

Design and Implementation of Effective Electrical Power System for Surya Satellite-1

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Abstract. Surya Satellite-1 is a nanosatellite developed by students of Surya University. The subject of this paper is the design and implementation of effective electrical power system for Surya Satellite 1. The electrical power system role is to supply other systems of the satellite with appropriate electrical power. First, the requirements of the electrical power system are defined. The architecture of the electrical power system is then designed to build the prototype. The orbit simulation is calculated to predict the power production. When prototype test and simulation data is gained, we make an operation scenario to keep the produced power and the consumed power in balance. The design of the modules of the electrical power system is carried out with triple junction solar cells, lithium ion batteries, maximum power point trackers, charging controllers, power distributions, and protection systems. Finally, the prototypes of the electrical power system are presented.

1. Introduction

Nanosatellite has emerged as a popular platform among academic and industrial space communities. They need less cost and time to develop than traditional and sophisticated satellites but can perform space technology demonstrations. The miniaturization of satellite technology allows the increase of interest among space communities to develop small spacecraft missions based on CubeSat standards [1]. The major challenge of designing nanosatellite are the limitation in volume, mass, and power available.

Surya Satellite-1, that commonly abbreviated as SS-1, is the first nanosatellite developed by undergraduate students and to be launched by Indonesia. This 1-unit CubeSat carried automated package reporting system (APRS) communication mission run on amateur radio bands. The use of APRS SS-1 are transmitting and repeating telemetry data from satellite and remote area to the ground station and amateur radio users.

This paper describes the electrical power system (EPS) built for SS-1 to provide the power to conduct the mission, how the design, the power produced, and the operation usage [2]. The EPS harvests energy from sun by solar panels, stores it in the batteries, and distributes to the subsystems specifically and safely. The challenge of the EPS design is to provide reliable power with the strict limitation of mass and volume available in 1U that is around 1.3 kg and 1 liter for the rest of the subsystem. Then the



amount of energy harvested is limited and so the storage size. The additional challenge is the lack of attitude control so SS-1 has a spinning rate that limit the power harvested from its body mounted solar panels. The satellite operation must consider the energy balance since it has eclipse phase and the dynamic demands of power.

Because the commercial CubeSat modules are yet rare and costly, the subsystem modules of SS-1 are mainly self-developed. The goal of developing the EPS is to demonstrate the reliable system but cost-effective constructed from commercially of the shelf (COTS) components to operate at the required conditions.

2. Requirements of the electrical power system

2.1. Space Environment

SS-1 is expected to orbit at low earth orbit (LEO) with the altitude at 400 km and inclination at 51.6 degree. In this environment the orbit duration is around 90 minutes with the 1/3 is in eclipse and 2/3 of it is in daylight. Then the temperature range within the orbit is around -20°C to 60°C. During the daylight, the solar panels harvest energy to be used by the subsystems and stored the excess. As the hot environment, the components selected must be survive and operate normally. During the eclipse, the temperature will be cold and there is no power harvested from solar panels. Lithium ion battery is the component that could not operate in the cold environment so that the battery temperature need to be maintained above 0°C by active thermal control.

Deployed from the ISS, the expected lifetime of the CubeSat is predicted to be 16 months according to the simulation with Jacchia Roberts atmospheric model. Then the batteries depth of discharge (DOD) need to be maintained to operate at 10% of the actual capacity to attain charge-discharge cycle till the end of life (EOL). Then the sizing of the battery capacity can be calculated.

2.2. Functional

The EPS should effectively be designed for the operational need of the other subsystems. EPS duties are to generate power from sun illumination by solar panels, harvest energy efficiently by maximum power point tracker (MPPT), store the energy for eclipse and peak demand use, distribute the power effectively to the loads, and provide protection systems for the components.

The subsystems are mainly operating at 5.0V but the communication module is operating between 3.5V to 4.5V. Then the power sources are designed to operate at the required bus voltage. The 5V bus regulated by a boost converter. And the communication module uses unregulated bus directly from the batteries. That is why the lithium ion battery is chosen because the nominal operating voltage is between 3.6V to 4.1V so there is no dissipated power from the dc-dc converter.

The solar panels are also designed to be suitable for the power demand. Each side of the body is installed two cells of triple-junction GaAs with 1.2W 2.4V connected in parallel. Then the power is harvested with MPPT that works as boost converter, so the voltage is high enough be used by charging controller to charge the lithium ion batteries.

The EPS should be equipped with protection system from reverse current, over-charge and deep-discharge, overcurrent, over and under temperature [3].

2.3. Power budgets

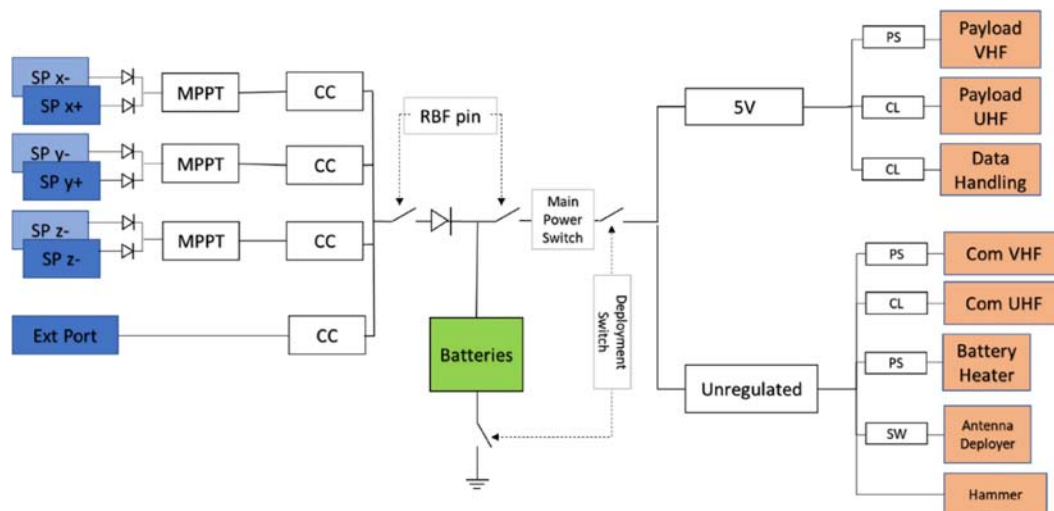
EPS responsible to provide the required electric power to entire the CubeSat system. There are the power required by the subsystems.

Table 1. Power Budgets of SS-1.

Subsystem	Peak Power (mW)	Standby Power (mW)	Power Bus
COM VHF	3000	240	Unregulated
Payload VHF	400	250	5V
COM UHF	3000	240	Unregulated
Payload UHF	400	250	5V
Heater	3000	0	Unregulated
Data Handling		40	5V

3. Design of electrical power system architecture

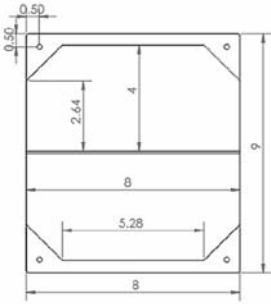
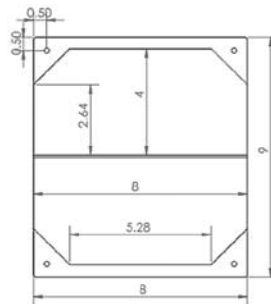
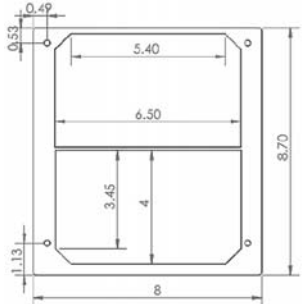
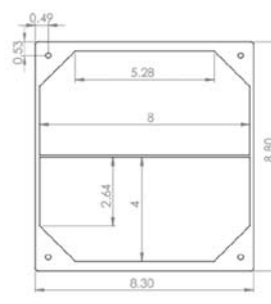
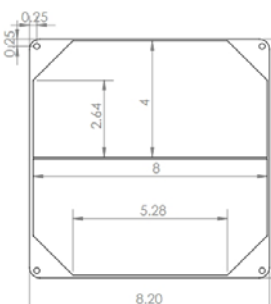
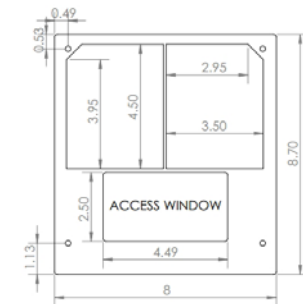
The EPS architecture design consist of three separate functional blocks: energy harvesting, energy storage, and power distribution. The voltage on the main power switch (MPS) is unregulated, normally 3.6 to 4.2 V, staying on the same voltage level as the battery cells. This architecture was chosen to minimize the need for voltage conversion steps for battery charging and discharging, therefore increasing efficiency. This architecture is also popular among other CubeSats with MPPT system, because it is very efficient. This configuration also allows battery cells to work as voltage stabilizers, reducing noise on the main power bus and therefore in the whole system.

**Figure 1.** The Block Diagram of EPS Design for SS-1.

3.1. Energy Source (Solar cells)

The energy harvesting subsystem of the EPS collects energy from 12 solar cells. Cells are placed pairwise on all of the 6 sides of the satellite. In this configuration only three sides of the satellite can be in direct sunlight at any given time, meaning that only the cells on those sides produce power.

Table 2. The specified design of solar panels.

Side	X+	X-	Y+
Area	2 x (4cm x 8cm)	2 x (4cm x 8cm)	2 x (4cm x 6cm)
Pmax (W)	2.432	2.432	2.071
Layout			
Side	Z+	Z-	Y-
Area	2 x (4cm x 8cm)	2 x (4cm x 8cm)	2 x (3cm x 4cm)
Pmax (W)	2.432	2.432	1.257
Layout			

3.2. Power Harvesting (Maximum power point trackers)

The most effective way of collecting energy from the solar cells is by using maximum power point tracking. Due to the placement of the solar cells, the satellite needs to track only three power points at any given moment in time and therefore three separate MPPT systems were planned for the EPS. In the final design, SPV1040 maximum power point tracking chips from STMicroelectronics were used. These chips were originally meant for battery charging and regulate their output voltage to match the effective input resistance of consumers with the optimal consumer resistance, corresponding to the maximum power point of the solar cells, making them ideal for the chosen power topology. The chips only work in boost mode, meaning that the solar cells had to be placed in parallel [4], which in turn creates relatively large currents and low voltages, making voltage drops on components an issue. To get around this problem, an ideal diode system was used, consisting of MOSFETs driven by LTC4415 ideal diode controllers from Linear Technology.

3.3. *Energy Storage (Lithium-Ion Batteries)*

For energy storage, lithium ion batteries were chosen because the higher energy density among the other type of batteries [5] [6]. NCR18650B cylindrical lithium ion battery cells were used with nominal capacity of 3200 mAh. There are three cells of batteries connected in parallel therefore the capacity is summed but the voltage remains the same as single cell. This simplified the bus voltage and charging system because the parallel connected batteries can balance each other without any balancer circuits needed.

3.4. *Charger controllers*

To protect battery cells and to provide suitable charging requirements, EPS is equipped with independent battery charger controller circuits, which allow to protect the cells from overvoltage, overcurrent, and charging outside the safe temperatures. The system was implemented through L6924D charger controller that allow input power to be turned off when the battery is fully charged. As an extra layer of protection, the temperature the batteries cells are constantly monitored. In case of battery temperature exceeding 60°C or dropped below 0°C charging will be turned off.

3.5. *Power distribution*

The power distribution subsystem uses the energy, harvested from the solar cells and stored in the battery cells, to power all of the subsystems. To do this, switching regulators and control circuits were used. For powering the other subsystems per requirements, it was decided to create two voltage buses within the EPS those are 5V bus and unregulated bus. The 5V bus is regulated by boost converter and the unregulated bus is directly taken from the battery voltage.

3.6. *Protections*

Safety requirements are needed to be implemented on EPS before and while in operation use. Before the operational use, there are two levels of protection to prevent the satellite turned on until deployed into orbit. The first level is the remove before flight (RBF) pin that disconnect the power harvester, storage, and subsystems until been pulled out by astronaut after the satellite has placed in JSSOD [7]. The second level is the deployment switch that disconnect the loads from the power source at both vcc and gnd.

While the satellites are operational, the loads need to be protected from fault such as in rush and over-current by current limiter. For additional protection, there is a hammer system that periodically reboot the entire system in case there are any error or lagging on microcontroller devices that can't be solved from the ground.

4. **Power Production**

4.1. *Power harvested*

Power production came from the harvested energy from the solar panels. As the satellite is spinning and has the daylight-eclipse cycle, then the power produced of the panels in an orbit be like the following graph that came from the orbital simulation. The simulation parameters set at solar irradiance of 1366 W/m² under AM-0 condition at the beginning of life (BOL) that the solar cells efficiency remain 30%.

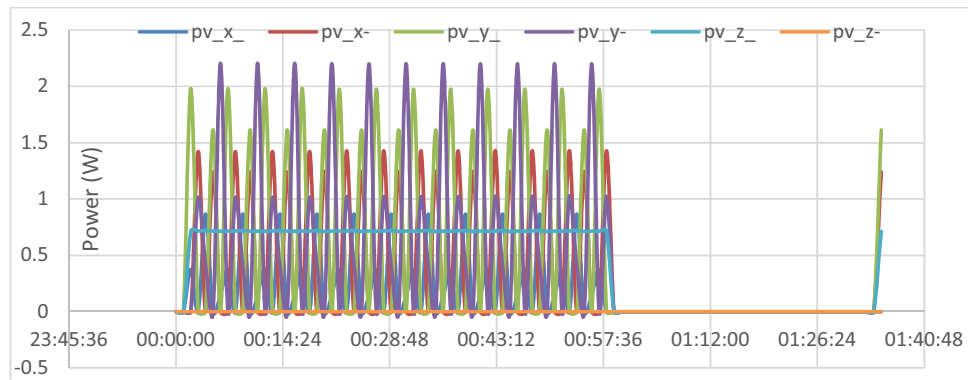


Figure 2. The solar power production in one orbit.

By calculating the sort of data repetition and considering the degradation of solar cells, then the power produced at EOL is summarized as the table below. The average power produced by solar cells during daylight is 2.844 W.

Table 3. Solar power production at end of life.

Average	Energy (J)	Duration (s)	Power (W)
Orbit Cycle	9609.13	5490	1.750
Daylight	9544.38	3356	2.844
Eclipse	0	2134	0

4.2. Efficiencies

The distributed power to the subsystems were dissipated during the conversion. Because the power converters have efficiencies when performing their duties. The EPS efficiency is the product of each converter efficiencies.

Table 4. Efficiencies of power converters.

Converter	Efficiency (%)
MPPT	0.95
Charger	0.95
Boost	0.90
EPS	0.81

Based on the average power production and the EPS efficiency, the calculated power distributed to the subsystem are the product of both value, that is 2.310 W.

5. Operation Strategy

5.1. Energy balance

The average power of the communication and payload subsystem that conduct the mission plan have calculated to be 1.47 W. Then the energy balance can be explained by the following table. The balance has deficit of 1101.5 J of energy in every orbit.

Table 5. Power balance in one orbit cycle.

Load	Demand			Supply			Balance of energy (J)
	Average Power (W)	Duration (s)	Energy (J)	Average Power (W)	Duration (s)	Energy (J)	
Com + Payload	1.47	5490.00	8042.85	2.31	3356.00	7752.42	-290.43
Heater	3.00	200.00	600.00				-600.00
Microcontroller	0.04	200.00	8.00				-8.00
Hammer	0.04	5490.00	203.13				-203.13
Total			8853.98			7752.42	-1101.56

5.2. Scenario

The deficit of energy balance can be overcome by the operation strategy. The simplest strategy is to hibernate the satellite periodically to perform exclusive charging. The sum of deficit orbits can be overcome by once hibernation as the simulation table below.

Table 6. Simulation of deficits and hibernation orbits.

Number of orbit	Deficit of Energy (J)	Charged Energy (J)	Energy balance (J)
1	-1101.56	7752.42	6650.87
2	-2203.11	7752.42	5549.31
3	-3304.67	7752.42	4447.76
4	-4406.22	7752.42	3346.20
5	-5507.78	7752.42	2244.65
6	-6609.33	7752.42	1143.09
7	-7710.89	7752.42	41.53
8	-8812.45	7752.42	-1060.02
maximum number of orbit before hibernation orbit			7

The satellite should be hibernated once in every seven orbits to keep the balance between energy produced and demanded.

6. Conclusion

The requirements and design of the electrical power system for the Surya Satellite-1 has been implemented. The EPS can supply reliable power production for the satellite with module built from commercially of the shelf components. The design has satisfied the requirements of environment, functional, and power demand. The solar power can be harvested by 95% efficiency and the total efficiency of module is 81%. To achieve the balance between supply and demand the operation strategy is implemented.

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