satellite throughout the entire orbit, even during periods of eclipse when the satellite is not able to generate power. The EPS should also provide data about voltage and current measurements, battery status, etc. to OBC (On-Board Computer).

ABBREVIATIONS

DC	Direct current
IC	Integrated Circuit
EPS	Electrical Power System
MCU	Micro-controller Unit
OBC	Onboard Computer
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
RBF	Remove Before Flight
TCS	Thermal Control System
TTC	Telemetry, Tracking and Command
ADCS	Attitude Determination And Control System
MPPT	Maximum Power Point Tracking
OCPC	Over Current Protection Circuits

Contents

List of Figures **ix**

List of Tables **x**

1 Introduction **1**

1.1 Background 1

1.2 Objective 3

1.3 Literature Review 3

2 The Electrical Power System **4**

2.1 Components of EPS 4

2.2 Tasks of EPS 5

3 Methodology **7**

3.1 Identifying Power Requirements 7

3.2 Literature Review 7

3.3 Architecture Design and Topology selection 7

3.4 Forming Specifications 8

3.5 Design and simulation 8

3.6 Procurement of components 8

3.7 Fabrication and Testing 8

4 Power Budget **9**

5 System Architecture **12**

6 Component Selection and Design **14**
6.1 Solar Panels 14
6.2 MPPT Circuit 15
6.3 Battery 17
6.3.1 Battery Selection 17
6.4 Battery Charger 18
6.5 Switching Regulators 21
6.6 Protection Circuits 22
6.6.1 PCB Layout 24
6.7 Micro-controller 26

7 Component List **27**

8 Conclusion **28**
8.1 Conclusion 28
8.2 Future Scope 28

References **29**

List of Figures

5.1 System Architecture of the CubeSat EPS 12

6.1 MPPT circuit with SPV1040 16
6.2 K_{ICHG} vs. I_{CHG} characteristics 19
6.3 Schematic of Battery Charger circuit with BQ25302 20
6.4 LTC3426 as boost IC and TPS62203 as buck IC 22
6.5 Schematic of Buck and Boost circuit with Protection and Voltage and Current Measurement ICs 23
6.6 Buck and Boost circuit PCB - All Copper Layers only 25
6.7 Buck and Boost circuit PCB - 3D Model 25

List of Tables

4.1 Orbital Parameters 10
4.2 Power Budget 10

7.1 Components Required 27

Chapter 1

Introduction

1.1 Background

Artificial satellites are foundational components of modern society. Satellites have played a huge role in communication, navigation, scientific research, military surveillance and the study of the solar system and beyond.

Artificial satellites are launched into space using rockets and are placed in orbit around the Earth or other celestial bodies using thrusters. Once in orbit, they remain in space and continuously circle around the Earth, following a specific path called an orbit.

There are two main types of orbits for artificial satellites: geostationary orbit and low Earth orbit. Geostationary orbit is a circular orbit located at an altitude of approximately 36,000 kilometres above the Earth's equator. Satellites in this orbit appear to be stationary relative to a fixed point on Earth, making them ideal for communication and navigation purposes. Low Earth orbit, on the other hand, is an orbit located at an altitude of up to approximately 2,000 kilometres above the Earth's surface. Satellites in this orbit circle the Earth more frequently and are used for scientific research, remote sensing, and military surveillance.

Artificial satellites are powered by solar panels that convert sunlight into electricity, which is used to operate the satellite's systems and instruments. They are also equipped with communication antennas that enable them to transmit and receive signals from Earth or other satellites.

The first artificial satellite, Sputnik, was launched in 1957. The launch of the first meteorological satellite, TIROS-1, in 1960 was followed by the U.S. The first Earth-observing satellite for land-based applications was Landsat-1, which was launched in 1972. Since then many more Earth-observing satellites have been put into orbit. Overall, artificial satellites have revolutionized our ability to communicate, navigate, observe, and study our planet and the universe beyond. They have become an essential part of modern life, and their applications are only expected to increase in the future.

The whole process of designing, building, and launching a satellite-flown remote sensing system is a very lengthy and costly process. The main driving force behind the enormously costly development of space technology has been the military, where cost is not usually a problem. With the relaxation on restrictions for ownership and operation of Earth-observing satellites it is now possible for anyone to build and launch satellites.

For more than a decade, CubeSats, or small satellites, have paved the way to low-Earth orbit for commercial companies, educational institutions, and non-profit organizations. These small satellites offer opportunities to conduct scientific investigations and technology demonstrations in space in such a way that is cost-effective, timely and relatively easy to accomplish. Due to their small size, CubeSats can be launched on smaller rockets or piggybacked on larger missions, allowing for more frequent and flexible deployment opportunities. The small size of CubeSats allows for faster development and testing of new technologies, which can be later applied to larger satellites or space missions.

A CubeSat is a class of miniaturized satellite based around a form factor consisting of 10 cm cubes. CubeSats have a mass of no more than 2 kg per unit, and often use commercial off-the-shelf (COTS) components for their electronics and structure. CubeSats are put into orbit by deployers on the International Space Station, or launched as secondary payloads on a launch vehicle. As of August 2021, more than 1,600 CubeSats have been launched.

CubeSat missions benefit Earth in varying ways. From Earth imaging satellites that help meteorologists to predict storm strengths and direction, to satellites that focus on technology demonstrations to help define what materials and processes yield the most useful resources and function best in a microgravity environment, the variety of science enabled by CubeSats results in diverse benefits and opportunities for discovery.

1.2 Objective

The aim of this project is to determine requirements for a typical CubeSat Electrical Power System (EPS) and develop a working prototype of the EPS for a CubeSat.

1.3 Literature Review

The EPS is a critical component of a CubeSat as it powers all the subsystems in the satellite. There are different EPS architectures of based on DC bus regulation and interface of PV panels [1].

This project focuses on the design of an EPS with a regulated DC bus and MPPT tracking.

Based on the difference between centralized and distributed architecture was discussed in [2] and we have selected centralized architecture.

As discussed in [3], solar panels operate at their most efficient points with a power point tracking algorithm, allowing the extraction of maximum power from the solar panels. Hence, peak power transfer is preferred to direct power transfer.

Different battery technologies used in CubeSats were discussed in [4] and Li-ion cells were selected as the energy storage device due to their high energy density and higher number of charge discharge cycles compared to LiPo and NiMH batteries.

From [5], the optimum ambient temperature for charging a Lithium ion battery is +5°C to +45°C and thus, charging is limited to this range of temperature.

Chapter 2

The Electrical Power System

The Electrical Power System (EPS) is an electronic circuit board that is designed to supply, manage and store energy in an efficient way. The EPS must be able to harvest energy from the solar panels and store it in the battery, as well as delivering power to the satellite, using switch controlled converters to supply a regulated voltage. Redundant circuitry must be present to ensure continuous and reliable operation of the satellite in case of the failure of EPS components.
The output of the solar panels is first run through the power path control. While in sunlight operation, the power path will select the voltage from the panels based on its higher voltage. The output of the Power Path control is sent to DC-DC converters to provide 5V and 3.3V regulated DC supply for the CubeSat modules. During the eclipse, the power path will select the battery to power the circuit components. The software is implemented in order to manage the overall energy of the satellite, regulate the converters to extract maximum power from solar panels, perform power diagnostics, engage redundant circuitry and to communicate with the On Board Computer. The software also employs four operating modes: Initialization mode, Safe mode, Normal mode and Low Power Mode.

2.1 Components of EPS

The EPS of a CubeSat can be designed with many different architectures, but some components are common to all designs, such as:

- Solar panels to harvest the energy from the Sun

- Battery charger to manage the charging profile of the battery
- Voltage regulators to feed the regulated power bus of the satellite
- Remove Before Flight (RBF) switches and deployment switches, to cut the power while the satellite is not deployed

Other components of the EPS are:

- Battery and associated charging circuit
- Solar panels on 6 faces of the satellite
- MPPT converters which help optimise power collection from the sun
- Buck and boost converters which help provide required voltage busses for components of different voltages
- An MCU which controls the tasks that the EPS performs and monitors the status of the components
- Over Current Protection Circuit which helps protects important components from high current flow
- Current and Voltage sensors to keep track of their consumption.
- Temperature sensors to measure battery temperature, based on which battery heater is used
- Battery heater circuit

2.2 Tasks of EPS

Tasks of the EPS are:

- Collect housekeeping for various components associated with it, like the various current & voltage sensors and the battery's state of charge.
- Handle housekeeping requests and other commands from the OBC (ON/OFF requests of any subsystem by OBC).

- Implement MPPT to optimize power generation.
- Control the Simple Beacon (which contains only the call sign of the satellite) before the TTC gets switched on.
- Implement a watchdog timer to keep a check on the operation of the OBC.
- Take action on the basis of OCPC triggers.
- Deployment of antenna at the time of satellite initialisation.
- Turn on the battery heater when temperature goes below critical level

Chapter 3

Methodology

3.1 Identifying Power Requirements

Before designing the EPS, the power requirements of the various subsystems of the CubeSat has to be identified. A power budget has to be prepared accounting all the energy, voltage and current requirements of the subsystems. The orbital parameters at which the CubeSat might be operating should also be considered. The orbital altitude, period and eclipse time and the daylight time has to be identified and documented. After this, the peak power budget has to be calculated and total energy and power demands are to be found out.

3.2 Literature Review

In order to select the suitable architecture and topologies, literature study has to be conducted. Various articles regarding the implementation of CubeSats and EPS were studied and the findings were recorded.

3.3 Architecture Design and Topology selection

The design of EPS starts with the selection of appropriate EPS architecture based on the comparison of overall efficiency, battery size, and reliability. The EPS design is critical for CubeSat mission success, therefore selection of proper EPS architecture is one of the important steps. Different standard EPS architectures are classified on the basis of various topologies like dc-bus voltage regulation, interface of

PV panels, location of power converters, and number of conversion stages. The necessary topology has to be selected based on the demands and constraints.

3.4 Forming Specifications

After deciding upon a suitable architecture, the specifications of various components of the EPS has to be finalised. This includes deciding the number of required power converters and their input and output parameters, deciding the number, size and type of battery for energy storage and the characteristics of the solar panels and specifications of the MPPT device.

3.5 Design and simulation

Suitable ICs able to perform the various functions of different components in an EPS have to be identified. The ICs must be suitable for operation in outer space. After selecting the ICs, the design of them are to be completed and necessary schematics and PCB design has to be completed. Also, the circuits obtained have to be verified with the help of simulation results.

3.6 Procurement of components

The components which were finalised has to be procured. Surface Mount components are preferred due to the space constraints, also the selected components must be applicable in outer space applications.

3.7 Fabrication and Testing

The components have to be soldered into the PCB and the results are to be observed. Initially, each component maybe developed individually and tested before optimizing the entire circuit into a single, centralized form.

Chapter 4

Power Budget

The power budget of a CubeSat is a critical aspect of its design and operation, as it determines the capabilities and limitations of the satellite. A well-designed power budget can ensure that the CubeSat operates efficiently and achieves its mission objectives, while a poorly designed power budget can lead to power shortages and mission failure.

It is important to determine the power budget at the beginning of the EPS design to determine the characteristics of the system. When the available space for the solar cells and the orbital parameters are known, power production can be estimated. The power requirements of CubeSat as a whole depend upon the power requirements of the individual components and how the components are used together for operations. Together with the efficiency information of the EPS components, this data is used to determine critical elements of the EPS design, like required solar array and battery size.

A CubeSat will have standard set of satellite subsystems: Structural subsystem, Telemetry, Electrical Power Subsystem (EPS), Thermal Control Subsystem (TCS), Attitude Determination and Control Subsystem (ADCS), On Board Computer (OBC) and Payload. For the calculations, a LoRa module was selected as the payload. The orbital parameters are given below:

Parameter	Value
Orbital altitude	590 km
Orbital radius	6968.14 km
Flight velocity	7.563 km/s
Orbital period	96.483 min
Eclipse time	31.164 min
Daylight time	65.319 min

Table 4.1: Orbital Parameters

The CubeSat has an orbital altitude of 590 km with an orbital radius of 6968.14 km to maintain a flight velocity of 7.563 km/s. The orbital period is 96 min 29 sec with an eclipse time of 31 min 10 sec and daylight time of 65 min 19 sec. Based on the power budget, the energy required by the CubeSat is 1.997 Wh per orbit. Hence, the solar panels must designed be able to produce at least 1.997 Wh per orbit.

Power requirements of various components of each subsystems are given below. Since the power production may vary due to parameters like efficiency of panels, margin and contingency are added to the total power requirements.

Sub-system		**Voltage (V)**	**Max. Current (mA)**	**Power (mW)**	**Contingency 5%**	**Margin 20%**	**Duty Cycle (%)**	**Energy (Wh)**
ADCS	ADCS	3.3	20	66	69.3	83.16	100	0.133725438
	Magnetorquer	3.3	100	330	346.5	415.8	50	0.334313595
OBC	OBC	5	40	200	210	252	100	0.4052286
Rx-Tx	Telemetry	5	300	1500	1575	1890	11	0.334313595
	Beacon	5	20	100	105	126	100	0.2026143
	GPS	3.3	40	132	138.6	166.32	30	0.0802352628
Payload	LoRa	5	20	100	105	126	10	0.02026143
EPS	EPS	-	-	160	168	201.6	100	0.32418288
	Thermal	-	-	250	262.5	315	32	0.16209144
					Tot Power(mW)	**3575.88**	**Tot. Energy**	**1.997**

Table 4.2: Power Budget

Conventionally, EPS will work on different modes to manage the overall power production and distribution of the CubeSat. The main modes are initializing mode, which is during the initial phase of CubeSat launch and the normal mode, which is the rest of the mission. The initializing mode is divided into three: **Pre- Launch mode, Launch mode and Initializing mode**.

In pre launch mode, all subsystems are off. In launch mode, that is when the CubeSat is deployed into orbit, the EPS and OBC turns on. Then, during initializing, all subsystems are turned on for a small amount of time to check whether all subsystems are working properly.

The normal mode consists of safe mode and nominal mode.

During safe mode, only the EPS and beacon of telemetry system works, and the CubeSat is in a power saving mode. The nominal mode is the general purpose mode were payload will function.

To calculate battery and solar panel specifications, the peak power budget of the CubeSat is only considered since the power requirements won't exceed that requirements. The other modes are only documented for designing the functioning of micro-controller which controls the EPS. Of all the modes, highest power consumption during sun phase is when transmission and payload active (1.016 Wh), and highest power consumption during eclipse phase is when transmission and payload active (0.769 Wh).

From the peak power budget table, the highest energy requirement is 2.307Wh.

Chapter 5

System Architecture

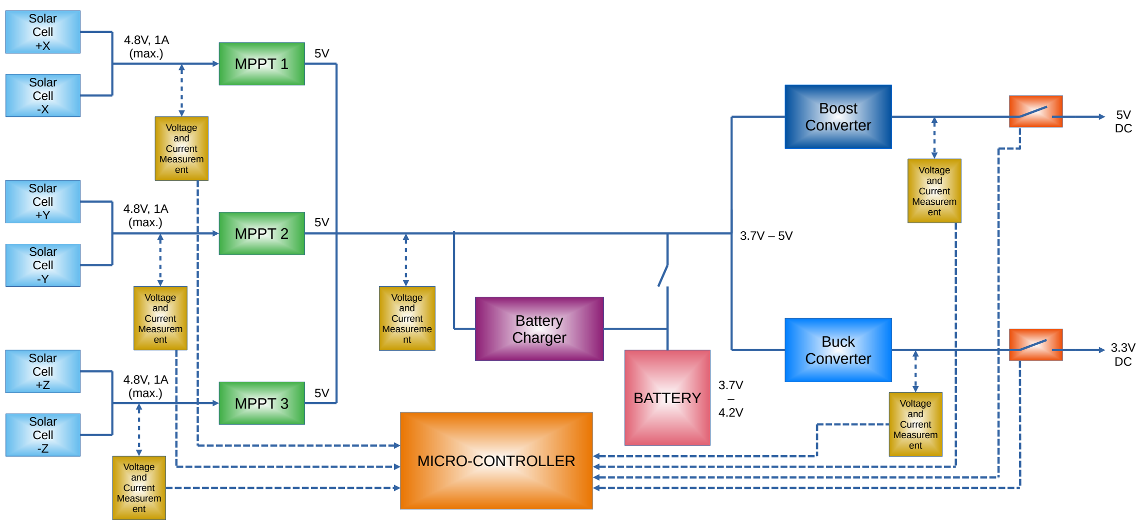

Figure 5.1: System Architecture of the CubeSat EPS

The CubeSat is equipped with six solar panels on each side. To ensure that the solar panels operate at their most efficient points, the solar panels are connected to MPPT ICs such that the solar panels on the opposite sides are connected to single MPPT IC. Since only one of the opposite sides of the cube is irradiated at any time, the MPPT of two solar panels can be achieved using a single IC. This arrangement reduces the number of MPPT ICs required by the system. The MPPT runs a constant voltage algorithm and delivers 5V at the bus.

When the CubeSat is capable of generating enough power through the solar panels, the components are directly powered by the panels through the bus. At the same time, a battery charging IC uses some of the energy to recharge the Li-ion cell. The battery charger takes the 5V from the bus and converts it to the voltage and current optimal for battery charging depending on the state of charge, temperature of the cell etc.During eclipse the battery power the energy from the panels is absent and the battery powers the CubeSat components. The voltage of the battery varies from 3.7V to 4.2V.

The buck and boost converters provide power to the 3.3V and 5V rails respectively. Their input voltage varies from 3.6V to 5V to account for direct power from the panels when sunlight is available and for battery power during eclipse.

To ensure proper functioning and to identify any faults in the system, there are various voltage and current measurement units placed at various points in the circuit. They measure the current and voltage at each point and the data is fed to a micro-controller, which is programmed to open the switches at the rails in case of any faults.

Chapter 6

Component Selection and Design

6.1 Solar Panels

TJ Solar Cell 3G30C - Advanced is selected. This cell is a GaInP/GaAs/Ge on Ge substrate triple junction solar cell. The end-of-life version of the 3G30C solar cell offers best EOL-performance values. Connected to the EPS via an external bypass diode protection.

Specifications:

- Average Open Circuit Voltage: 2.7V
- Maximum Power Point Voltage: 2.41V
- Average Short Circuit Current: 520.2 mA
- Maximum Power Point Current: 504.4mA

It has an average efficiency of 29.8% at 1353 W/m^2. This solar cell is excellent for space applications.

Since a CubeSat has six sides and one cell of selected model fits half of a side, a total of 12 cells can be placed.

Power from a solar panel, P :

$$P = P_i \times Area \times \eta \times cos\alpha$$

Where,

P_i = incident power from sun (1367 W/m^2 at Low Earth Orbit)

η = conversion efficiency of cell (take 20% for contingency)
α = angle between normal of cell and incident light (avg: 35^o)

Area of solar cell at one face : 0.0032 * 2 = 0.0064 m^2

Therefore, $P = 1367W/m^2 \times 0.0064 \times 20 \times cos35^o$ = 1.43W

Assume two faces of CubeSat is lit by sunlight every time except eclipse and total sun time(T_s) is 1 hour (from orbital parameters).

Therefore, total energy produced is, $P \times T_s$ = $(1.43 \times 2) \times 1$ = 2.86 Wh

Of all modes specified in power budget, nominal mode at sun phase with transmission and payload ON consumes the most energy (1.016 Wh), and most energy consumed at eclipse phase is 0.769 Wh. This add upto 1.785 Wh, which is the worst case energy demand. This can be compensated by the designed solar panel configuration.
Solar panels are connected in such a way that each side has two cells connected in series.The maximum voltage developed per side is 4.4V and the maximum current that can be generated per side at peak power point is 0.5A. Panels on opposite sides are connected in parallel.

6.2 Maximum Power Point Tracking Circuit

Maximum Power Point Tracking (MPPT) is a technique used in photovoltaic (PV) systems to optimize the power output of the PV panel. The goal of MPPT is to ensure that the PV panel operates at its maximum power point (MPP), which is the point on the current-voltage (I-V) curve of the panel where the panel can produce the maximum amount of power.

As each solar panel has different temperatures and incident radiance angles, the Maximum Power Point (MPP) is also different. So each solar panel has a MPPT converter to assure that the maximum power available at the solar panels is transferred independently from their working power points. Since the peak power point cannot be accurately predicted, many different algorithms exist for finding the best approximation. MPPT controllers use different algorithms such as **Perturb and Observe (PO), Incremental Conductance, and Fuzzy Logic** to track the MPP. These algorithms operate by incrementally changing the load impedance of the panel and measuring the corresponding change in voltage and current until the MPP is reached.

The SPV1040 was chosen as the MPPT IC. It is a boost converter with duty ratio controlled by Perturb and Observe MPPT algorithm. The perturb and observe algorithm is based on monitoring either the voltage or the current supplied by the DC power source unit so that the PWM signal duty cycle is increased or decreased step-by-step according to the input power trend. This chip has inbuilt over-current protection and a cutoff mechanism if the solar panel connection is reverse-inserted to prevent damage to the IC and the external circuit.

Specifications of SPV1040:

- Input Voltage: 0.3 - 5.5V
- Output Voltage: 5V
- Switching Frequency: 100kHz
- Efficiency: 95%

The MPPT circuit schematic is shown below:

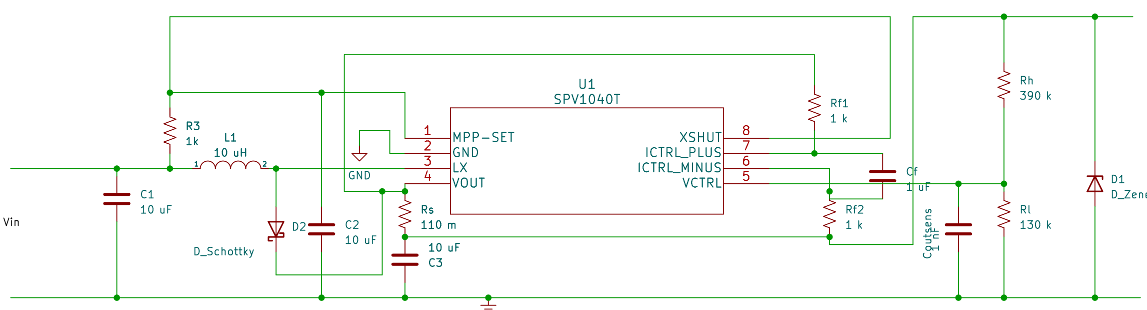

Figure 6.1: MPPT circuit with SPV1040

6.3 Battery

The most popular types of batteries use the following materials: Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH), Nickel Hydrogen (NiH2), Lithium Ion (Li-Ion) and Lithium Polymer (Li-Po). The Li-Po and Li-Ion became the standard use in space technology due to their high energy density (Upto 200 Wh / kg on Li-Po and upto 250 Wh / kg on Li-Ion) and also due to the number of charging cycles being as high as the NiMH, whilst presenting higher operating temperatures.

6.3.1 Battery Selection

According to solar power calculations, the solar panel can produce 2.86 Wh of energy in a single orbit, of which 1.016 Wh will be used up in sun phase in worst case (E_{max}). So there will be atleast 1.844 Wh of energy left to charge the battery.
In power budget, the most amount of energy required during eclipse phase is 0.769 Wh.

Assign 50% contingency, the battery needs energy of 1.1535 Wh for charging, to use in worst case eclipse mode. This energy corresponds to 30% of total battery capacity (End Of Life capacity of battery).

So, we need a battery with Beginning Of Life capacity of 3.845 Wh.

$$\text{Required Ah of battery} = \frac{Estimated\ \ Wh}{Battery\ \ Voltage}$$

$$\text{So, required Ah} = \frac{3.845Wh}{3.6V} = 1.068 \text{ Ah}$$

Considered options are Samsung 18650 and Panasonic 18650 Li-ion cells. Samsung 18650 has 2500 mAh capacity, 3.6V and a capacity loss of 60% after 250 charging cycles (N_{in}=250). Panasonic 18650 has 3350 mAh capacity, 3.6V and a capacity loss of 60% after 300 charging cycles (N_{in}=300).

for a CubeSat mission of 3 months, required battery cycles will be around 1460 cycles (since each day, CubeSat goes through 16 sun phase).

Total no. of cycles a cell can provide = N_T

$$N_T = \frac{N_{in} \times C_B}{C_{exp}}$$

Where,

N_{in} = initial number of cycles a battery can provide)

C_B = Capacity of the battery

C_{exp} = Capacity expected to use

$$C_{exp} = \frac{E_{max}}{V_B}$$

Where,

E_{max} = Maximum energy consumed in a phase with 50% contingency

V_B = Battery voltage

Therefore, $C_{exp} = \frac{1.524}{3.6V}$ = 450 mAh

Total no. of cycles Samsung 18650 can provide =$\frac{250 \times 2500}{450}$ = 1388 cycles

Total no. of cycles Panasonic 18650 can provide =$\frac{300 \times 3350}{450}$ = 2200 cycles

Therefore, Panasonic 18650 is selected, as it can compensate the charging cycle requirements. Specifications of Panasonic NCR 18650 GA Li-Ion cell:

- Voltage: 3.7V - 4.2V
- Capacity: 3500mAh
- Can withstand 2200 charge-discharge cycles
- 1800 cycles till capacity reduces to 60%

6.4 Battery Charger

The battery also needs a charger to regulate its current and voltage while charging. BQ25302, a synchronous Buck Battery Charger IC was selected and connected in external power path mode as given in the data-sheet.

To preserve battery life, the charging current has to be limited. The charging current provided to the battery by BQ25302 IC can be limited by adjusting the resistor value at the ICHG pin according to the equation below:

$$I_{CHG}(A) = K_{ICHG}(A.\Omega)/R_{ICHG}(\Omega) \tag{6.1}$$

Where,

- I_{CHG} is the charging current
- K_{ICHG} is the charge current ratio. The K_{ICHG} vs. I_{CHG} typical characteristic curve is shown in fig. 6.2
- R_{ICHG} is the resistor value at the ICHG pin

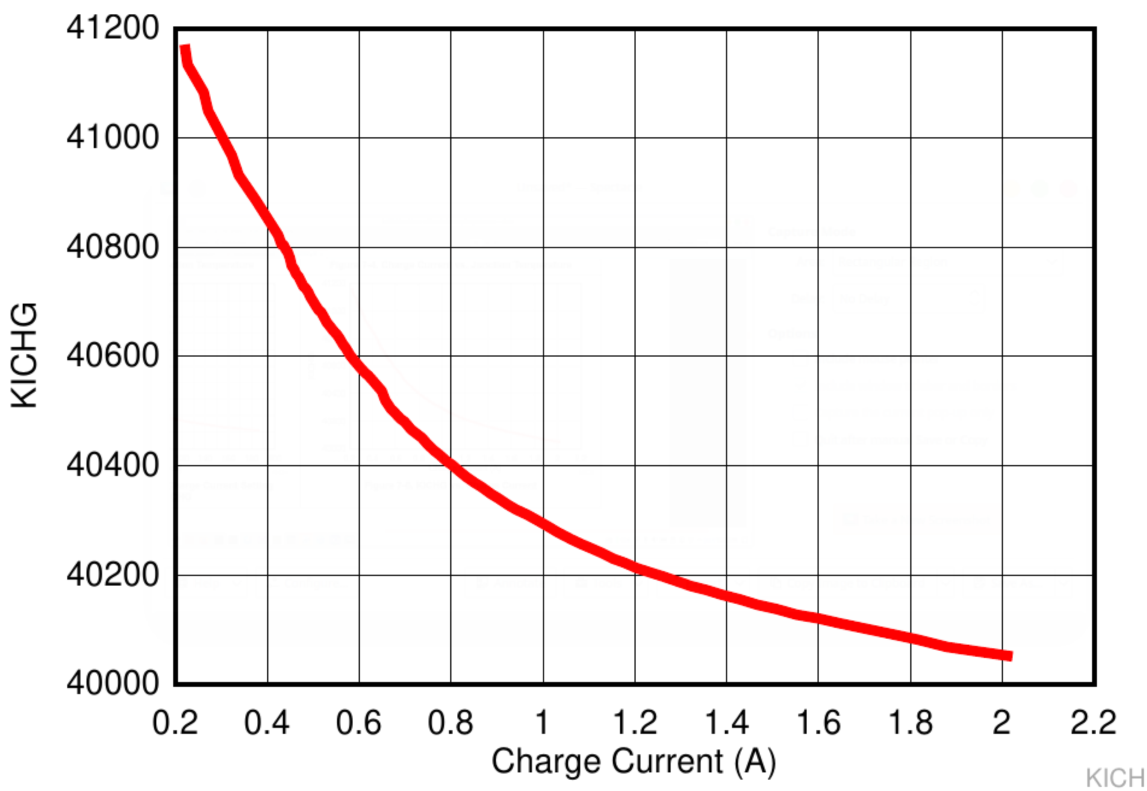

Figure 6.2: K_{ICHG} vs. I_{CHG} characteristics (Source: BQ25302 data-sheet)

From the fig. 6.2, it is clear that the value of K_{ICHG} should be 40200 to limit the charging current near to 1.2A. Thus, from equation 6.1 the calculated value of resistance at the ICHG pin is 33.5kΩ.

Specifications and Operating Conditions of BQ25302:

- Input Voltage: Upto 5V
- Output Voltage: Upto 4.2V
- Switching Frequency: 1.2MHz
- Output Current: Limited to 1.2A by connecting a 33.5k resistor at ICHG pin
- Efficiency: 94.3% at 1A from 5V input
- Thermistor: Semitec 103AT-2 (10kΩ)
- Charging Temperature: Limited between 0 - 45 ^{o}C

The Battery Charger circuit schematic is shown below:

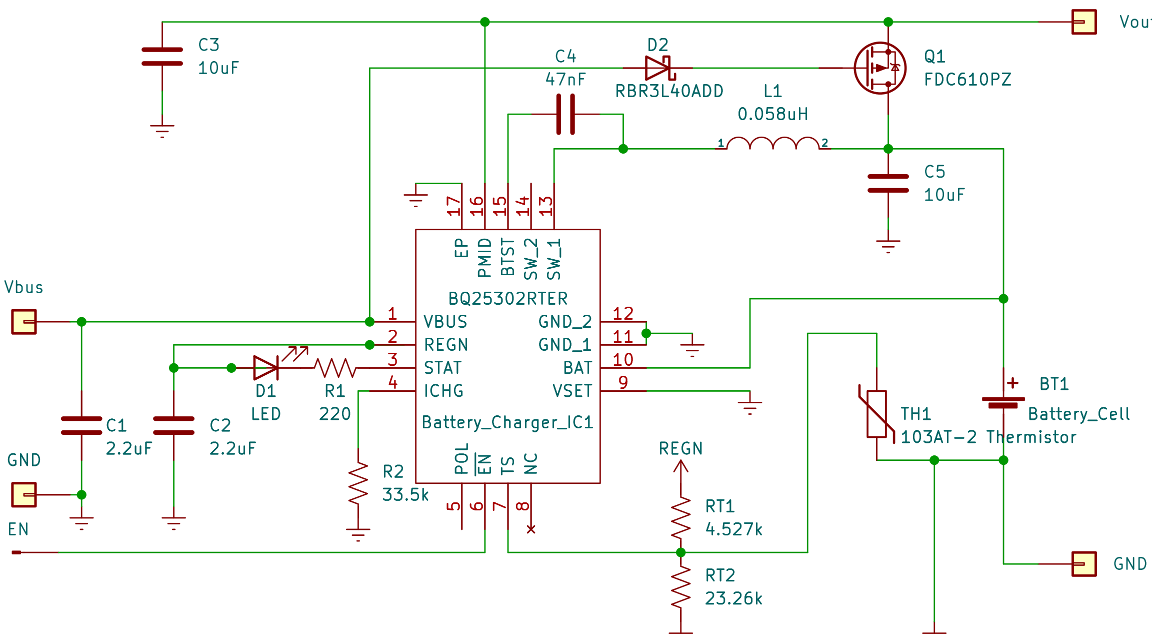

Figure 6.3: Schematic of Battery Charger circuit with BQ25302

6.5 Buck and Boost Converters

The power conditioning is associated with regulating the voltage to accommodate for the charging voltage and the voltages of the satellite's subsystems. In most subsystems, the need for a specific voltage requires a regulation of either a step-up or a step-down of the supplied voltage. It can be done by buck convertor(step-down) and boost converter(step-up).
TPS62203 was selected as the buck converter to provide step down voltage of the DC bus to supply the 3.3V loads. It is a high-efficiency synchronous step-down converter with up to 95% efficiency.

Specifications and Operating Conditions of TPS62203:

- Input Voltage: 3.6 - 5V
- Output Voltage: 3.3V
- Switching Frequency: 1MHz
- Output Current: 300mA (max.)

LTC3426 was selected as the boost converter to provide step up voltage of the DC bus to supply the 5V loads. It has an internal 2A MOSFET as the switch.

Specifications and Operating Conditions of LTC3426:

- Input Voltage: 3.6 - 5V
- Output Voltage: 5V
- Switching Frequency: 1.2MHz
- Output Current: 500mA (max.)

All convertors operate in continuous conduction mode.

The Buck and Boost Converter circuit schematic is shown below:

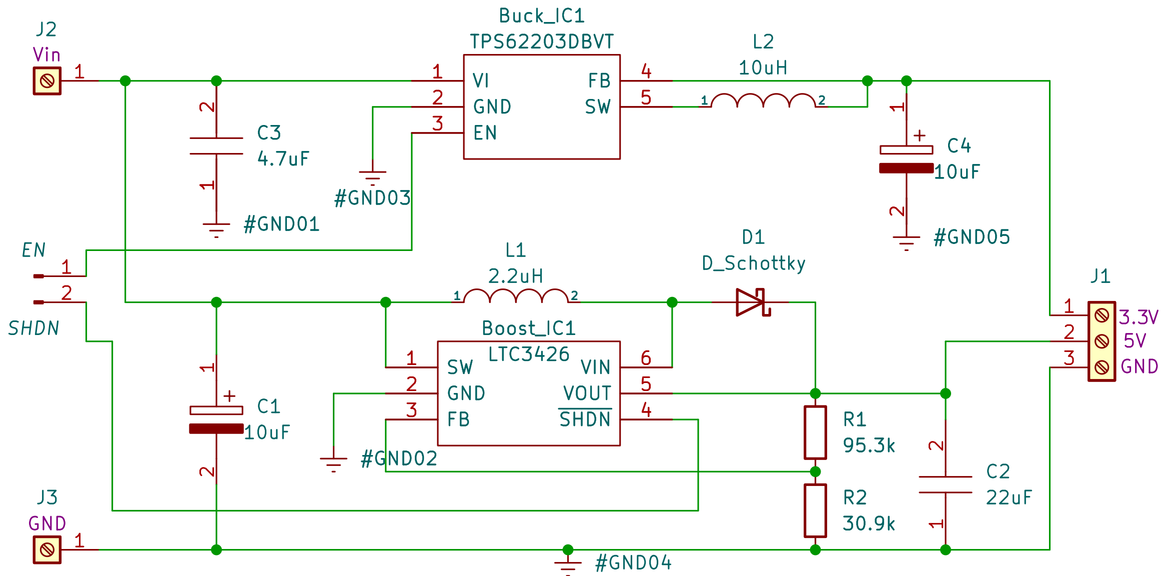

Figure 6.4: LTC3426 as boost IC and TPS62203 as buck IC

6.6 Protection and Measurement Circuits

LTC4361-2 is selected as the over voltage and over current protection IC. It control an external N-channel MOSFET as a switch to cut the path of current if there is an event of over current or voltage. Manual control of the MOSFET is also possible which may be useful to turn off power to buses by the micro-controller as per different modes of operation of the CubeSat.

Voltage and current passing through each bus and subsystems are continuously monitored by sensors and this information is fed to the micro-controller. These measurements help in estimation of load requirement of subsystems and also help in triggering of protection circuits if a subsystem needs to be turned off in case of an occurrence of a fault.

LTC2990 was chosen as the voltage and current monitor. It can measure the voltage of four external channels and it's supply voltage (V_{cc}) simultaneously. It has a 14 bit ADC for measurement. The LTC2990 has the ability to perform 14-bit current measurements with the addition of a current sense resistor. The measurements are passed on to the micro-controller through the two wire I2C interface.

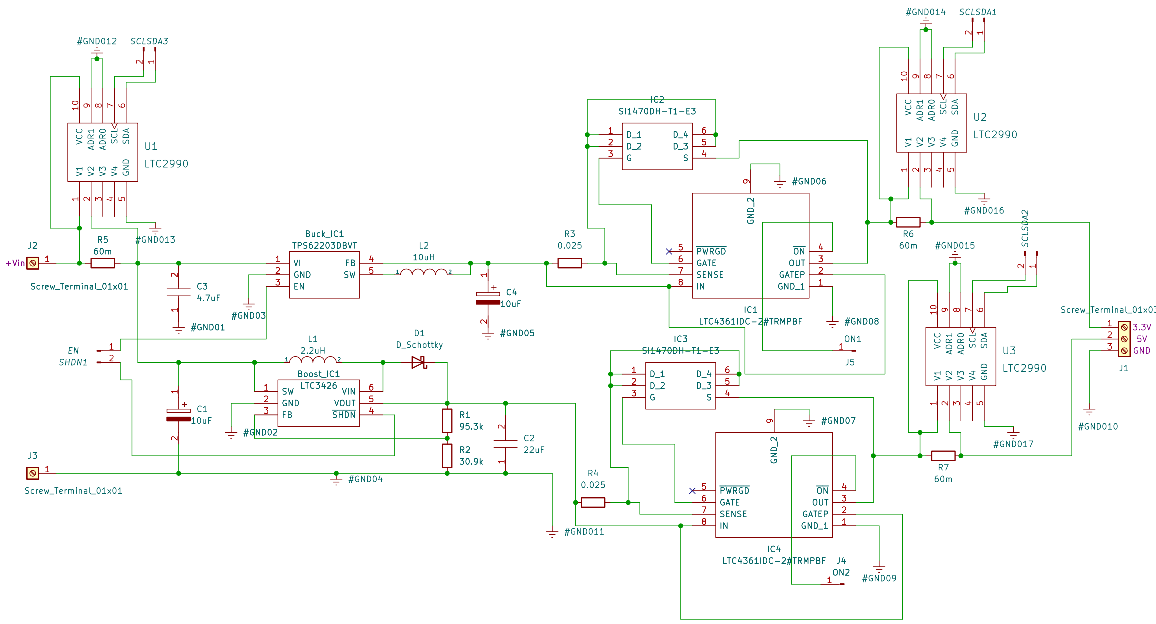

Figure 6.5: Schematic of Buck and Boost circuit with Protection and Voltage and Current Measurement ICs

The screw terminals are used to connect to the power inputs and outputs of the PCB. Pin header connectors are provided for connecting IC control pins to the micro-controller. The pin headers and their functions are given below:

- EN pin of Buck IC: Setting LOW turns off the buck IC
- SHDN pin of Boost IC: Setting LOW turns off the boost IC
- ON1 pin of IC1 (LTC4361): Setting HIGH turns off the MOSFET (IC2 - SI470DH) of the 3.3V bus
- ON2 pin of IC4 (LTC4361): Setting HIGH turns off the MOSFET (IC3 - SI470DH) of the 5V bus
- SCLSDA1 pins: I2C connection to micro-controller relaying measured parameters of 3.3V bus by U2 (LTC2990)
- SCLSDA2 pins: I2C connection to micro-controller relaying measured parameters of 5V bus by U3 (LTC2990)

- SCLSDA3 pins: I2C connection to micro-controller relaying measured parameters of input bus (V_{in}) by U1 (LTC2990)

6.6.1 PCB Layout

A double layer PCB was designed from the schematic (Ref. Fig. 8.4). The second layer was used as the GROUND plane. The schematic and PCB design was done in KiCad EDA.

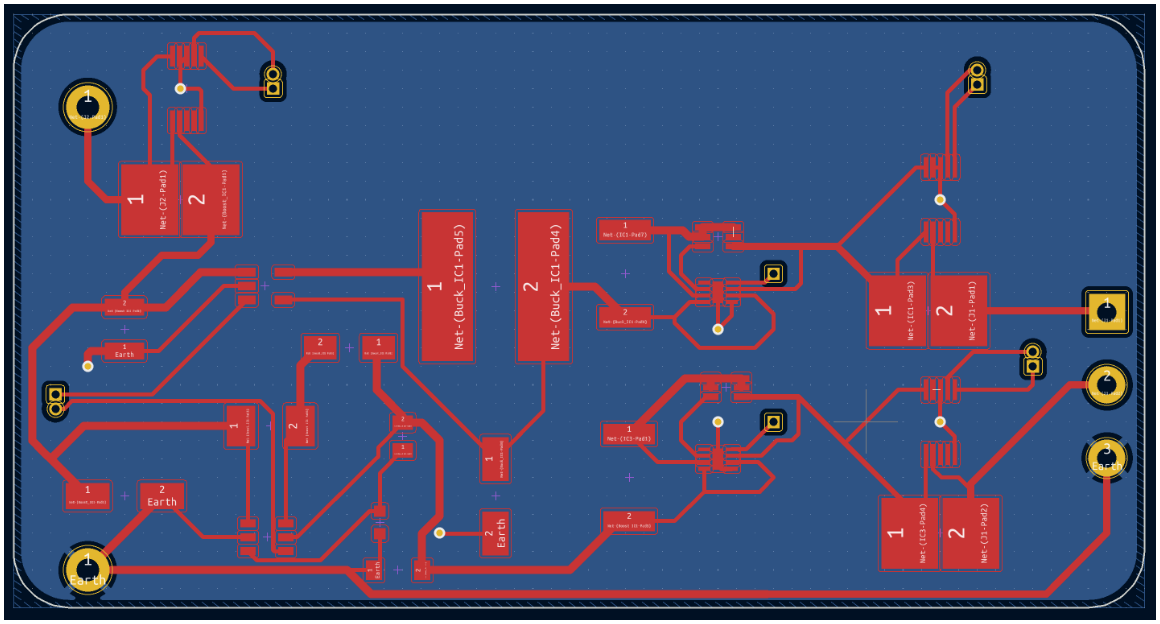

Figure 6.6: Buck and Boost circuit PCB - All Copper Layers only

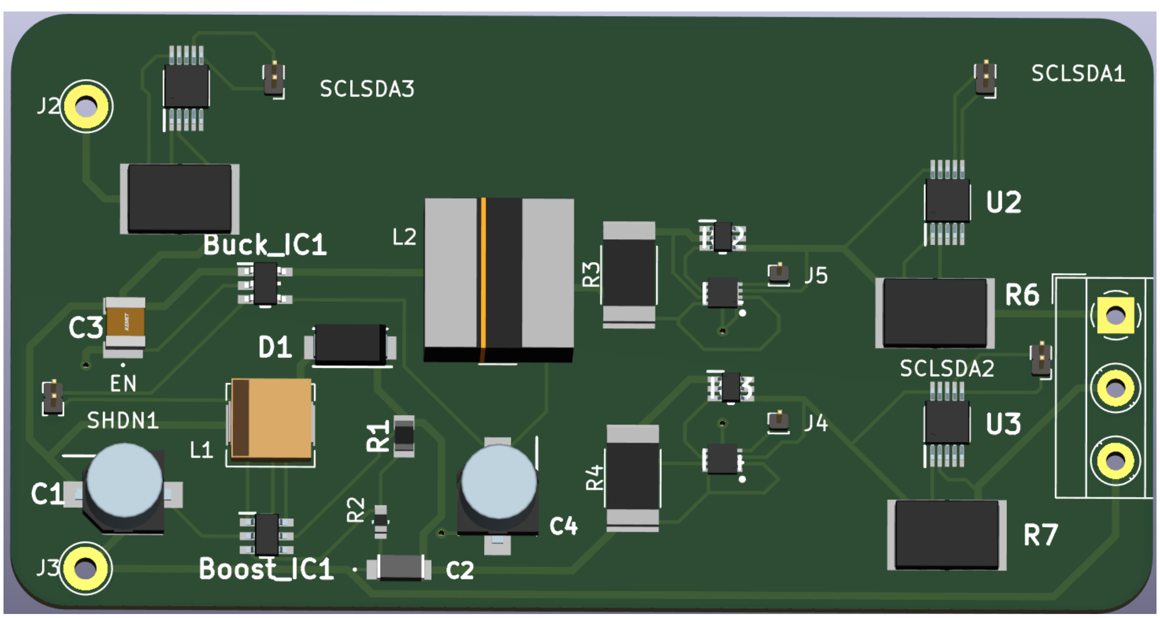

Figure 6.7: Buck and Boost circuit PCB - 3D Model

6.7 Micro-controller

The requirements of micro-controllers depend of the BUS, the other links as digital/analog outputs, the energy consumption, the voltage range and the memory.

The micro-controller has to handle the energy distribution of the entire CubeSat, and has to communicate with the OBC of CubeSat. Thus, it needs digital/analog outputs (for lines going to ADCS, Telemetry, OBC, battery , monitoring IC etc), UART for two-way communication between the micro-controller and the OBC and SPI to send data of the battery level to the micro-controller.

The micro-controller should have low energy consumption, around the mirco ampere range for the "Active mode" and around the hundreds of nano ampere for the "Off mode". It also should need sufficient memory storage to store the readings to provide it to OBC when requested. It should also independently take action during over-current, over voltage happenings, and also should control different power modes of the EPS.

Few considered options were Arduino, Raspberry Pi, TI micro-controllers, STM32 etc. Arduino has limited programming capabilities, and Raspberry Pi was too large for the need and also has high power consumption. STM32 was selected due to its wide range of capabilities, still maintaining the size and power constraints. It also has more community support which makes the programming easier.

STM32 is a ARM Cortex M4 32-bit micro-controller having a flash memory of 512 Kb. It can have upto 81 I/O ports with interrupt capabilities. It can have upto 78 fast I/Os upto 42 MHz, 3 I2C interfaces, 3 USARTs, 4 SPIs etc. We selected STM32401RE development board to test its capabilities, and one of its advantage is that, it can be programmed using Arduino IDE or even MATLAB, apart from its own programming IDE called STM32CUBE IDE.

Chapter 7

Component List

Sl. No.	Component	Description
1	TPS62203	Buck Converter IC
2	LTC3426	Boost Converter IC
3	BQ25302	Battery Charger IC
4	Panasonic NCR 18650 GA	Battery
5	SPV1040T	MPPT
6	TJ Solar Cell 3G30C	Solar Cell
7	STM 32 F401RE	Micro-controller
8	Resistors	
9	Capacitors	
10	Inductors	
11	PCB	

Table 7.1: Components Required

Chapter 8

Conclusion

8.1 Conclusion

After conducting proper literature study, we have decided upon the type of architecture to be implemented on the EPS and have formed the specifications of the components. The design of all the circuits was also completed and PCB design was started. Next, we are planning to procure all the components and design the PCB layouts. We look forward to completing the project as per the schedule.

8.2 Future Scope

The STM 32 Micro-controller could be used to monitor and display the voltage and current levels of the different buses and hence determine whether a bus is operating or not. Also, the micro-controller could be used to provide the PWM for the converter in the MPPT circuit depending upon the available irradiance by following an algorithm.

REFERENCES

[1] A. Edpuganti, V. Khadkikar, M. S. E. Moursi, H. Zeineldin, N. Al-Sayari and K. Al Hosani, ”A Comprehensive Review on CubeSat Electrical Power System Architectures,” in IEEE Transactions on Power Electronics, vol. 37, no. 3, pp. 3161-3177, March 2022, doi: 10.1109/TPEL.2021.3110002.

[2] B. Hussein, A. M. Massoud and T. Khattab, ”Centralized, Distributed, and Module-Integrated Electric Power System Schemes in CubeSats: Performance Assessment,” in IEEE Access, vol. 10, pp. 55396-55407, 2022, doi: 10.1109/ACCESS.2022.3176902.

[3] A. Edpuganti, V. Khadkikar, H. Zeineldin, M. S. E. Moursi and M. Al Hosani, ”Comparison of Peak Power Tracking Based Electric Power System Architectures for CubeSats,” in IEEE Transactions on Industry Applications, vol. 57, no. 3, pp. 2758-2768, May-June 2021, doi: 10.1109/TIA.2021.3055449.

[4] Knap, Vaclav Vestergaard, Lars Stroe, Daniel-Ioan. (2020). A Review of Battery Technology in CubeSats and Small Satellite Solutions. Energies. 13. 4097. 10.3390/en13164097.

[5] E. Ayoub and N. Karami, ”Review on the charging techniques of a Li-Ion battery,” 2015 Third International Conference on Technological Advances in Electrical, Electronics and Computer Engineering (TAEECE), 2015, pp. 50-55, doi: 10.1109/TAEECE.2015.7113599.

[6] Robert W. Erickson, ”Fundamentals of Power Electronics”, Kluwer Academic Publishers, 1997