Intelligent Power Management System for a CubeSat

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• *Abstract*-- **Recently, CubeSat has been becoming economically attractive in many applications. As they provide cheap facilities to validate new ideas by using the advanced technologies. Every satellite needs an electrical power supply to feed the satellite buss with needed levels of voltage and the payload (Camera). The power flow is controlled by an Intelligent Power Management System (IPMS) which contains Maximum power point tracking charger (MPPT), feedback sensors, switching control circuit and Boost-Buck converters to coordinate the flow between generation and storage units and the payload as in the CubeSat, solar panels take the role of power generation and secondary batteries serve as energy storage. The main criteria of PMS are decreasing the power consumption of the devices and feed each device with optimal power required, send telemetry data to the station about the status of individual devices, switching between the modes of operation according to the mission and finally the main objective is increasing the life of time of the battery.**

Index Terms-- **PMS, EPS, Power management system for CubeSat. cube satellite, CubeSat, Nano-satellite, electronic power system.**

I. INTRODUCTION

In recent years, CubeSat has grown significantly, Every CubeSat require a power system that will supply, regulate, control, monitor, feedback status about individual devices, distribute optimal power to different subsystems and protect the power system components from any possible faults. The primary source for feeding our system is the solar cell and the secondary source "storage" is battery which is used during eclipse or while the output power from the solar cell is insufficient. According to the limitation of the power which produced by the solar cell, there are many modes of operation which are used according to the mission as power save mode, control mode, camera mode, communication mode.

A. *Selection of optimum solar cell*

The solar cell is the primary source of energy because it is a renewable source of energy which means a semiconductor device that can convert solar radiation into electrical power. There are solar cell parameters which be considered to choose the optimal solar cell needed as shown in Figure1, as Efficiency (η), Short Circuit Current (I_{SC}), Open Circuit Voltage (V_{OC}), Maximum Power Point (PM), Current at Maximum Power Point (IM).

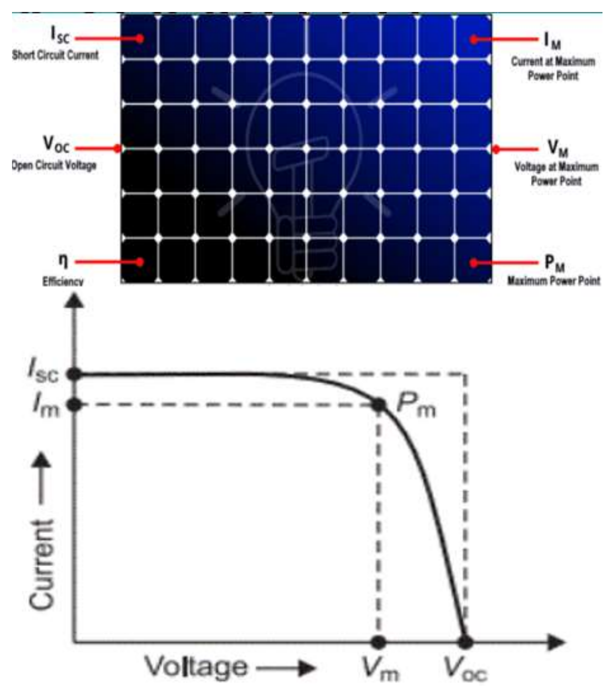

Figure 1 Solar cell parameters

There are output energy factors as shown in figure 2, as The intensity of the light, the angle of incident, Cell Area, Operating Temperature, Number of cells per each face.

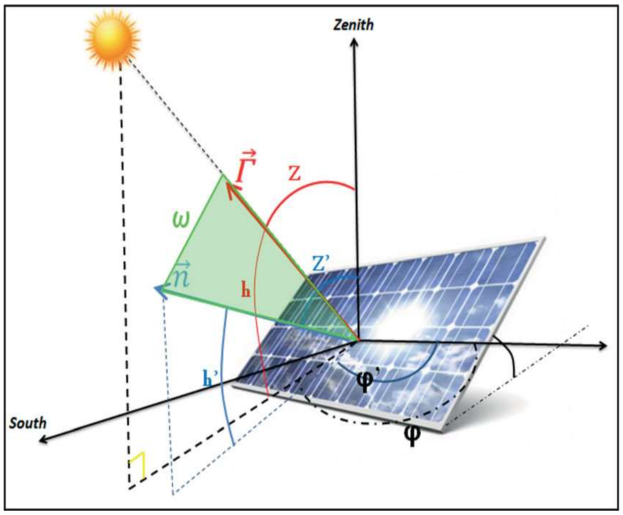

Figure 2 Output energy factors

B. Selection of optimum battery

Battery is the secondary source of energy, which has some important terms to choose the optimum one. Some factors to choose it are Capacity, Depth-of-discharge, Peak power requirements, the worst-case orbit energy requirement, Number of cells, Weight, Size, Operating temperature, lifetime. And the chemical composition of the battery as lithium- ion (Li-ion), Nickel-Cadmium (Ni-Cd), Lithium-polymer (Li-pol), Lithium-Chloride (Li-Cl). According the size factor Cylindrical 18650 COTS cells are widely used for CubeSat, due to their suitable size.

C. Power management system (PMS)

Power Management system is a computing device digitized power distribution network as shown in figure3, which includes connected devices and sensors that collect data from key points across the electrical system, that allows the user to control the amount of electrical power supply to each device.

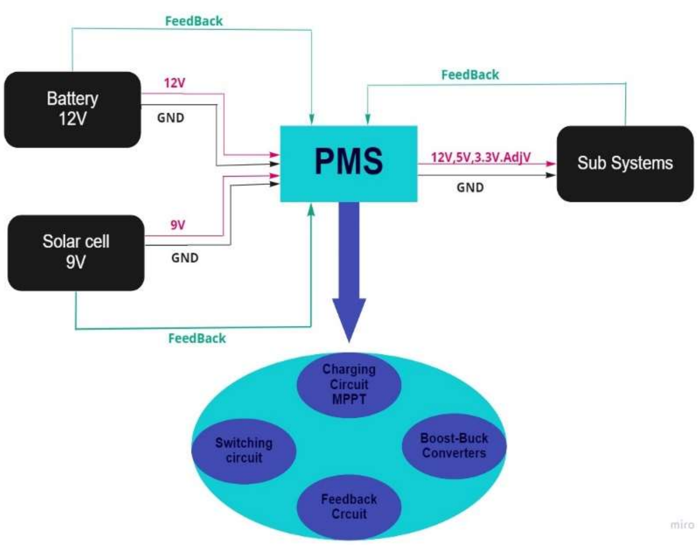

Figure 3 PMS block diagram

There are typical PMS architectures (Tsuruda, 2014) as shown in figure 4 as: **solar cell only** (system is not able to work during

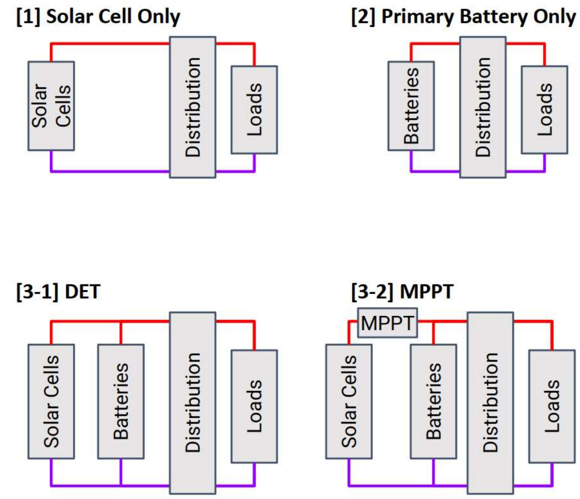

Figure 4 Comparison of DET vs MPTT

an eclipse), **Primary battery only** (System is able to work up to the battery life**)** and **Solar cell + Secondary battery** (for long-time operation) which divided into two techniques: Firstly **Direct Energy Transfer** (DET) in which shunt regulator circuit is connected between solar cells and batteries in parallel to control solar cell operating points as shown in figure5 secondly **Max Peak Power Tracking** (MPPT) in which MPPT circuit is connected between solar cells and batteries in series to control solar cell operating point. Our paper discus the using of MPPT in CubeSat to optimize the charging and obtain the maximum energy from solar cell and battery.

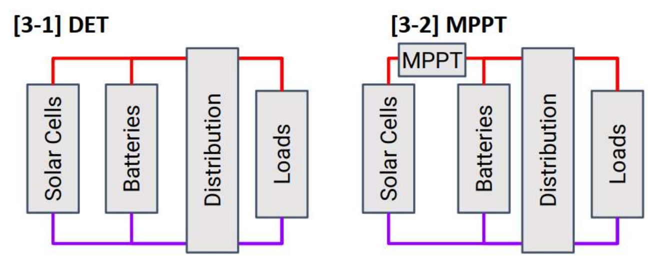

Figure 5 Comparison of DET vs MPTT

D. Maximum power point tracking(MPPT)

Main element of PMS is the MPPT-based buck converter is designed and simulated to organize the feeding of the system and charging the battery by the solar panel, to achieve maximum power point, the MPPT buck converter can be designed using different MPPT algorithms. Most common algorithms for recognition of MPP are the constant voltage method (P. C. M. De Carvalho, 2004), short-current pulse method (M. Park and I. K. Yu, 2004), open voltage method (T. Takashima, 2000), perturb and observe method (N. Femia, 2006), and incremental conductance method (W. Wu, 2003).According to MPPT, the efficiency of the power transition from the solar cell is dependent on the electrical properties of the load as well as the amount of ambient sunlight. The load characteristics which provides the maximum power transmission changes when these variables change to maintain the best efficiency of power transfer, in this point of maximum efficiency is called maximum power point (MPP). In the next figure6 show the optimal benefit of power from solar cell and the battery.

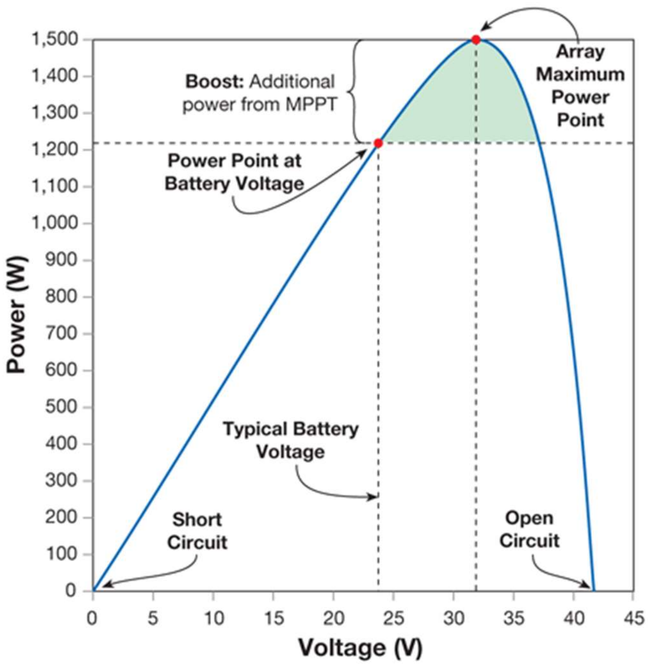

Figure 6 MPPT VS. NON-MPPT

II. PMS ARCHITECTURE

PMS consists of main components as shown in figure7

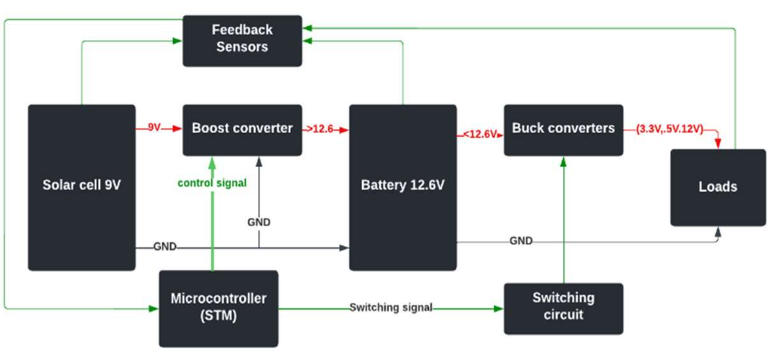

Figure 7 PMS ARCHITECTURE

as **boost converter** to increase the level of voltage of 9V solar cell to more than 12V to let the charging process of battery to be done, **Buck converter** to decrease and stabilize the output voltage (3.3V,5V.12V) from solar cell and battery to feed the sub systems with needed power, **Mosfets** to apply the switching control signal on the hardware devices according to the mode of operation, **feedback sens**or which feed the system with needed information about the capacity of battery, power consumption and any fault of system, A **microcontroller** (STM32) is used to determine the maximum power point (MPP) from solar cell panel using data, **protection circuit** from over voltage and over current on devices and finally our PMS send telemetry status information to station and monitoring by **Graphical User Interface** (GUI)**.**

III. METHODOLOGY

For implementing our project, it passes through some process firstly searching in different sources then simulation each individual schematic by using **Proteus** software then implement circuits by **breadboard** then implement by **Prototype Printed Circuit Board** and finally produce PCB by using EasyEDA online software, and for MPPT algorithm it is done by using MATLAB software.

A. Boost converter

Used as charging circuit which increase the output voltage of the solar cell from 9V to larger than 11.1 (lower voltage of 3 series Li-Ions batteries) and maintains the difference voltage between solar cells and battery constant to make the charging rate constant which these factor increase the life time of battery (A. Jossen, 1999; Hany A. Serhan, 2018). This converter is implemented by using **LMR62014** IC circuit.

B. Buck converter

Used to feed the network with different levels of voltage as required as 3.3V,5V,12V and ADJV. Those converters are implemented by using **lM2576T-5, lM2576T-12** and **lM2576T-Adj**.

C. Switching circuit

Used to apply the different modes of operation as (Power save mode, control mode, camera mode and communication mode) this circuit is implemented by using **TIP41C** transistor, which receive signals of switching from microcontroller (STM).

D. Feedback sensors

Used to feed the system with required states as (voltage, current, temperature and capacity of battery), the capacity of battery is implemented by using **LM741** OPAMP IC, **7805** Positive Voltage Regulator IC and **IRF540N** N-Channel Mosfet IC and current sensor is implemented by using **MAX471CSA IC** or **ACS712 IC**.

IV. RESULTS

To implement PMS, we will implement each stage individual before integrate them to obtain the PMS and we will implement the optimized solar cell specification and the optimized battery after survey.

A. Solar cell selection

The most efficient type of the solar cells is the triple junction solar cells *(D. J. Friedman, 2008) (Jan Schöne, 2009) (Martin Rutzinger, 2016)* which efficiency ≈ 41 % but it is over expensive.

so we will use the Si solar cells which efficiency ≈ 18 % and its price in the range from 2.5 $ to 10 $ per piece , so we Selected Si-solar panels with 15% efficiency its dimension was (11*11*0.3)cm .As shown in figure 8

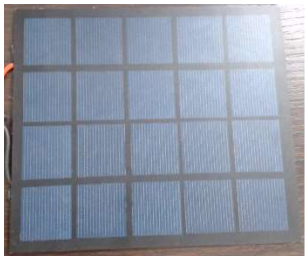

Figure 8 Si Solar cell

B. Battery selection

Figure 9, (Benjamin Lynch, 2014) shows the representation of the battery chemistries used in CubeSat:66% Lithium-ion (Li-ion), 16% Nickel-Cadmium (Ni-Cd), 12% Lithium-polymer (Li-pol), 4% Lithium-Chloride (Li-Cl), and 2% none. So we use 3 batteries (Li-ion 3200 mAh, one cell) in series to obtain12V.

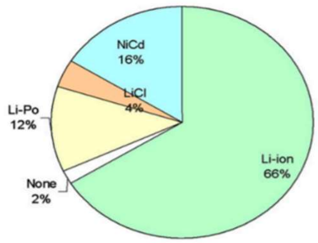

Figure 9 Conclusion of battery survey

C. PMS implementation

1) DC-DC Boost converter

By using LMR62014 IC or MC34063 IC. As in figure [10,11]

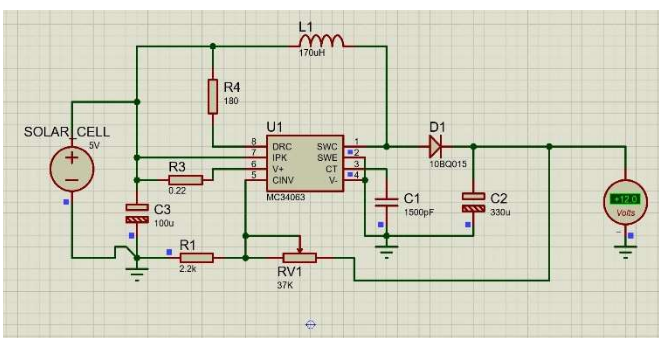

Figure 10 Simulation of boost converter

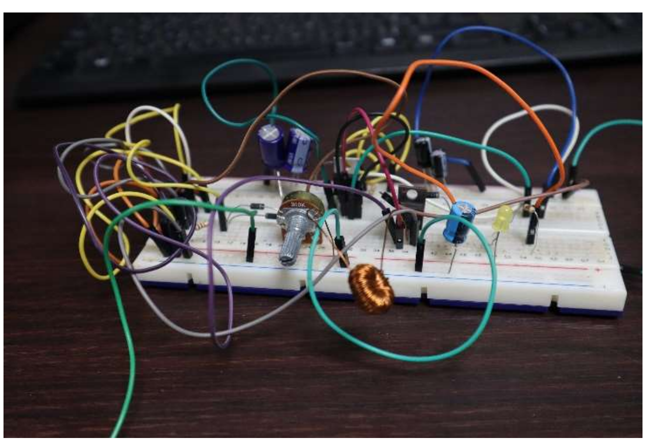

Figure 11 Boost converter implemented in breadboard

2) DC-DC Buck converter

By using **LM2576T-Adj** as shown in figure [12.13.14]

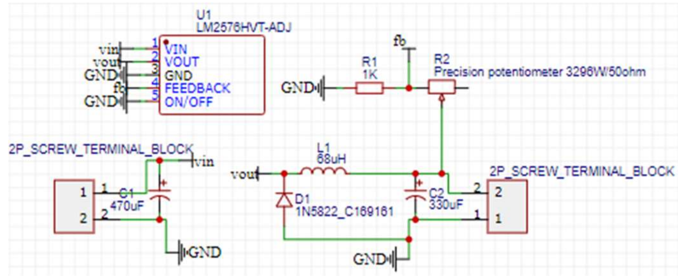

Figure 12 LM2576T-Adj schematic

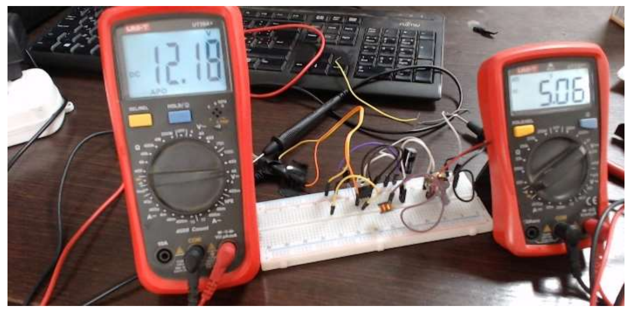

Figure 13 LM2576T-Adj implemented in breadboard

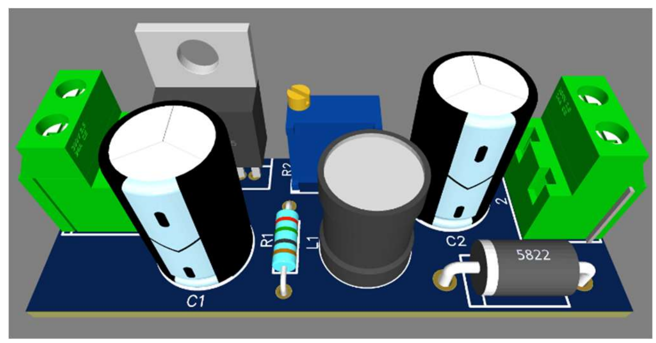

Figure 14 LM2576T-Adj 3D model of PCB

3) One input / multi output buses of voltages with switching circuit.

By using **TIP41C** transistor as shown in figure [15.16.17].

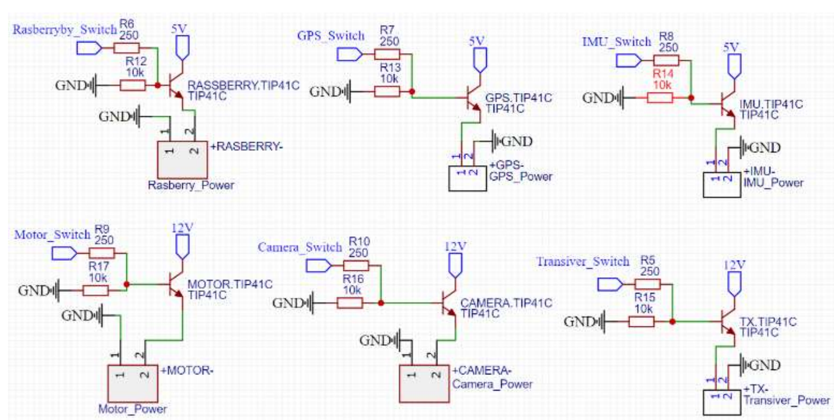

Figure 15 Switching circuit schematic

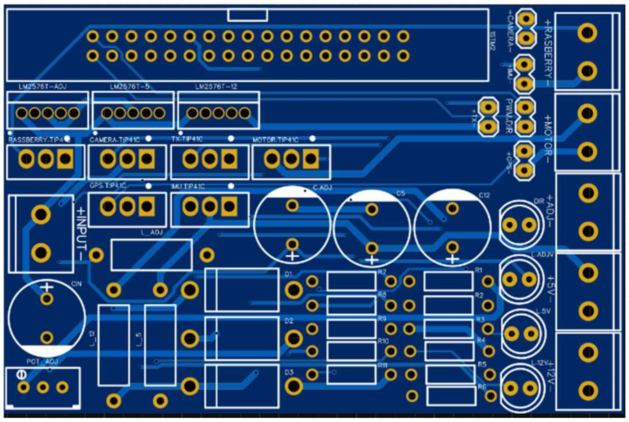

Figure 16 Switching circuit 2D PCB

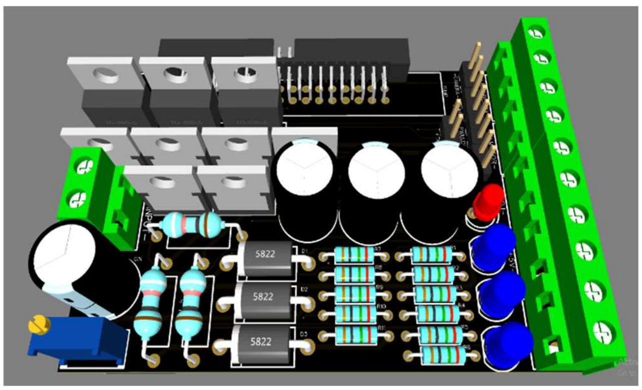

Figure 17 Switching circuit in 3D model

4) Final PMS design

PMS consists of two PCB firstly the main PCB which contains (Boost converter, Buck converter, switching circuit, feedback circuits) and the another one connected to the microcontroller (STM), as shown in figures [18.19.20.21.22.23.24]

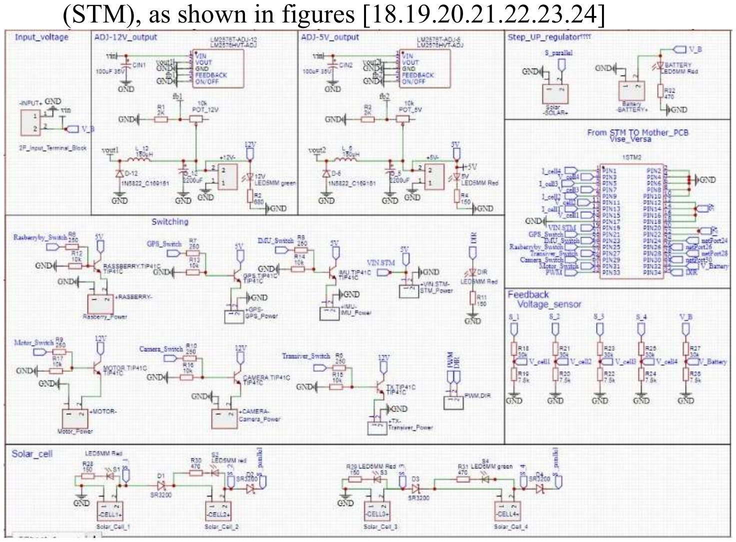

Figure 18 Main PMS schematic

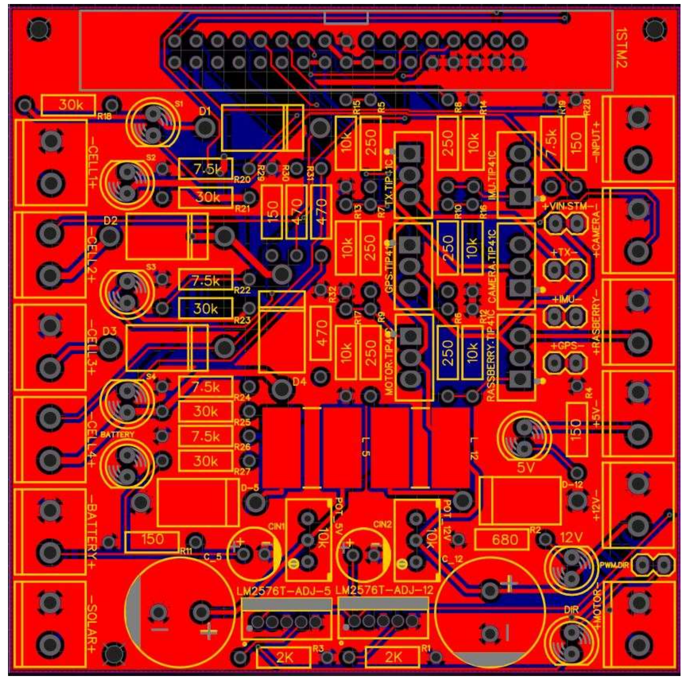

Figure 19 Main PMS PCB

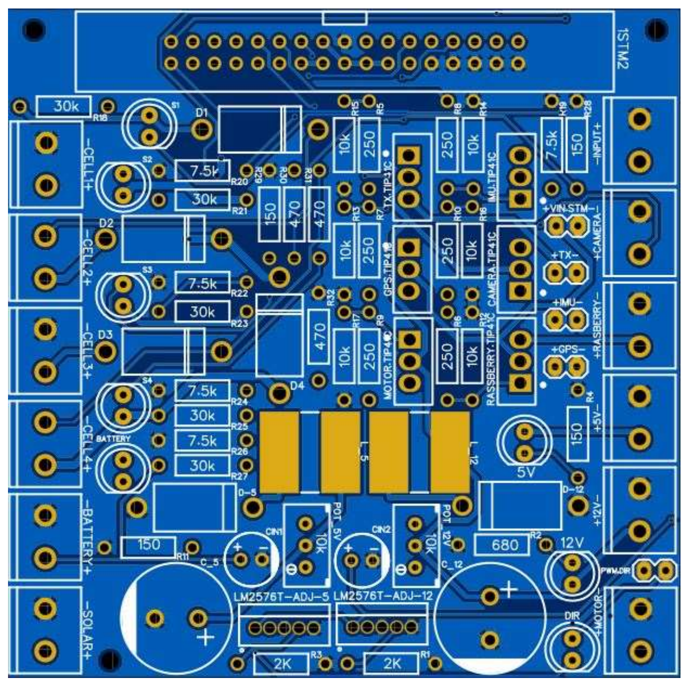

Figure 20 Main PMS 2D

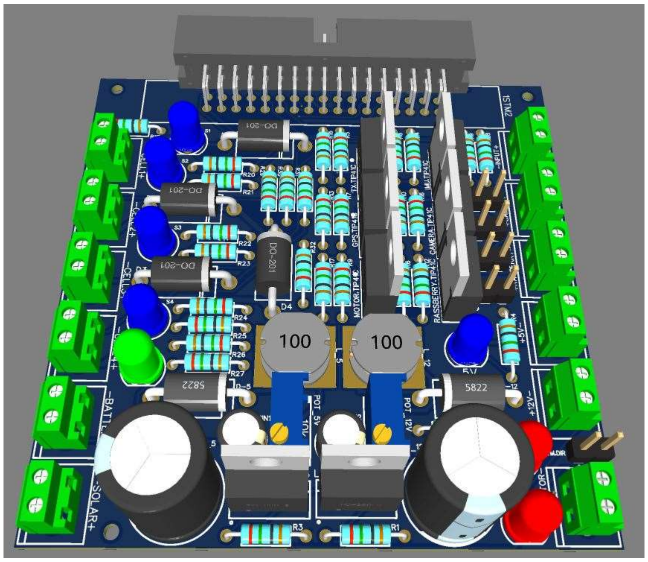

Figure 21 Main PMS 3D

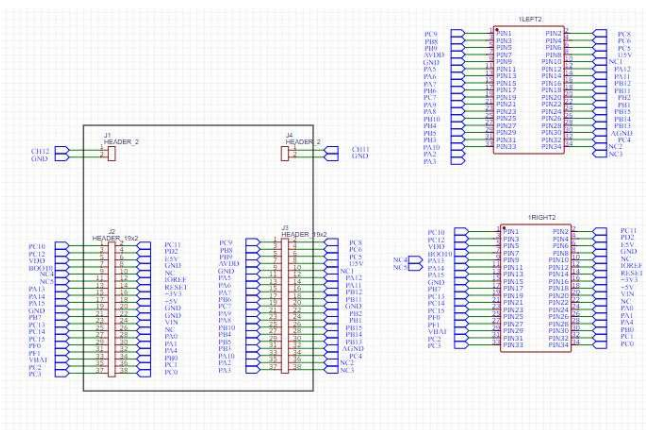

Figure 22 Secondary PCB contains STM Schematic

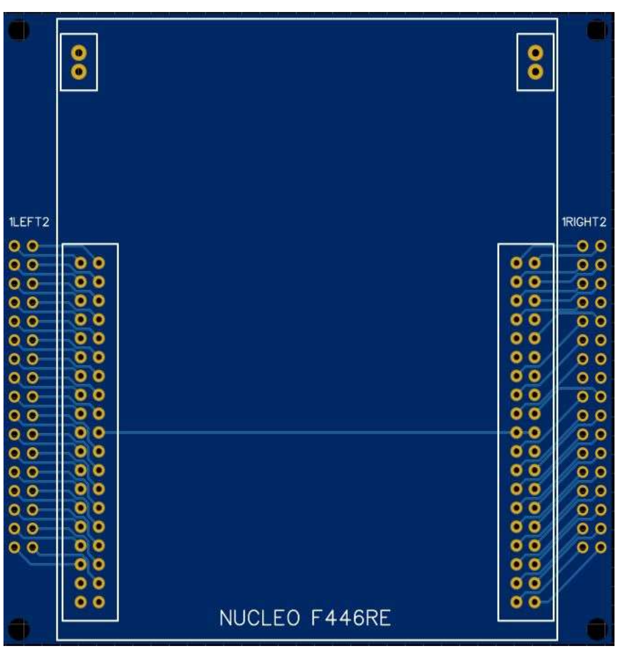

Figure 23 Secondary PCB contains STM 2D

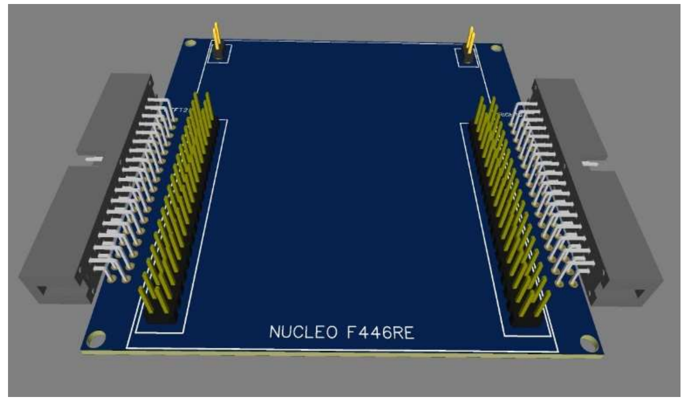

Figure 24 Secondary PCB contains STM 3D

5) *GUI for PMS*

By using HTML to design graphical unite interface (GUI) to monitor the states of devices, capacity of battery, performance of solar cell and predict the fault, as shown in figure 25.

Figure 25 PMS GUI

V. CONCLUSION

According to the size limitation of CubeSat we obtain limited electrical energy from solar cell as it is the renewable source of energy and during The Eclipse duration that takes around 33% of the orbit time that we cannot use direct energy from solar cell so we need storage source of energy (battery), So we design PMS to organize the distribution the power to the other subsystems with different voltage busses according to the subsystems electrical properties.

VI. ACKNOWLEDGMENT

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