Implementation of an Intelligent and Reliable Power Supply Management System of a Small Satellite

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Abstract

This paper presents the development of an important part of the first Pakistani student Satellite. It is aimed to complete this satellite within a span of five to ten years. The initiative towards the development of small Satellite was taken by the exhaustive research and analysis of Satellite Power Supply Management System. It was aimed to develop a highly reliable small satellite power management subsystem that will continue to provide maximum power to all its loads or subsystems efficiently even if the satellite is in eclipse. A thorough study of all the possible subsystem in a satellite is also covered with detail analysis and calculations.

Key words: Small satellite, Pakistani students, Power supply management system, MPPT

1. Introduction

In developing countries, very hard constraints and difficulties are imposed to students and researchers leading usually to inadequate pedagogic results, especially when attempting to learn and experiment complex modern systems. These constraints may stem from the lack of economical budgets, from a bureaucratic discouraging environment, from a mismatch between university and industry, etc.

This project deals with the designing, development, implementation , and testing of a power supply for the Small student satellite. It took almost one year to finish this project (November 2007 – January 2008). A satellite to be launched satellite will be located in a Low Earth Orbit (LEO) at a height of approximately 600 kilometers from the surface of the Earth.

Figure 1. Small Satellite Power Supply Management System

2. Small satellite

Satellites can operate in several types of Earth orbit. The most common orbits for environmental satellites are geostationary and polar. The other orbits are

1. Geostationary Orbit
2. Medium Earth Orbit
3. Low Earth Orbit

2.a Low Earth Orbit

Satellites in low earth orbit (LEO) orbit the earth at altitudes of less than 2000 km (1242 miles). [1] Satellites in LEO can get much clearer surveillance images and require much less power to transmit their data to the earth. The satellite which we are planning to build is also for a LEO Earth Orbit. The satellite will be placed on a circular Low Earth Orbit with the inclination of 96 degrees and height of approx. 600 km. Velocity of the satellite on orbit is estimated to be 27000 km/h. Based on these parameters, revolution time has been computed.

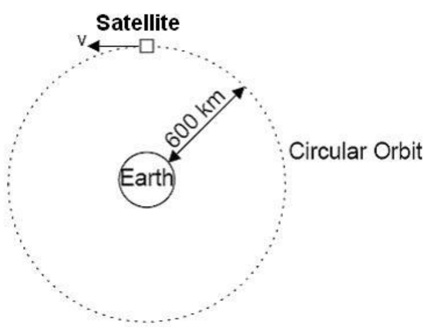


Figure 2 . Block Diagram of Satellite Power Management System

Time of orbit	*100 min*
Time in sun:	*65 min*
Time in eclipse	*35min*

Table 1 approximate calculated timings of satellite

3. Satellite Subsystems

The modern satellite is an extremely complicated piece of equipment composed of more than a half-dozen major subsystems and thousands of parts. Below is the list of the subsystems satellite.

1. Satellite structure.
2. Satellite power system.
3. Satellite Attitude Control System.
4. Satellite thermal control system.
5. Satellite propulsion system.
6. Satellite Onboard Computer and Data handling unit.
7. Satellite telemetry and Tele-command system.
8. Satellite Antenna and RF system.
9. Satellite earth station(s).

As part of the project all these subsystems were thoroughly researched and a complete report was written.

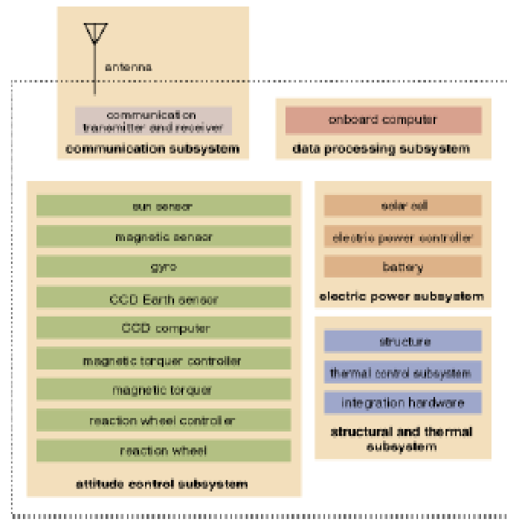


Figure 3 . Various Subsystems of the satellite

4. Design Requirements

The Requirements for the small satellite power supply subsystem set by the designers are usually the following [2]

1. To maximize the power available from the solar arrays.
2. To provide a high efficiency interface between the solar arrays and the rest of the spacecraft to minimize losses.
3. Include an integrated light weight (lithium ion) battery.
4. Provide common regulated voltages of 5V, 3.3V and other special required voltages so that it could be to be compatible with a multitude of mission profiles and be scalable in power handling capability.
5. Vying for a reduction in mass and more flexibility and modularity in the satellite make-up.
6. Provide a standard digital interface that can deliver telemetry and Telecommand functions for the power system.
8. Cost effective as well as better performance.

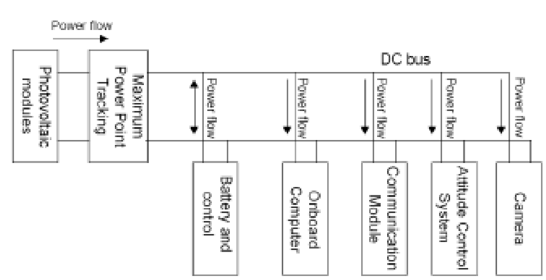


Figure 4 . Overview of the simplified satellite system

5. Existing Power Subsystem Sources

5.a Types of power sources

There are five types of power sources in use today:

1. **Solar cells** also denoted Photovoltaic (Silicon, Gallium-Arsenide)
2. **Secondary batteries (rechargeable)** – used as energy storage medium to supply power during eclipse or adverse pointing of the solar arrays.
3. **Primary batteries (non-rechargeable)** – used only on launchers and on small experimental missions with a lifetime of a few days.
4. **Fuel cells** – producing electricity by electrochemically “burning” oxygen and hydrogen to water. Used presently only on the Space Shuttle.
5. **Radioisotope Thermal Generators (RTG)** – using the heat produced by radioactive decay of Plutonium-238 to produce electricity via thermoelectrical cells. Used only on interplanetary missions to the outer planets. [8]

5.b Commonly deployed power subsystem implementation using photovoltaic

There are three most common power implementation approaches found on today’s small satellites [2] using photovoltaic. These power systems are as follows

1. Direct Energy Transfer (DET) with Battery Bus.
2. DET with Regulated Bus.
3. Maximum Power Point Tracker with Battery Bus.

5.c. Proposed Block diagram of the system

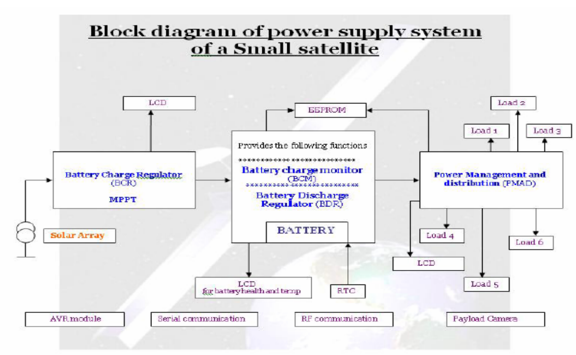


Figure 5 . Block diagram

6. Design of the power supply management subsystem

The Power Supply Management subsystem comprises of the Solar Array, Battery Management module , and Power Distribution module for all its loads. [125]

The solar array is a prime source of energy on the satellite and to accumulate voltages and store this to multiple backup battery banks. This power system architecture incorporates a Maximum Power Point Tracking System (MPPT) algorithm between the solar array and the battery. The power distribution module is responsible for providing required power efficiently with the aid of voltage converters to all the subsystems and load attached for any procedural work. The report includes complete research over a LEO based satellite and hardware used for Power Supply Management System module implementation.

6.a Battery Management module

The battery management module is concerned mainly with the charging, discharging and of the batteries and telling the levels of the voltage a certain battery has. This module is also responsible for switching to battery banks if the power from solar cells is not adequate to run the system. There are two main power batteries in the system, one is the backup battery and can be used if the first battery goes out of order. There is one other battery in the system that is used to provide the reference voltage for the system and is responsible to run the system if the power is at a very critical level and helps in running the most important parts of the satellite. DC –DC converters for supplying power to the system is also included in this module. For this module and achieving these purposes several circuits were developed

- **Graphical LCD**
- **Charge monitoring circuit for Battery**
- **Current sensor:**
- **Analog to Digital converter ADC0804**
- **8 channel Analog to Digital converter**
- **Charge controller + battery**

The heart of this system is the Charge controller; it is controlled by 8051 and employs 3 relays and comparators. When the adequate power from the solar cells is unavailable, it switches to the Battery and provides the power from the battery to the whole system. Also it charges the battery to its maximum and disconnects the battery if its below a certain set voltage level while supplying the power to the whole system and switches to the other battery. When the adequate power from the solar cells is available, it helps in switches back to the solar cell and provides the power from the solar cells to the whole system.

6.b Maximum Power Point Tracking

Maximum power point tracking (MPPTs) is a system which plays an important role in photovoltaic (PV) power systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency. It may be an analogue circuit, a digital circuit or a microprocessor controlled converter.

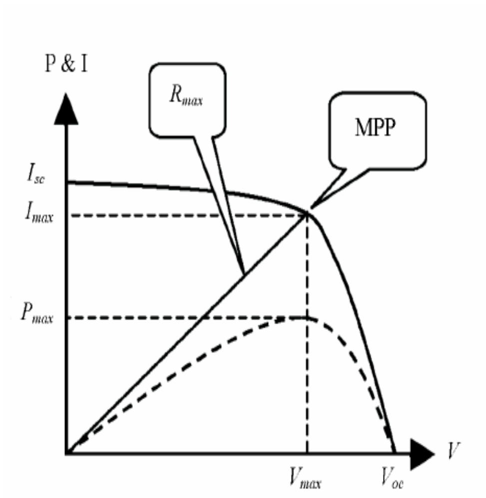


Figure 6 . V-I characteristic of a solar cell.

In the case of a solar array power source of the small satellite , the maximum power point varies as a result of changes in its electrical characteristics which in turn are functions of insolation, temperature and aging. Thus, an MPPT can minimize the overall system cost. MPPTs find and maintain operation at the maximum power point, using an MPPT algorithm.

The building block of PV arrays is the solar cell, which is basically a p-n semiconductor junction, shown in Figure 1. The V-I characteristic of a solar array is given by Eq. (1).

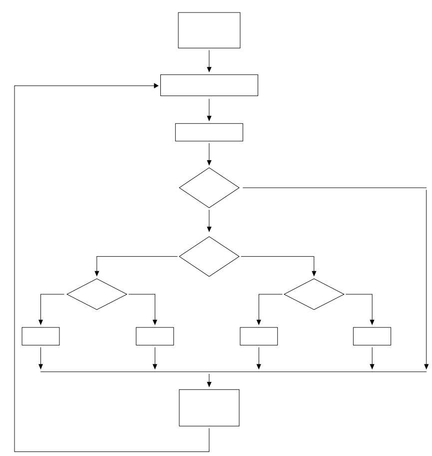
$$I = I_{SC} - I_O \left\{ \exp\left[\frac{q(V + R_S I)}{nkT_k} \right] - 1 \right\} - \frac{V + R_S I}{R_{sh}} \quad (1)$$

There are many different forms of MPPT implementations but there are two main classes:

(1) The Perturbation and Observation method (P & O Method)
(2) The Incremental Conductance method.

In addition there are other lesser known variations such as [4]

1. Voltage feedback method.
2. Neural network method.
3. Curve fitting method.
4. Load matching method.



Flow chart 1:
Implementation of P&O MPPT algorithm

We implemented the P& O MPPT algorithm to get the maximum power output from the solar cell. The advantages of this method are that it is relatively easy to implement, without the need of prior knowledge of parameters and is less influenced by the intrinsic capacitance of the solar array.

6 c. Power distribution module

Power distribution unit is developed to simulate the various loads that a satellite could have. It is responsible for running the important loads and turning the other loads off if the power is low in the system. [5] It turns on the system later when the satellite goes out of the power critical situation (eclipse). The loads that have been simulated are

o Stepper motor 1 (8051)
o Stepper motor 2 (Controlled with/without a controller)
o DC motor 1 controlled by a H bridge (Relay based circuit)
o DC motor 2 controlled by a H bridge (Relay based circuit)
o A H bridge (Transistor based) using power transistors using TIP142 and TIP 147 has been used to control another DC motors
o Solenoid Control board has also been developed to control solenoids usually found in the propulsion subsystem.

These six loads are turned ON or OFF according to the power requirement of the system.

There are some other circuits that have been developed to support this system.

- Analog to Digital converter ADC0804
- 8 channel Analog to Digital converter
- Protection Circuit
- Generic board
- Real Time Clock:
- AVR board
- Additional circuits

1. Radio Frequency module for data transfer (would simulate TTC Subsystem)
2. Camera (As pay load of the subsystem

DC-DC converters

DC-DC converters are electronic devices used whenever we want to change DC electrical power efficiently from one voltage level to another. They are needed because unlike AC, DC can't simply be stepped up or down using transformer. [6] In many ways, a DC-DC converter is the DC equivalent of a transformer. There are many different types of DC-DC converter, we have used buck as well as boost converters for power distribution. Also Buck Boost converters for MPPT have been used.

6.d Electronic Loads

Several Electronic loads such as stepper motors, dc motors, contactors, solenoid valves, camera which are typical electronic loads of the satellite have been attached with the system to monitor the system response.

7. Future work

The different parts of the power management unit which we think need some improvement are

i. Solar cells:
Power supply management system must be tested on the real cells that are used in satellite.

ii. The subsystems:
If possible; most of them should be coupled directly on the battery bus; to avoid the use of semiconductors as the probability of failure is higher. This means that they must be able to use an unregulated power source. Each subsystem must be equipped with an enable pin with true shut-down.

iii. DC/DC and DPS:
Supply every subsystem with two DC/DC converters in parallel to create redundancy and to make the stress on each converter smaller. [7] If the same voltage divider is used on the converter the output voltage will be equal hence the load placed on each converter.

iv. EMC
Measurement by using spectrum analyzer on our board must be performed.

v. MCU
Tests of the communication with OBC must be performed. Tests on the more efficient solar cells must be done to test the MPPT control signal. AVR microcontroller must be used throughout.

vi. Analog part of the PSU
In order to verify well-functioning of all the modules and to prove the accuracy of the design, further separate experimental tests for each circuit must be performed. After that a general test must be made for proving expected behavior.

vii. I2C must be implemented

vii . Simulators
With respect to the design work done so far its necessary that more tests on components and circuits be performed using the simulators such as PSPICE, Electronic Workbench, Saber, ANSYS and solar simulators to make the system more reliable and

efficient. Simulation must be done for testing the various parts of the Power supply system such as 2D and 3D model for Thermal analysis

8. Conclusion

There are many unknown factors that can't be tested on earth. One of those is how efficient the solar cell really is in space. Another factor is how well the stabilization systems will work, and how this will affect the energy from the cells and how efficiently batteries would work. The temperature on the cells is also an important factor that can't be tested property on earth. Therefore solution to it has to be found.

During this satellite project the Power supply and power management system has been designed, produced and tested. The power supply system consists of different parts. One solar cell of rating 20W is used. A battery package and a microcontroller that handles the housekeeping data and controls the subsystem is placed in the prototype of the satellite. We faced heavy difficulties in the project due to the lack of information about the technical details of the satellite and heavy cost involved in developing reliable power supply using satellite graded components.

A detailed study of the various subsystems of the satellite was also done. It could help the other groups working on the other subsystems of the project tremendously; we have collected this information over a period of more than 8 months.

9. Acknowledgement

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References

[1] Power Supply Unit for the AAU-Cubesat Institute of Electronic Systems University of Aalborg 01GR509 December 20, 2001

[2] POWER SYSTEM CHALLENGES FOR SMALL SATELLITE MISSIONS Craig S. Clark, Alejandro Lopez Mazarias Clyde Space Ltd., 6.01 Kelvin Campus, West of Scotland Science Park, Glasgow G20 0SP Scotland,

[3] Tsinghua-1 Micro-satellite Power System Architecture and Design, Wu Zhifei(%%R4E), You Zheng(%@), jbr8me Salvignol, Space Center, Tsinghua University, Beijhg, China, Surrey Space Center, University of Surrey, Guildford, Surrey GU2 5XH, UK

[4] Intelligent and Reliable Power Supply System for Small Satellites, B.L. Tan' and K.J. Tseng', Senior Member IEEE 'Satellite Engineering Centre, Nanyang Technological University 'Centre for Advanced Power Electronics, Nanyang Technological University Blk S2, Nanyang Avenue, Singapore 639798, Republic of Singapore

[5] Plug-n-Play, Reliable Power Systems for Nanosatellites Craig S. Clark and Alejandro Lopez Clyde Space Limited, 6.01 Kelvin Campus, West of Scotland Science Park, Glasgow G20 0SP, Scotland. +44 (0)141 946 4440 craig.clark@clyde-space.com,

[6] Jaycar Electronics Reference Data Sheet: Dc Dc converters Pdf (1)

[7] nCube - Power supply, Narvik University College

[8] Spacecraft Solar Array Technology Trends
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