Electric Power System for ISTnanosat-1
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Abstract — This paper describes the design process for Electric Power System (EPS) of a Nanosatellite. The EPS aims to make the collection of solar energy in space environment and perform the correct storage in internal battery. The energy collected is converted into regulated power supplies 3.3 V, 5 V and 12 V for use across the Nanosatellite. The EPS must meet space and performance requirements of Cubesat architecture, using DC / DC converters to perform the power supply regulation in high yield, making the performance recording and correcting the faults.

Index terms – Electric Power System, Nanosatellite, Cubesat, DC/DC converters.

I. INTRODUCTION

With the development of space technology and amateur radio communications made possible the release of amateur satellites of small dimensions, with the first amateur satellite OSCAR-1, launched on 12 December 1961, the possibility of collaboration was established in scientific projects among amateur builders of satellites and government companies to launch satellites.

The success spurred the emergence of various experiences in the development of amateur satellites design and numerous features, which raised the need for standardization, originating in 1999, the appearance of the CubeSat project at California Polytechnic State University, which proposes a universal design based on a cube of 10 cm edge. This initiative was success in amateur satellites[1].

Since the first launch of the first CubeSat in 2003 were launched more than 75 projects using CubeSat architecture by 2012[2]. Initially the nanosatellites were only aimed for the development of flight systems of control, power and design of the structure for CubeSat. The second phase was followed by nanosatellites projects with space reserved for scientific experiments and measurements in orbit.

The project of a NanoSat is divided into subsystems, namely the Attitude Determination and Control System (ADCS) which is responsible for determining in real time position and satellite framework with the Earth; Electric Power System (EPS) whose mission is to collect energy supplied by solar panels, battery management and distribution of a regulated power throughout the system; Communications (COM) which is the system responsible for all digital communications between the satellite and the ground stations; Command and Data Handling (CDH) that performs the processing of data provided by the on-board components, the responsibility to maintain the proper functioning of the satellite; Housing which is the host of all nanosatellites, which makes communication and control between the other subsystems.

These subsystems perform full control of the nanosatellite which may include a placeholder to a scientific experiment called payload.

This paper have design choose to electric circuit use in EPS divide in four sections: the converters use to regulated power supply collected by solar panels, the architecture used to distribute or store the energy collected in the battery, the power distribution module that converter energy in regulated outputs use for power in all Nanosat and the section devoted to the microcontroller used to collect measurements and carry out the monitoring of all EPS.

II. TECHNOLOGY STUDIED

For the development of EPS was studied the existing alternatives on the market and used architectures in satellites over time. Typically EPS has at least one outer power collection circuit using solar panels and a circuit to generate the regulated power outlets (Power Distribution Module – PDM). Because of changing in batteries began to have circuit dedicated to their loading and with the emergence of low-power microcontrollers led to use in the EPS so that it can be applied independent control of energy and application of more complex management algorithms so to increase the EPS performance in relation to energy collected and provided for use in Nanosat. The first step is to analyze the energy collectors in order to find the architecture that gets the best performance for EPS.

A. Solar Panels

A stand-alone system there must be way to collect energy and because of the great sun exposure from an orbiting satellite, solar panels benefit from satellite altitude where there is less atmospheric attenuation of solar radiation making the best solution. Existing solar panels using the triple junction cells ensure the best performance, because using a junction GaInP/GaAs/Ge is absorbed throughout the visible spectrum of light, figure 1 [4][5].
A solar panel can be demonstrated by the equivalent circuit of figure 2 [4].

For a solar panel has a performance shown in Figure 3, where the MPP point corresponds to the maximum power point provided by a panel [4].

The DET select the solar cells with the higher current and that is at the same voltage level, used to charge the battery or power the PMD.

This solution does not provide great savings in space and weight due to the direct coupling of the cells, using switches to determine the amount of current to be supplied to the system by adding the cells in operation. It is solution only works for battery on which a regulated load is not necessary to not to damage the battery, and would require cutting the panels when the battery is not charging temperature, decreasing the efficiency in the assembly.

C. Direct Energy Transfer with Regulated Bus

The DET with regulated bus uses the same S3R system to select solar cells, but has the particularity of implementing a charging/discharge controlled system on the battery (BCDR), figure 5 [3][6].

This mounting charges the battery without damage and get the most out of the energy collected by the solar cells, because the BCDR perform the correct charging the battery, removing the existing limitations of energy gathered in DET.

The biggest problem is the existing losses associated with the BCDR in the phase of battery discharge.

D. Maximum Power Point Tracker with regulated bus

Using a Battery Charge Regulator in the output of each solar panel is fixed with a bus operating voltage in two different operating modes. While the battery does not contain full charge, the panels provide power to the PMD and using the Battery Charge Monitor (BCM) the load is monitored in several battery cells up to the maximum load value.

When the battery reached end of charge (EOC) the MPPT determining the bus at EOC voltage level, causing the current course to the battery change to slow charge level, figure 6 [3][6].
This assembly has the advantage in battery discharge time is effected directly onto the PDM, without having the losses of the DET with the regulated bus.

The existing disadvantage with the use of a MPPT not controlled is that, in times of sun exposure, the point of MPPT will vary due to the angle of incidence of solar energy and the variation of the solar panel temperature.

**E. Maximum Power Point Tracker with microcontroller**

Due to the evolution of technology, the use of a microcontroller solely dedicated to EPS [3][6] became viable, allowing implement a specific control and releasing other systems of having to monitor the EPS, figure 7.

![Figure 7](image)

**Figure 7. Maximum Power Point Tracker with regulated bus controlled by a microcontroller [3][6].**

With the use of a processor to control the BCRs in solar panels it is possible to counteract the MPPT variations due to temperature and angle of incidence, increasing the efficiency in collecting energy.

**F. Power Distribution Module**

The power distribution module aims to generate regulated outputs of 3.3 V, 5 V and 12 V and can be powered from 3 V to 11 V. To generate the outputs it’s used DC/DC converters [8][9] architecture with is used boost converter for 12 V, figure 8.

![Figure 8](image)

**Figure 8. DC/DC boost converter.**

To generate 3.3 V and 5 V is necessary to use an buck-boost converter [8][9] with four switches so that all outputs have the same ground reference, figure 9.

![Figure 9](image)

**Figure 9. DC/DC buck-boost converter with four switches.**

Instead of the buck-boost converter with four switches can be used one singled-ended primary-inductor converter (SEPIC) [8][9] which has the advantage of using only one switch for controlling the converter, figure 10.

![Figure 10](image)

**Figure 10. DC/DC SEPIC converter.**

**III. ARCHITECTURE**

The implementation of the architecture to be used in EPS is necessary to take into account the restrictions existing for maximum dimension, figure 11.

![Figure 11](image)

**Figure 11. Maximum physical dimensions of the EPS.**

The architecture implemented in EPS is based on Direct Energy Transfer system with regulated bus and the Maximum Power Point Tracker controlled system. Similar to most of existing architectures, EPS has an input block which serves to regulate the voltage from the solar panels, a bus intended for energy storage in a battery and finally the block used to generate the regulated output voltages used to feed the other subsystems of Nanosat, figure 12.

![Figure 12](image)

**Figure 12. Global block diagram for EPS.**

The advantage of using this assembly is that by using the input block to make the most of the energy collected by solar panels, using to charge the battery or power the PMD. It was chosen to use a microcontroller to minimize dependence of others Nanosat systems, to draw up a pretreatment of the data
collected by the sensors of EPS plate and using Extremum Seeking Control algorithm [10][11] to take the full advantage of solar panels.

IV. Section 1 – Entry Block

The electronic circuit used in the input block uses an MPPT block for every two solar panels on opposite sides of Nanosat, figure 13.

Because it is necessary a level of voltage higher than the maximum provided by the panel, all outputs of the panels are regulated for the same voltage using a boost converter control by the microcontroller, figure 14.

Through input and output reading power in the converter is desired to use the MPPT algorithm in commutation control signal (PWM B1) to obtain the best performance of the solar panel. When feeding the battery charger is necessary that the converter can get between 8.5 V and 11 V output to ensure proper operation, figure 15.

Table 1 – Solar panel electric characteristics.

<table>
<thead>
<tr>
<th>Description</th>
<th>BOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average voltage in open circuit</td>
<td>5380 mV</td>
</tr>
<tr>
<td>Average current in short circuit</td>
<td>519.6 mA</td>
</tr>
<tr>
<td>Current in MPP</td>
<td>4818 mV</td>
</tr>
<tr>
<td>Voltage in MPP</td>
<td>502.9 mA</td>
</tr>
<tr>
<td>Power in PMP</td>
<td>2423 mW</td>
</tr>
<tr>
<td>Average efficiency</td>
<td>29.3%</td>
</tr>
</tbody>
</table>

Each solar panel consists of two triple-junction cells, from Azurspace, in serially assembled which has the characteristics in beginning of live (BOL) shown on Table 1.

Figure 13. Electronics scheme for section 1.

Figure 14. Electronics circuit for the boost converter.

Figure 15. CH1 output of boost converter, CH2 PWM B1 signal, input in the converter 4.5 V.

V. Section 2 – Bus and Battery Charger

Section 2 has a battery charger and a multiplex assembly to making the power selection for PMD supply between the battery or regulated bus, figure 16.

The battery selected for use in the EPS was two cells of crystals lithium ion model of 3.7 V using in series. The battery provides 1300 mA storage with voltage of 7.4 V for the output which decays during discharge to the cutoff voltage of 6 V, table 2.

Table 2 – Battery electric characteristics using two cells.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Voltage</td>
<td>7.4 V</td>
</tr>
<tr>
<td>Capacity</td>
<td>1300 mA</td>
</tr>
<tr>
<td>Load operating temperature</td>
<td>0°C a 45°C</td>
</tr>
<tr>
<td>Discharge operating temperature</td>
<td>-20°C a 60°C</td>
</tr>
<tr>
<td>Dimensions</td>
<td>71 mm x 62.5 mm</td>
</tr>
<tr>
<td>Height</td>
<td>5.2mm</td>
</tr>
<tr>
<td>Weight</td>
<td>42 g</td>
</tr>
</tbody>
</table>

Due to charging the lithium battery is necessary to regulate a constant charging current to prevent damage, it is used MCP73213 to monitor and ensure proper battery charging.

To select the power of the PDM is used an assembly using mosfet pmos controlled by an analog mux that if the microcontroller is not running has selected as the bus to power the PDM, figure 17.
One of the project's basic requirements was to delineate three outputs regulated to power the ISTnanosat-1 with 3.3 V, 5 V and 12 V. Another requirement was to ensure that there is an alternative way to ensure output generation for 3.3 V and 5 V in case of failure of one or two main converters.

To ensure, in case of failure of the primary converters of 3.3 V or 5 V, were placed two reserve converters, which are dependent on the operation of output of the higher voltage converter to generate the desired regulated output. Since the power of the three primary converters may vary as a rule between 2.5 V and 10 V, it is necessary to use two buck-boost converter using four switches, used instead assembly SEPIC to generate 3.3 V and 5 V outputs.

Since it is necessary to use four control signals for the buck-boost converter using four switches, used instead assembly SEPIC to generate 3.3 V and 5 V outputs.

Was necessary for the regulated power supplies to function even without the microcontroller being active, for this reason it was decided to use independent commutated converters controllers to generate de 12 V output and for the reserve converters that can be deactivated by the microcontroller.

Due to the DC/DC SEPIC does not work without the switched signal from the microcontroller, when it is not running the 12V converter is still active and the two reserve converters start operation using the architecture of Figure 18.

The boost converter to 12V was selected TPS553300 model, from Texas Instruments, that operates with power between 3 V and 11 V and has a working power range of 4 W. In the case of reserve converters is used the buck converter topology with TPS62163 to converting 12 V to 5 V and TPS62091 converting 5V to 3.3V. Both have a 4W power range. The SEPIC were sized to be equal, but after the first test has placed one SEPIC using coupled inductor with 39 μH and another with 68 μH to perform the comparison of performance. All converters have been tested performing a sweep in power supply and the output power provided to determine the conversion efficiency.

In the case of SEPIC converters and the 12 V boost converter the results are in figure 19, using each converter with 1.2 W in output.

The second test has using the sweep in the output power (P_{out}) with the supply power to SEPIC been been 9.5 V.

In both test revealed that the efficiency of the converter using the inductor 68 μH is higher than 39 μH, although the model used 68 μH has a high fluctuation in inductance with increasing current flow in the inductor, leaving a behavior similar to 39 μH model where higher consumption.

For the boost converter has use the same test, figure 21.
For the two reserve converters the expected change in the input is low due to being powered by the regulated outputs. Two yield test was conducted in TPS62163 with varying the power converter operates at an output power of 1.2 W and another varying the output consumer with a 12 V power supply, figure 21.

The same two tests previous were used in TPS62091, one using a variation in power supply keeping the output consumption in 1.2 W and another test is making a variation in the output power consumption remaining the power supply at 5 V, figure 22.

As expected due to all converters are designed to operate up to 4 W yield falls when the consumption is less than 200 mW.

SECTION 4 – MICROCONTROLLER BLOCK

The fourth section is the block where put the microcontroller, the circuits used for the selection of measures to be acquired by the microcontroller and the only power supply used by this block. The idea established on using an independent source for the 3.3 V to power the microcontroller and the sensors in the system is to isolate the maximum EPS control block, figure 23.

The TPS62172 converter used buck topology, starting to work at 3.5 V up to 11 V with a maximum power output of 1.5 W, in testing the operation yield is high, figure 24.

Section 4 uses two mux to connect current and voltage sensors placed in the EPS to the microcontroller which uses internal analog to digital converter for acquiring the value of a point and thus can corrected the performance of the EPS.

VIII. CONCLUSION AND FUTURE WORK

At the end of the development of the first prototype for the EPS board can determine that several of the solutions developed during the project resulted. The circuit used in section 1 can operates using the boost converter, although they have only been used ideal sources for testing, which can force to be re-projected to ensure high efficiency with solar panels. The positive result of using the boost converter is that it allows to feed the output circuit directly from the solar panels, in case of the microcontroller is not in operation.

Section 2 found two solutions to the battery charger with 1 did not result and the MCP73213 solution yet to be tested. The use of MOSFET-p switches shown to be an assembly which adds quality in terms of performance and in case of being necessary to allow expanding the assembly for use with more switching points, which is necessary in case of using a second expansion card EPS.

The development section 3, with the results obtained using of the SEPIC converter architecture prove to be the most efficient solution in terms of performance over the occupied area, in addition to allowing disconnect feeds generated by SEPIC converters. The TPS55330 converter also results within the expected proving to be a solution for use in the end plate. The biggest problem was not possible to use the converter section 3 all together to determine whether the best
solution in terms of performed, although the tests using the converters are in desired performance values.

Due to lack of time, the main objective of area 4 which was to hold the microcontroller programming in order to control the entire EPS board was not done entirely having only been implemented some EPS testing algorithms using the control carried out by the microcontroller. On the electric circuit of Section 4 TPS62172 converter is the best solution to generate an independent power because it ensures a power regulated with a high yield.

For the future work, the project is not ready to make the flight, and must first test the solution of the MCP73213 battery charger is the most suitable for use in Nanosat. It needs to perform the resize prototype board to the final dimensions of the EPS following the flight standards, with the placement of end connectors and the structure supports.

A second prototype board is required performance tests with all converters working together, performing functional tests in extreme situations for performance with external and internal influence.

It is necessary to performance testing at different temperatures from ambient temperature and external conditions. The results may require changing the EPS.

In terms of programming is necessary to develop a program that performs the EPS management with better efficiency and implement communication protocols with other subsystems.

With all made the last step is a test run with the other subsystems and get spaceflight certificate by the ESA.

REFERENCES


