Analysis of Different Topologies Available when Designing a Power System for Nano-satellites

MOHAMMED BEKHTI,
Algerian Space Agency
Centre for Satellites Development
Research Department in Space Instrumentation
ALGERIA

Abstract: - One of the basic problems in making nano-satellites is the scarcity of power due to the available area on these nano-satellites. By their nature, nano-satellites cannot carry large areas of solar panels. However, their radio transmitters require just as much power as those of small satellites such as microsatellites if they are to be received by a ground station of the same size. Nano-satellites must have extremely efficient power systems while using low power consumption processors and payloads. Also, the batteries must have a high energy density if they are to fit inside the nano-satellite tight volume available.

Keywords: - Electrical Power System, Direct Energy Transfer, Battery Charge Regulator, Battery Discharge Regulator, Shunt Regulator.

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1. Introduction

The purpose of the Electrical Power System EPS is to supply regulated and unregulated electrical power to the spacecraft subsystems. In our design, all the systems require power at a regulated 5 volts.

At minimum, the EPS must be able to supply an average load power of 2 watts under 400 mA. However, it must also withstand peak load power demands averaging 10 watts under 2 A for short periods of time when all spacecraft's systems are in the active mode simultaneously.

The EPS is one of the critical subsystems in a spacecraft. If it fails, then the mission is interrupted. For reliability reasons, it must be able to survive most credible components failures.

2. Conventional Power System Topologies

There are three conventional power system topologies that might be suitable for our nano-sat power system design.

2.1. Regulated Direct Energy Transfer

There are three conventional power system topologies that might be suitable for our nano-sat power system design. Figure 1 shows the first topology, a regulated direct energy transfer. While our nano-sat carries four solar panels, only two of them are shown for clarity. Each panel requires a series of blocking diodes preventing reverse currents from flowing in the solar panels when the satellite is in the shadow.

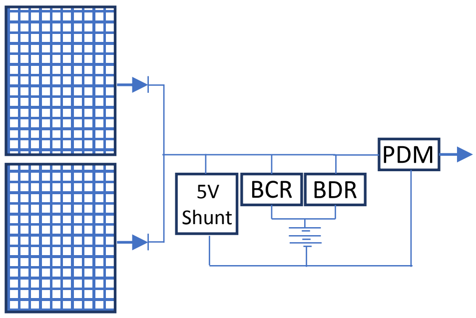

Figure 1: regulated direct energy transfer topology.

A shunt regulator holds the bus voltage at 5V needed by the spacecraft's systems. The battery is connected to the bus via the battery charge regulator BCR and the battery discharge regulator BDR. These are switching power converters designed to match the variable battery voltage to the fixed bus voltage. Control logic activates the BDR when the loads exceed the power available from the solar arrays. The BCR is similarly controlled to charge the battery when needed and stop the battery charging when the End of Charge EoC state is reached.

The recommended load voltage of the solar arrays is 7.12 volts at 25°C. However, in this case the solar panel is held to 5 volts by the shunt regulator. This means that 29.77% of the available power is lost which is unacceptable. The regulated direct energy transfer topology is unsuitable for our nano-sat because the size of the solar arrays and the available GaAs solar cells.

2.2. Unregulated Direct Energy Transfer

Figure 2 shows the topology called the unregulated direct energy transfer where the solar panels are held at the battery charge voltage. The shunt regulator bleeds current from the solar arrays once the battery is fully charged to prevent overcharge and battery temperature increase.
As seen, the shunt is situated behind the blocking diodes therefore there is no danger associated with the current flowing from the battery. The power conditioning module PCM is a switching converter that converts the battery voltage to the desired +5 volts. The great advantage of this topology is its simplicity and the fact that it can easily be made highly redundant.

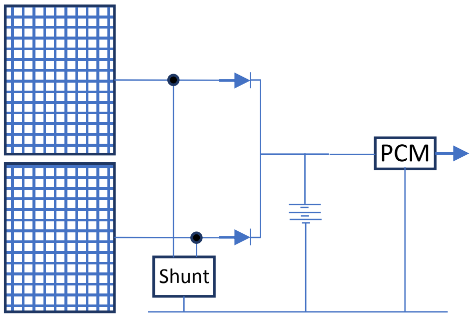

Figure 2: unregulated direct energy transfer topology.

2.3. Peak Power Tracking

Figure 3 shows the peak power tracking topology. As noticed, here the solar arrays are connected directly to the battery charge regulator BCR. Note that blocking diodes are not shown on the circuit layout because a careful design of the BCR may allow us to avoid them. The only other component is the switching power conditioning module PCM which converts the battery voltage to the 5 volts needed by the rest of the spacecraft.
Unlike the direct energy transfer topologies, peak power tracking allows for a very flexible choice of components. The solar array, battery and load are each connected by a switching regulator that is capable of transforming one voltage to another. For simplicity, it is required that each regulator be either of a step up or a step-down type. Thus, the array voltage should be either always above or always below the battery voltage. Similarly, the battery should be always above or below the load voltage. For our nano-sat power system design, the peak power tracking topology was largely selected because of its flexibility and ease in the design.

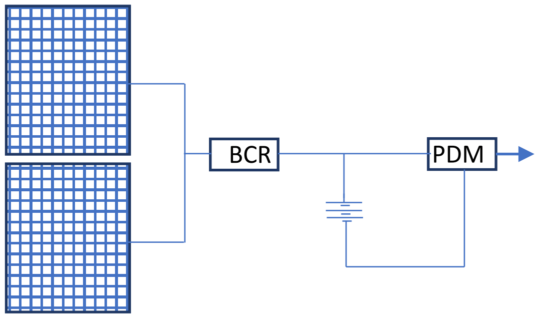

Figure 3: peak power tracking topology.

3. Battery Voltage Choice

The solar panel voltage has been chosen as a nominal 7.12 volts while the power system output is 5 volts. Now the voltage of the battery must be fixed. There are three (03) choices that could be investigated in the frame of our power system design:

- The battery voltage is between the solar panel voltage and the output voltage,
- The battery voltage is less than both the solar panel and the output bus voltages,
- The battery voltage is greater than both the solar panel and the output bus voltages.

- **The battery voltage is between the solar panel voltage and the output voltage**

The first choice is shown in figure 4. It is based on a buck converter which operates at high duty cycles and could be expected to reach high efficiencies. Unfortunately, this design places difficult constraints on the battery voltage.

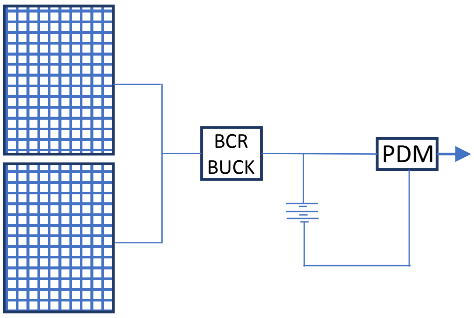

Figure 4: battery voltage is between the solar panel voltage and output voltage.

- **The battery voltage is less than both the solar panel and the output bus voltages**

Figure 5 shows the situation where the battery voltage is less than both the solar panel and the output bus voltages. The panel voltage is stepped down to the battery voltage with a buck converter and then stepped back up again with a boost converter to satisfy the mission requirements providing an output voltage of 5 volts.

The prime attraction of this power system is the small number of battery cells required. A maximum of four NiCd battery cells or a single Li-Ion battery cell may be used.
Another advantage of this power system is that the output bus can be kept in regulation until the last drop of power is drained from the batteries. This is not a major issue for NiCd batteries whose voltages tend to drop quickly at the end of charge. However, it would allow alternative storage systems such as supercapacitors to be fully exploited.

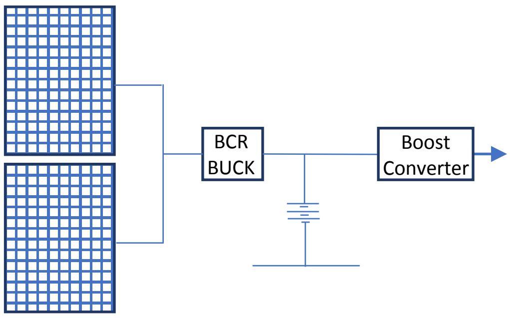

Figure 5: battery voltage is less than both the solar panel and output bus voltages.

- **The battery voltage is greater than both the solar panel and the output bus voltages**

Figure 6 shows the last option where the battery voltage is greater than both the solar panel and the output bus voltages. The BCR uses a boost converter and the PCM will then be based on a buck converter. The only restriction on the battery is that its voltage is always greater than the array voltage. Six or more NiCd battery cells would satisfy our requirements. Otherwise two or more Li-Ion batteries would do as well.
In conclusion, while the first choice was rejected, the second and third options both seem to satisfy the mission requirements as long as certain parameters are well considered.

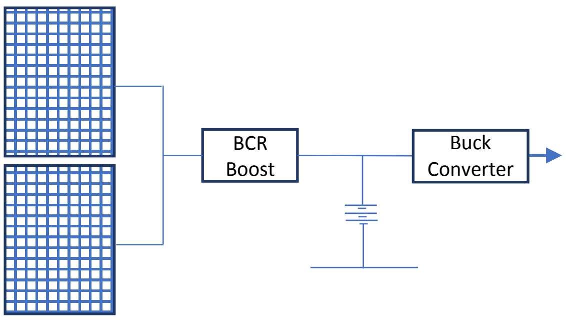

Figure 6: battery voltage is greater than both the solar panel and the output bus voltages.

4. Solar Panel Design

At an intermediate load impedance, between short and open circuits, the solar cell voltage is somewhere between its open value and zero. Similarly, the current is somewhere between short circuit value and zero. Figure 7 shows the relationship between voltage and current for single solar cell.

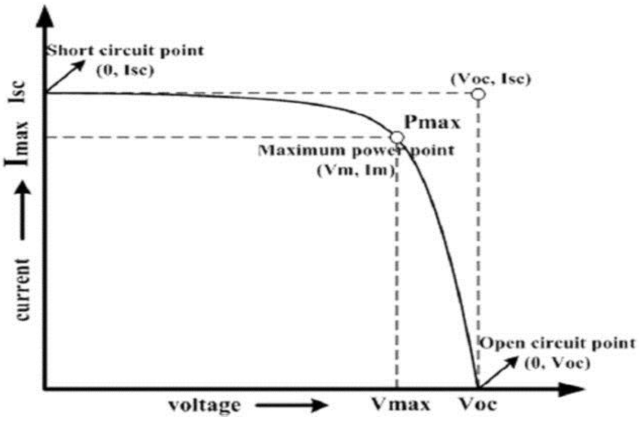

Figure 7: relationship between voltage and current for a single solar cell.

Recall that the power transferred from the solar cell to the load is the product of the solar cell voltage times the current. At short Isc or open Voc circuit conditions, the power is equal to zero. The power generated by the solar cell is maximum somewhere close to the knee at the power peak point Pmax.
The properties of the solar cell change with temperature. As the temperature goes up, the forward voltage of the diode decreases. This causes the open circuit voltage of the cell to drop, along with the peak power voltage. The current does increase slightly with temperature but overall the cell power drops as it is heated.
The solar cells used are 20mm * 40mm.the solar cells require a 1mm spacing when laid down on the panels. As seen on figure 8, eight solar cells are connected in series. This gives the panel eight times the voltage of a single cell but no additional current.
Table 1 shows the electrical characteristics of a panel of eight single junction GaAs solar cells.

Solar cells parameters	GaAs (single junction)	Temperature coefficient
Isc (mA)	252.6	+0.2624 mA/°C
Voc (V)	1.047	-0.01392V/°C
Vmp (V)	0.894	
Imp (mA)	238	
Pmp (mW)	212.8	
Efficiency (%)	19.8	-0.028%/°C
FF (fill factor)	0.82	
Sol. Cel.area (cm^2)	8	

Table 1: GaAs solar cells electrical characteristics at 25°C and AMO.

Solar panel design calculations:

- load voltage: 8*0.894 V = 7.12 Volts

- load current: 2*238 mA = 476 mA
- solar panel power: 7.12 V*0.476 A = 3.39 Watts
- solar panel area = 128 cm^2

Figure 8: GaAs solar array layout.

5. Conclusions

The present paper details an analysis of different topologies available when designing an Electrical Power System for nano-satellites.

The paper goes in details for the three existing topologies and explains how we can select one topology to the other.

References

[1].Satellite Power Systems Solar Energy Used in Space Technology Programs, 2003. European Space Agency, ESA Publications Division, Netherlands, BR-202.

[2].Larson, W.J. and Wertz J.R., 1992. Space Mission Analysis and Design, 2nd Edition. Microcosm, Inc. Torrance, California.

[3].Fortescue, P.W., Stark J. and Swinerd G., 2003. Power System Design. Spacecraft System Engineering, 3rd Edition, Wiley Intl.

[4].Patel, M.R., 2005. Spacecraft Power Systems, CRC Press, Florida.

[5].C Underwood, G Richardson, J Savignol, "In-orbit results from the SNAP-1 nanosatellite and its future potential", Philosophical Transactions of The Royal Society, 2003

[6].P Fortescue, J Stark, G Swinerd, "Spacecraft Systems Engineering", Third Edition, Wiley - Section 18.7, pages 597-599

[7].R Lancaster, C Underwood, "The SNAP-1 Machine Vision System", 14th AIAA / USU Conference on Small Satellites, 2000.

[8].D Gibbon, C Underwood, "Low Cost Butane Propulsion Systems for Small Spacecraft", 15th AIAA / USU Conference on Small Satellites, 2001.

[9].C Underwood, G Richardson, J Savignol, "SNAP-1: A Low Cost Modular COTS-Based Nano-Satellite – Design, Construction, Launch and Early Operations Phase", 15th AIAA / USU Conference on Small Satellites, 2001

[10]. C Clark, K Hall, "Power System Design and Performance on the World's Most Advanced In-Orbit Nanosatellite", 6th European Space Power Conference, Porto, Portugal May 2002

[11]. Mohammed Bekhti. "Design and Qualification Tests of Alsat-1 High Efficiency Solar Panels". International Journal of Renewable Energy Research 3.1 (2013).

[12]. Mohammed Bekhti and M N Sweeting. "Temperature effects on satellite power systems performance". Advances in Communications, Computers, Systems, Circuits and Devices (2010).

[13]. M Bensaada., Mohammed Bekhti and al. "Sliding Mode Controller Design Synchronized by PLL Application to Buck DC/DC Converter". International Review of Automatic Control (2012).

[14]. Mohammed Bekhti and T Adda Benattia. "Maximum Power Point Tracking Simulations for PV Applications Using Matlab Simulink". International Journal of Engineering Practical Research (IJEPR) 3.4 (2014).

[15]. Mohammed Bekhti. "In Orbit Irradiation Effects Evaluation of the Alsat-1 Solar Panels". International Journal of Energy Science and Engineering 1.1 (2015): 24-30.

[16]. Mohammed Bekhti., et al. "Small satellite power distribution module adopting overcurrent protection". International Conference on

Industrial Application in Engineering Science, IEEE IAS Intel IEEE ICIAES, February 5-9,2019.

[25].Mohammed BEKHTI, Comparative Study for LEO Satellites Solar Arrays Design Using Single and Multi-junctions Solar Cells, Acta Scientific COMPUTER SCIENCES, Volume 3 Issue 4 April 2021.

[26].Mohammed BEKHTI, A Conceptual Solar Array Design for a Geostationary: Mini-communications Satellite for Algeria, Acta Scientific COMPUTER SCIENCES, Volume 3 Issue 9 September 2021.

[27].Mohammed BEKHTI, Battery and Solar Panels Temperature Compensation for Small Satellites Applications, Acta Scientific COMPUTER SCIENCES, Volume 3 Issue 12 December 2021.