POWER SUBSYSTEM DESIGN OF THE MALAYSIAN YOUTH SATELLITE (MYSAT)

By

SASIDARAN SUBRAMANIAM

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ENDORSEMENT

I, Sasidaran s/o Subramaniam hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

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(Signature of Student)

Date:

____

(Signature of Supervisor)

Name: Dr. Norilmi Amilia Ismail

Date:

____

(Signature of Examiner)

Name: Dr. Ahmad Faizul Hawary

Date:

DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

(Signature of Student)

Date: 14th May 2018

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POWER SUBSYSTEM DESIGN OF THE MALAYSIAN YOUTH SATELLITE (MYSAT)

ABSTRACT

MYSat (Malaysian Youth Satellite) is a nanosatellite that is being developed by the Universiti Sains Malaysia Space Lab team. Its purpose falls under the scope of earthquake forecasting in which functions to sense and transmit electron density data using special equipment during its one year orbit at Earth's ionospheric altitude. This final year project focuses on the design and implementation of electronic power subsystem (EPS) of MYSat. The main task of EPS is to provide a continuous supply of power to the entire satellite bus in orbit without failure. The power system consists of several main parts: Solar cells, batteries, power distribution bus which consists of voltage converters and protection, sensors monitoring different parts of the system and a microcontroller or an on-board computer used to control the system. The output of this project is a simplest yet feasible EPS model on a breadboard and to test its capability to ensure successful power delivery to all payload and will be fabricated as an Engineering model in the form of the printed circuit board (PCB) before its integration into the MYSat mainframe. The procedure of this project is to size every stage of the EPS by considering the architecture, power budget, type of power management and regulations, switching methods and trade-off between different hardware that are reliable and available in the market. Initially, this system is made to be an independent system for the testing purpose. Each critical component was tested individually

followed by the combined circuit form to investigate the power output. The system is then has incorporated a standalone microcontroller unit that functions to provide fault protection and displays necessary voltage and current data at particular parts of the system. The control system will be switched to MYSat On-Board data handling subsystem later on.

REKA BENTUK SUBSISTEM KUASA MALAYSIAN YOUTH SATELLITE (MYSAT)

ABSTRAK

MYSat (Satellite Youth Malaysia) adalah sebuah nanosatelit yang sedang dibangunkan oleh pasukan Makmal Angkasa Universiti Sains Malaysia. Tujuannya terletak di bawah skop ramalan gempa bumi. Misi nanosatelit ini adalah untuk mengesan dan menghantar data ketumpatan elektron sepanjang orbitnya pada ketinggian ionosfera Bumi dengan menggunakan peralatan khas selama satu tahun. Projek tahun akhir ini memberi tumpuan kepada reka bentuk dan pelaksanaan subsistem kuasa elektronik (EPS) MYSat. Tugas utama EPS adalah untuk menyediakan bekalan tenaga berterusan ke seluruh bas satelit dalam orbit tanpa gagal. Sistem kuasa terdiri daripada beberapa bahagian utama: sel suria, bateri, bas pengedaran kuasa yang terdiri daripada penukar voltan dan perlindungan, sensor pemantau bahagian-bahagian sistem dan mikropengawal atau komputer yang digunakan untuk mengawal sistem tersebut. Produk akhir projek ini adalah sebuah model EPS yang paling mudah dan boleh dilaksanakan pada papan reka dan untuk menguji keupayaannya dalam memastikan penyampaian kuasa yang baik ke seluruh model tersebut. Model ini akan direka sebagai model Kejuruteraan dalam bentuk papan litar bercetak (PCB) sebelum mengintegrasi ke dalam kerangka utama MYSat. Prosedur projek ini adalah untuk membentuk setiap peringkat EPS dari segi arkitektur, belanjawan kuasa, jenis pengurusan dan peraturan kuasa, cara peredaran kuasa dan perbandingan antara perkakasan yang sesuai

dan sedia ada dalam pasaran. Pada mulanya, sistem ini dibuat untuk menjadi sistem bebas untuk tujuan ujian. Setiap komponen kritikal diuji secara individu diikuti oleh litar gabungan untuk menyiasat keluaran kuasa. Kemudian, sebuah mikrokontroler telah disambung kepada model untuk memberikan perlindungan kerosakan dan memaparkan data voltan dan arus pada bahagian-bahagian yang tertentu dari semasa ke semasa semasa. Setelah itu, sistem kawalan akan digantikan dengan subsistem utama pengendalian data MYSat.

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LIST OF ABBREVIATIONS

1U	:	1-Unit
ADCS	:	Attitude Determination and Control System
BOL	:	Beginning Of Life
DC	:	Direct Current
DET	:	Direct Energy Transfer
DOD	:	Depth of Discharge
EOL	:	End Of Life
EPS	:	Electrical Power System
GaAs	:	Gallium Arsenide
LDO	:	Low Drop-out
LiPo	:	Lithium Polymer
Li-ion	:	Lithium Ion
MJ	:	Multi-junction
mNLP	:	Multi-needle Langmuir Probe
MPP	:	Maximum Peak Power
MPPT	:	Maximum Peak Power Tracking
MYSat	:	Malaysian Youth Satellite
NiCd	:	Nickel Cadmium
NiH_2	:	Nickel Hydride
NiMH	:	Nickel-Hydrogen
OBC	:	On-Board Computer
OBDH	:	On-Board Data Handling
PCB	:	Printable Circuit Board
PV	:	Photovoltaic
RTG	:	Radio-isotope Thermionic Generator
Rx	:	Receiver
SJ	:	Single-junction

Tx	:	Transmitter
UHF	:	Ultra-High Frequency
UTJ	:	Ultra-Triple Junction
VHF	:	Very-High Frequency

LIST OF SYMBOLS

A_{sa}	:	Area of solar array [m^2]
C_r	:	Battery capacity [Ahr]
E_g	:	Electroband gap [mm]
G_S	:	Sun constant [W/m^2]
I_{in}	:	Input current [mA]
I_{out}	:	Output current [mA]
I_d	:	Inherent degradation [%]
L_D	:	Lifetime degradation [%]
I_{REG}	:	Regulation current [mA]
n	:	Load transmission efficiency [%]
P_{BOL}		Power at the Beginning of Life [W/m^2]
P_e	:	Power during eclipse [W]
P_{EOL}	:	Power at the End of Life [W/m^2]
P_d	:	Power during daylight [W]
P_{sa}	:	Power generated by solar array [W]
P_o	:	Solar cell power output per unit area [W/m^2]
θ	:	Worst sun angle [°]
T_e	:	Eclipse duration [s]
T_d	:	Daylight duration [s]
V_{in}	:	Input Voltage [V]
V_{REG}	:	Regulation Voltage [V]
V_{out}	:	Output Voltage [V]
X_d	:	Direct transfer efficiency in daylight [%]
X_e	:	Direct transfer efficiency during eclipse [%]
μ_E	:	Earth Gravitational parameter [km^3/s^2]
η	:	Solar cell efficiency [%]

CHAPTER 1

INTRODUCTION

This chapter introduces the general concepts, ideas and current development of nanosatellites and the importance of power subsystem in satellites.

1.1. Overview

Many research and technological improvement have been done on space technologies such that now we have simple, miniaturized satellites or nanosatellites. One example of a nanosatellite is the CubeSat, which is what the MYSat design is based on. One unit (1U) CubeSat is a cubed-shaped U-class nanosatellite with dimensions about 10cm by 10cm by 10cm and weighs at a maximum of 1.33 kilograms. What is interesting about a CubeSat is that it uses very low power and suitable for long-duration missions at low-Earth orbit (LEO) altitude. As for this project, the main focus is centered on **electrical power system (EPS)** of the MYSat, deriving power requirement and later on to come up with designs and iterations of the circuit model.

In general, the main elements of the electrical power system of a spacecraft includes power generation, conditioning, control, distribution and its storage within the specified voltage band to all bus and payload equipment. The basic components of the power system are the solar array, solar array drive, battery, battery charge and discharge regulators, bus voltage regulator, load switching, fuses, and the distribution harness. The harness consists of conducting wires and connectors that connect various components together. Figure (1.1) below shows the flow of energy supply within the system.

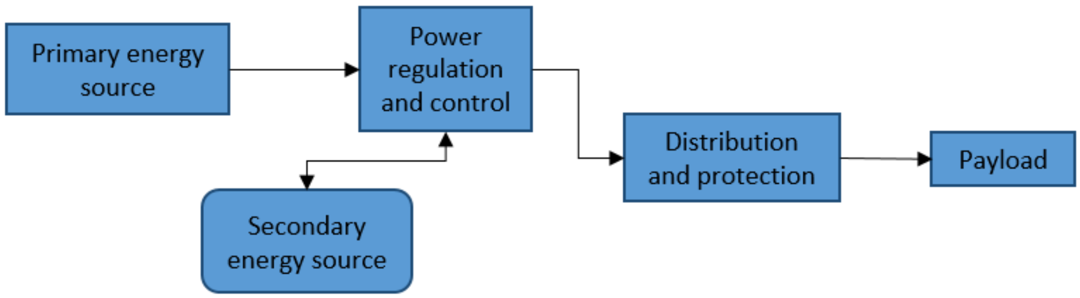

Figure (1.1): Flow of energy throughout the EPS of a satellite

1.2. Problem statement

An optimally operational CubeSat has a stable and reliable EPS. A single mistake and the Cubesat will drift aimlessly in orbit, deeming it as a mission failure. The EPS of a CubeSat is a fully autonomous system that receives power from a power source and conditions or distributes this power to some subsystems on board the satellite. If the power obtained from the power source is greater than the consumed power by the connected subsystems, then the excess power must be stored in the secondary source or release through the heat with a shunt in general satellites. It may happen that the power consumed by the subsystems exceeds the input power from the power source. In this case, the batteries must be able to produce enough power to provide the needed output power. But, if a subsystem draws a current that is large enough to suggest a malfunction, then this current must be limited to protect the subsystem.

1.3. Objectives

1.3.1. To derive the power requirement for the entire bus and payloads of MYSat

1.3.2. To build a functioning breadboard baseline model of the power subsystem

1.3.3. To analyze and test the model to ensure successful power management

1.4. Thesis outline

The general layout of this thesis is broken down as follows:

- **Chapter 2 (Literature Review):** This chapter handles the critical review of literature related to the topic of the thesis as well as the theoretical background concerning the concepts discussed the through the thesis.
- **Chapter 3 (Methodology):** This chapter considers the design of the power subsystem that is expected to meet the goals of the project. It describes the methods and techniques used for this research and also contains validation of methods used.
- **Chapter 4 (Results and Discussions):** This chapter presents the implementation of the tests, a complete account of results obtained from the design described in chapter 3 and the discussion regarding the obtained results.
- **Chapter 5 (Conclusion and Recommendation):** This chapter illustrates the significance of the study and stresses the findings and problem faced when running the design in both of breadboard model and hardware implementation. Recommendations for future work are suggested with the objectives set and acknowledgment of limitations.

CHAPTER 2

LITERATURE REVIEW

2.1. Electrical Power Subsystem

Almost all of the equipment in MYSat need a continuous power supply. Therefore, implementation of a reliable power system is a must. It should be capable of handling the task of providing the needed power for each subsystem in the Cubesat (Osmar, 2012).

The CubeSat Electrical Power System aims to provide conditioned power for the Cubesat which involves continuous power generation for supplying the CubeSat, power storage for supplying the Cubesat when the main power generation cannot, monitoring the power to be distributed and protection of the CubeSat in case of a fault situation.

2.2. Power generation

2.2.1. Types of Power Sources

For a long duration mission like MYSat which is one year, the most suitable power sources are;

- Nuclear energy
- Solar/Nuclear thermionic
- Photovoltaic cells

Nuclear energy approach involves decaying of radio-active matter. These matter decays and generates heat, which can be converted into electrical power using a Radio-isotope Thermoelectric Generators (RTG). Although this approach is best suited for deep-space (inter-planetary) missions because of its long-lasting capabilities, there is a high risk of spreading of nuclear matter in case of a failed launch (Osmar, 2012). Also, power generated from nuclear source is way too high for a CubeSat, which requires only a few watts of power.

Thermionic may have two sources; Sunlight or radio-isotope matter. For sunlight, a satellite uses special equipment that concentrates incoming solar energy into heat energy while for nuclear, the decaying of matter or controlled-fission reaction produces heat energy. These heat energy heats up steam and drives a rotating turbo-generator or a reciprocating alternator to produce electrical energy. The energy output is higher and more efficient than Photovoltaic cells yet due to the complexity of this system, it is not practical to use it on a nanosatellite.

Photovoltaic cells (PV cells) functions to convert photons irradiated by the sun into electrical energy. PV cells or typically called solar cells are widely used in almost all nanosatellites due to its simplicity and suitability in structural weight, materials and capability to provide continuous energy sources in the presence of sunlight. Solar cells provide very low output due to its fairly lower efficiency than solar thermionic, which is adequate to power up the entire bus of nanosatellites. Therefore, solar cell is deemed most practical energy source for this CubeSat.

2.2.2. Working principle of Solar Cells

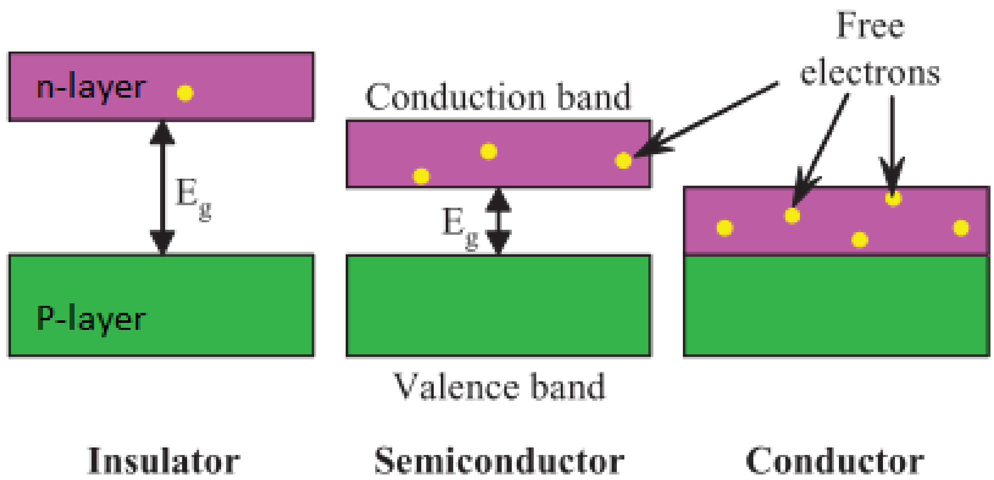

Figure (2.1): Structure of a solar cell (Rodriguez, 2013)

A typical PV cell is made up of 2 semi-conductive layers which sandwich a thin crystalline silicon layer of the junction. The silicon layers denoted as n-layer is phosphorus-doped, which is has extra valence electrons, while the p-layer is boron-doped, which has holes or voids for electrons to fill in. When photons hit the panel, energy absorbed in the atom gets higher than the bandgap energy, E_g and knocks the electrons of the silicon atoms, creating electron-hole pairs (Rodriguez, 2013). Due to their polarities, electrons are drawn towards the n-layer and holes tends to move towards the p-layer. This creates an electromotive force across the cell. When a load is connected, electrons will immediately flow through and get to the other side of the panel to cancel out the charge. As long as there are exposure to photons, electricity can be generated continuously.

The efficiency of the solar cells is determined by the doping characteristics of the semiconductors. When doping the semiconductors, it is important to either have an excess of positive charged carriers (p-type) or a surplus of negative charged carriers (n-type). When contact occurs between the two layers of the semiconductor, a p-n junction is formed. This junction casts an electrical field which separates charge carriers. This leads to free electrons in the proximity of the electric field, which then forces the electrons from the p-side to the n-side, creating a current.

At the present market, Photovoltaic cells comes in various types of material and cell configuration. Based on previous work by Rodriguez (2013), the CUBESTAR nanosatellite implements Ultra Triple Junction (UTJ) cell by Spectrolab (2010). This cell has an area of 26.62 cm2, an efficiency of 28.3% and has been part of many successful space missions. Due to the triple junction, the efficiency of this cell is among the highest available on the market at the time.

The most recent one also made by (Spectrolab, 2016) is the XTJ Prime, a triple junction space grade PV cell. This cell has an efficiency of 30.7% and made exclusive for a space mission.

The two important factors that influence the amount of solar energy that the cell can harvest are the irradiation and the temperature of the cell. The greater the irradiation, the greater the number of photons being absorbed into the panels. Therefore, greater generation of power. However, the higher the temperature, the lower the generation of power.

2.3. Power Storage

Theoretically, PV cells can provide energy for the indefinite amount of time as long as it is exposed to sunlight. In a real situation, satellites orbiting the Earth will face cycles of day and night in a very short time. PV cells will be rendered useless every time it moves into the Earth's shadow. This is when power storage comes into play to temporarily replace the solar cells as the secondary energy source for the satellite.

A battery converts chemical energy to electric energy through the use of an electrolyte, which is a substance that consists of free ions and as thus electrically conductive (Osman *et al*., 2012). When connected to a load, discharge of electrons from cathode to anode produces current that flows in the other direction. Battery charge is said to be depleted when the number of electrons in both terminals are same, which means net electrical potential becomes zero.

A battery that is chosen to be the power storage must be rechargeable, that is using a rechargeable battery. Unlike common batteries, rechargeable batteries are batteries that can reverse its chemical process by introducing a higher voltage over the batteries, causing electrons to flow in the opposite direction, thus increasing its electric potential across the battery and making it reusable again.

In orbit, as the satellite passes into the eclipse, the solar panel will no longer receives sunlight and stops producing power. Immediately at the same time, the rechargeable battery will produce the necessary power for the entire bus until it receives sunlight again. The battery is then recharged with the energy attained from the solar panel.

Table 1.1: Comparisons of battery technology (Navarathinam *et al*., 2011)

Characteristics	Battery chemistry			
	Nickel Cadmium (NiCd)	Nickel Metal Hydride (NiMH)	Lithium Ion (Li-ion)	Lithium Polymer (LiPo)
Discharge terminate voltage (V)	1.00	1.00	2.80	2.80
Charge terminate voltage (V)	1.55	1.55	4.20	4.20
Nominal discharge voltage (V)	1.25	1.25	3.70	3.70
Operational Temperature (^{o}C)	-20 to 50	-10 to 50	-20 to 60	-20 to 60
Sensitivity to overcharging	Medium	High	Very high	Very high
Gravimetric energy (Wh/kg)	40–60	30–80	100–200	130–250
Volumetric energy (Wh/l)	50–150	140–200	150–250	150–300

Gravimetric Power (W/kg)	150–200	150–1000	200–500	More than 1000
Comments	Suffers memory effects, has good space heritage	Minimal memory effects, capable of high discharge currents	Capable of higher voltages per cell than other cells, relatively new to the space industry	Same as Li-Ion but often much lighter due to lack of metal shell casing

Choices of battery type is one of the essential keys to successful power management. Table (1.1) shows the characteristics of various types of rechargeable batteries. The most advantageous among them is the Lithium-Polymer battery. According to Navarahinam *et. al* (2011) Lithium-ion cells, in general, have a larger capacity compared to the Lithium Polymer cell. However, the Lithium Polymer cells have a volume that is 16 to 17% of the Li-ion cell and has a gravimetric energy capacity that is 1.2 to 1.6 times larger. Such features are well suited for nanosatellite missions.

2.4. Power Management

Power Management describes the structure and configuration of how power is regulated and distributed in a satellite EPS. The two main types of architecture primarily considered for satellites are;

- Power Regulation and Control
- Power Distribution and Conditioning

2.4.1. Power Regulation and Control

The most common implementation approaches found on today's CubeSats are the **Direct Energy Transfer (DET)** and the **Maximum Power Point Tracking (MPPT)**.

DET configuration is the simplest in a power system. The system has a low mass

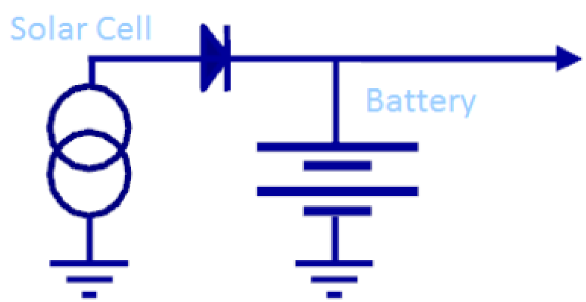

Figure (2.2): Direct energy transfer with battery bus (Osmar, 2012)

because it consists of only a solar array regulator interface with no switch mode power supply element as shown in Figure (2.2). (Bester et al., 2012) With DET systems there is a direct connection between the solar array and battery unit (as load), with no active components in-between. All other systems are labelled as non-DET systems.

One of the disadvantages of DET is that DET is that the solar array is only operated near its MPP as shows in the Figure (2.3). Based on the figure, when it is hot, and the battery is fully charged. This is because upon exiting eclipse, the array is cold (with a high voltage) and the battery is depleted (with a low voltage), creating a big difference between the solar cell voltage and bus voltage. Therefore, most of the current is consumed to charge up the battery, leaving the remaining to power up the payload. In this situation, the remaining current that is delivered to the payload may or may not be sufficient, and this can cause complications to the on-board circuit.

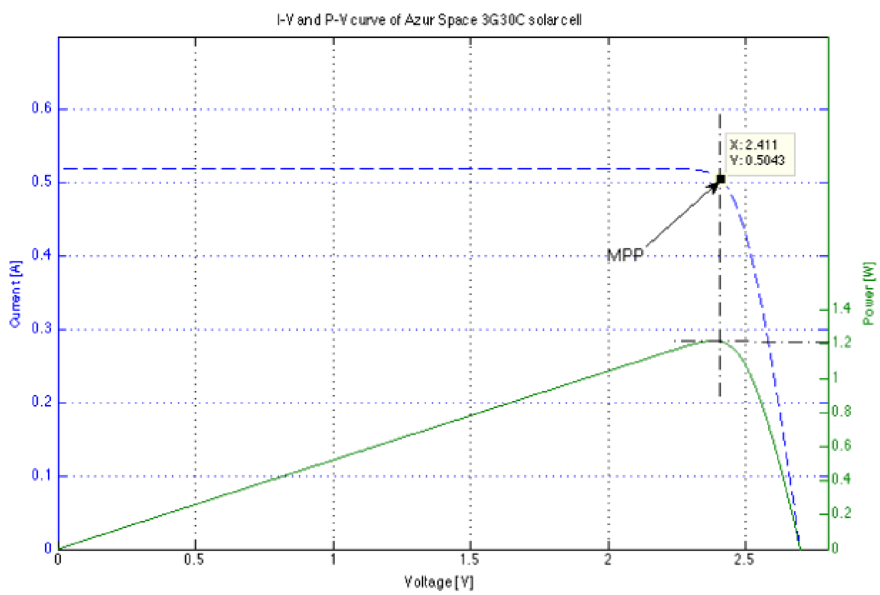

Figure (2.3): I-V curve and P-V curve of Azur Space 3G30C cell

(T=28°C, E=1367 W/m2).(Hemmo, 2013)

To solve this problem, Maximum Peak Power Tracking (MPPT) can be implemented. MPPT functions to draw maximum amount of power possible from the solar and maintains bus voltage while charging the battery, all with the help of specific algorithms from a MPPT converter unit. The MPPT converter is situated between the solar panel and battery (Osmar, 2012). MPPT normally uses one of the three algorithms stated below;

- Perturb and Observe
- Incremental Conductance
- Constant voltage

The Perturb and Observe algorithm is the most widely used algorithm for MPPT because of its simplicity and efficiency. It is based on the fact that power increases when the operating point is moving towards the MPP. If total power production increases when changing voltage, the operating point is closer to the MPP. This method can cause oscillations to power output because it cannot accurately determine the point where the MPP is actually reached. It can also function erroneous if irradiance levels are changing rapidly. Therefore, more advanced versions of the algorithms are developed to reduce oscillations.(Hemmo, 2013)

Incremental Conductance method measures incremental changes in photovoltaic cell's current and voltage to predict the effect of a voltage change (Osmar, 2012). This method requires more computation in the Maximum Peak Power Tracking converter (MPPTC), but it can track changes in conditions quicker when compared to Perturb and Observe method. The maximum power point is achieved when:

$$\frac{dI}{dV} = -\frac{I}{V} \tag{2.1}$$

Where:

dI/dV: Incremental conductance of the array

-(I/V): Negative instantaneous conductance

The incremental conductance method computes the MPP by comparison of the incremental conductance (dI/dV) to the photovoltaic conductance, -I/V (Hemmo, 2013). The controller maintains this voltage until the irradiation changes, and the process is repeated.

Constant Voltage method momentarily interrupts the delivery of power to the subsystem and measures the open-circuit voltage with zero current. The controller then resumes operation with the voltage controlled at a fixed ratio, such as 0.76, of the open-circuit voltage, which has empirically been determined as the estimated MPP. The operating point of the photovoltaic cell is kept near the MPP by regulating the cell voltage and matching it to a fixed reference voltage. The reference voltage is set equal to the MPP voltage of the characteristic of the photovoltaic module or another calculated best-fixed voltage (Osmar, 2012).

The drawback of MPPT is that the system is complex and contributes more efficiency losses in the system compared to DET.

2.4.2. Power Distribution

This section describes the architectures of power subsystems and at what levels the power will be altered and distributed to the satellite busses. Common architectures found in satellites are centralized architecture and distributed architecture.

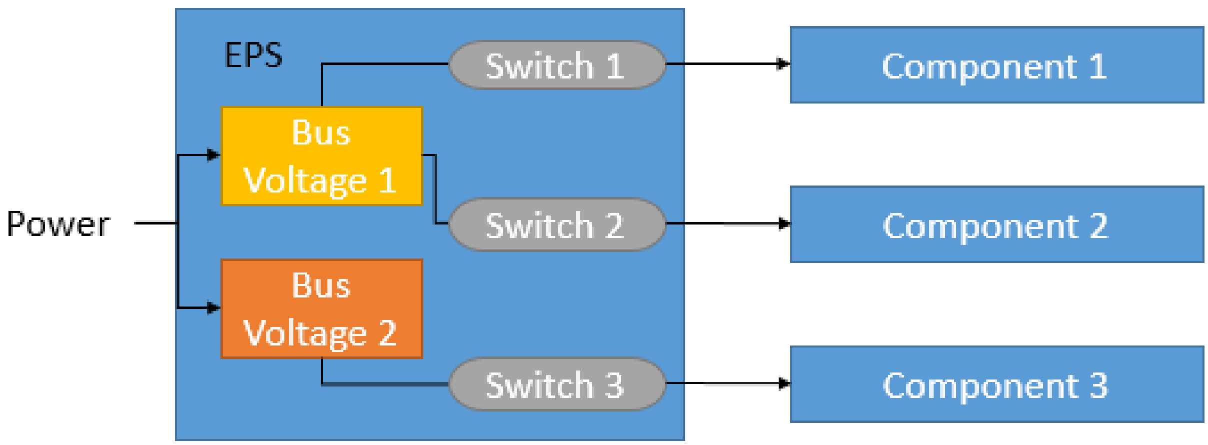

Figure (2.4): Distributed architecture

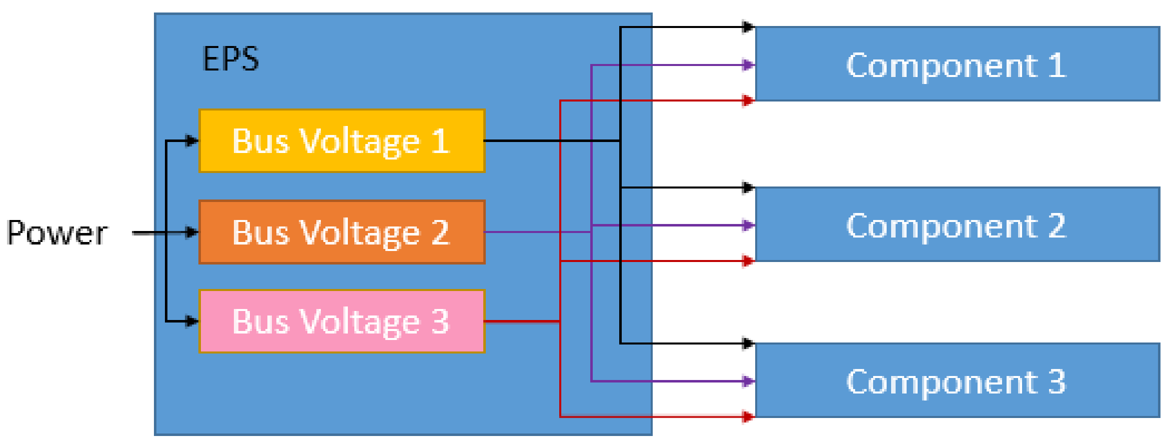

Figure (2.5): Centralized architecture

The differences between these two architectures can be seen clearly in Figures (2.4) and (2.5). The centralized architecture allows the conditioning of power into single or multiple voltage bus in the beginning before distributing to all payload. Meanwhile, distributed architecture shows that power is distributed first and is conditioned later to specific voltage bus for specific component.

Burt (2011) has stated that centralized systems normally implemented in small satellites, using point-of-load regulation for special voltages not provided by the EPS card. Depending on the degree of allowable voltage ripple, a Low Drop-Out (LDO) regulator is often the choice to convert to the new, lower voltage. The main advantage of the centralized architecture is that fewer regulators are required since one regulator can provide the same regulated voltage to multiple subsystems or components. One disadvantage is that the regulator must be sized to fit all of the loads and potential loads that will be connected to it.

Distributed architecture usually implemented on a large satellite that uses large voltage bus. This is because multiple specific components or payloads requires a wide range of voltages. For example, a subsystem requires 28 Voltage bus meanwhile others requires as small as five Voltage bus. Although this is a good advantage for distributed architecture, the downside means a requirement of multiple regulators or converters for each voltage bus.

2.4.3. Power Conditioning

There are two ways of power being conditioned before delivery to payload;

- Linear mode
- Switching mode

Linear mode functions to only lower down voltage using resistors connected in series with a resistor and parallel with another resistor. The connection is simply a voltage divider.

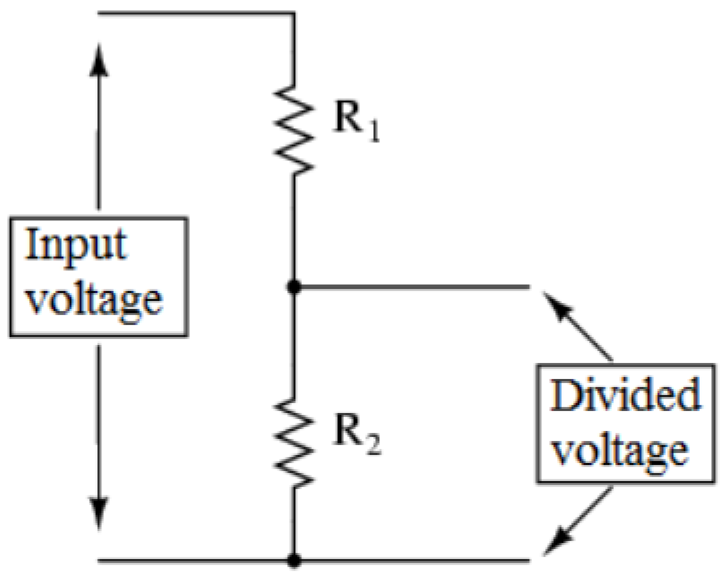

Figure (2.6): Linear mode configuration

The divided voltage is calculated with the equation below, denoting input voltage as V_{in} and divided voltage as V_{out};

$$V_{out} = V_{in}\left(\frac{R_2}{R_1 + R_2}\right) \tag{2.2}$$

Although the configuration is simple, V_{out} is very dependent to V_{in}, which means any changes to the input will also affect the amount of dividing voltage. This will contribute to a great amount of power loss.

Linear mode is best replaced with switching mode. Switching mode allows stepping up or down voltage to either a fixed voltage or a wide range, adjustable voltages using buck

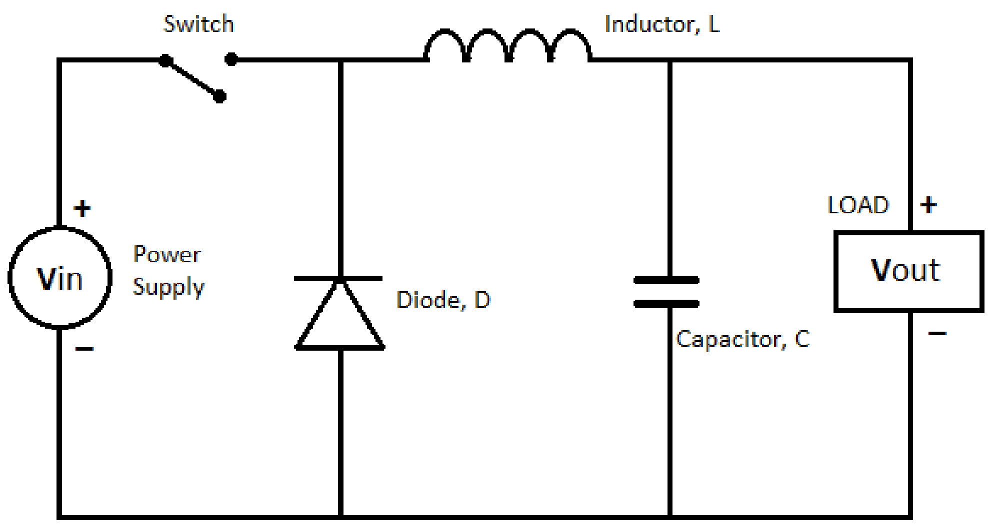

Figure (2.7): Schematics of a Buck Converter

and boost converters. The schematics of the buck converter and boost converters are shown in Figures (2.7) and (2.8) respectively.

A buck converter steps down input voltage to a lower output voltage. Based on Figure (2.7), the inductor stores energy when the switch is closed. At this point, the voltage across the inductor is equal to the difference between supply voltage and load voltage. When the switch is open, energy from the inductor is discharged into the load, which has a voltage equals to the load voltage (Osmar, 2012). Energy stored in the inductor is represented in the equation below;

$$E = \frac{1}{2} L \cdot {I_L}^2 \tag{2.3}$$

Where:

L: Inductance of the Inductor

I_L: Current through the Inductor

The energy stored in the inductor is determined by the current and the periods of the ON and OFF states of the switch. The voltage over the inductor is determined by the ratio of ON/OFF state of the converter, which is referred as duty cycle (Osmar, 2012). The duty cycle of a buck converter is calculated with the equation below (Hauke et al., 2015);

$$D = \frac{V_{out} \times \eta}{V_{in}} \tag{2.4}$$

Where:

V_{out}: Output voltage

V_{in}: Input voltage

η: Efficiency of the converter

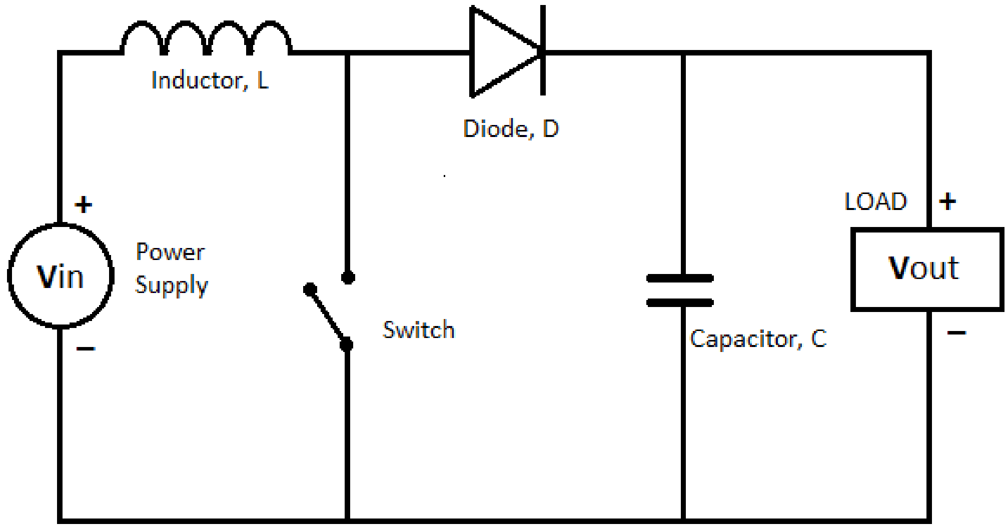

Figure (2.8): Schematics of a Boost Converter

According to the figure above, the difference from the buck converter schematics from Figure (2.7) is that the inductor is placed on the same side as the power supply of the switch. (Osmar, 2012) When the switch is closed, the power supply stores energy in the inductor but does not supply any energy to the load in the ON state. At this moment, the voltage across the inductor is equal to the voltage supplied to it. When the switch alters, the energy in the inductor tends to collapse, and the polarity changes. This results in that the energy in the inductor sums up with the supplied energy, giving it a boost and hence produces a larger output than the input. Energy stored in the inductor is still calculable with equation (2.4), and duty cycle for a boost converter is shown in equation (2.5);

$$D = 1 - \frac{V_{out} \times \eta}{V_{in}} \tag{2.5}$$

A better solution suggested to condition power is implementing buck-boost converter (Rodriguez, 2013). This type of converter combines the functions of its predecessors; to step up or step down a wide range of input voltage level to a fixed or any adjustable voltages. (Hemmo, 2013) Buck-boost converters are practical when input voltage varies below or above the desired output voltage. This is common especially in different kinds of portable equipment, for example, single lithium-battery discharges from 4.2V to 3.0V. Thus the system is not able to provide an output voltage of 3.3 V in all situations if a single buck or boost converter is used.

CHAPTER 3

METHODOLOGY

3.1. Power Requirement

3.1.1. Identifying Requirements

This part covers the study and analysis of MYSat top power requirement, mission type, spacecraft configuration, mission life and the definition of payload. These steps are important to acquire the design initial requirement and create a proper power profile. The most important requirements and necessary parameters are shown in Table 1.2 and Table 1.3 respectively. The information are for solar and battery sizing and design which is discussed in Chapter 3. The key is to ensure that based on these requirements, a suitable solar array and battery will be chosen to power up the EPS.

Table 1.2: MYSat top requirement

Daylight power requirement	3 Watt
Eclipse power requirement	3 Watt
Mission life	One year
Inherent degradation, Id	0.72
Sun incident angle	0.410152374 radians (23.5 degrees)

Table 1.3: Orbital parameters

Total orbit duration	5546 s
Daylight duration	3515.355 s
Eclipse duration	2032.645 s
Sun constant, Gs	1368 W/m2
Semi-major axis of orbit	6775 km
Earth radius	6378.14 km
Earth gravitational parameter (μ_E)	398600 km3/s2

3.1.2. Power Budget

The table below shows the power budget of MYSat. This table is created based on the requirement from all subsystem including its duty cycle and average power needed to power up the CubeSat. According to Table 1.4, the total power needed to deliver to the entire cubesat is 3.14 Watts, and it is estimated that it will use about 1.7 Watts on average. This also indicates that the power storage (batteries) capable of storing more than 3.14 W needs to be implemented. Besides that, the subsystem with the most required power is the communication. Therefore, it is wise to have large amount of power ready to allow transmission of data without interrupting power delivery to another payload.

Table 1.4: Power budget of MYSat

Subsystem	Component	Max Power (mW)	Orbit ON (%)	Time ON (s)	Avg. Power (mW)
OBDH	OBC	132	100.00%	5548	132
Power	EPS	215	100.00%	5548	215
Communication	Tx UHF	1500	9.00%	499.32	135
	Rx VHF	396	9.00%	499.32	35.64
Payload	Mnlp	900	100.00%	5548	900
ADCS	Magnetorquer	0	100.00%	5548	0
	Magnetometer	3	100.00%	5548	3
	Gyroscope	12	100.00%	5548	12
TOTAL		3143			1432.64
20% Margin					1719.168