International Journal on Emerging Technologies (Special Issue NCETST-2017) **8**(1): 209-215(2017)
(Published by Research Trend, Website: www.researchtrend.net*)*

ISSN No. (Print) : 0975-8364
ISSN No. (Online) : 2249-3255

Distributed Electrical Power Systems in Cubes at Applications

Pankaj Bisht and Rakesh Pandey
Electrical and Electronics Department,
Amrapali Institute of Technology and Sciences, Haldwani, (U.K.), India

ABSTRACT: The single bus voltage distributed architecture is the mainstay architecture for small satellite spacecraft. Even large satellites follow this architecture. While they may have more than one voltage that is distributed, such as a high voltage bus and a low voltage bus, within a subsystem, there is usually one bus voltage. Each subsystem component is responsible for further regulation or point-of-load regulation. The Nan satellite class, and more particularly the cubesat, have broken away from this norm and overwhelmingly implement a centralized architecture. With the advances of small, highly efficient, monolithic dc-dc converters, this thesis researches the possibilities of implementing the distributed architecture at the cubesat scale. The goal is to create a very efficient electrical power system design that has a high degree of utility, allowing it to be used for multiple missions, without having to redesign the system every time.

The cubesat spacecraft was conceived over ten years ago. Since that time, close to 100 cubesat satellites have either been launched or are in the process of construction. Although started as an educational teaching tool, the cubesat is gaining popularity in the satellite industry and is making inroads as a standard architecture for many nano and pico satellite applications. The electrical power system for the cubesat class satellites almost exclusively conforms to a centralized architecture.

There are several key advantages of a distributed architecture that are desirable. Design reuse is one well known advantage and it is exploited almost exclusively in larger spacecraft. However, since the first cubesats were very simplistic in their electrical power system design, custom centralized architectures were initially selected and made sense. As the cubesat standard begins to proliferate, the need to have a non-custom, generic electrical power system design that can be reused over and over again is needed to support the ever increasing design complexities.

To begin the research, an electrical power system survey is discussed that provides insight into the current state-of-the-art in cubesat electrical power system design. Next, an actual cubesat electrical power system design based on the centralized architecture is broken down into its individual components. A complementary design is then created using a distributed architecture. The two designs are analyzed, compared, and contrasted. The results are presented and discussed as part of the research.

Keywords: distributed architecture, Nan satellite class, monolithic dc-dc converters, cubesat spacecraft.

I. INTRODUCTION

The cubesat, or Nanosat class satellites, have traditionally used highly integrated Electrical Power System (EPS) electronics designed to optimize for power. For the cubesat to become a mainstay bus used for real world missions, the EPS must not only be efficient but flexible. The ideal EPS design is one that meets the power requirements of a specific mission, and can then be used multiple times in different mission scenarios, without having to be redesigned for each mission. Distributive architectures are flexible. They have enable modular designs that result in greater design reuse, while still meeting system requirements of varying satellite payloads and spacecraft configurations; but can they be efficient?

The charge pump is of interest for this research. In addition to standard dc-dc converters, the charge pump will also be considered as the distributed Point-of-Load (POL) converter. The point-of-load converter is one where the converter is located near the load that it sources power to. The load can be a card or it can be a component or sub-circuit element on a card. The charge pump is typically only used in low-power applications. The cubesat is exactly that, a low-power application. The charge pump may also be preferable in magnetic sensitive applications and therefore has some utility outside of efficiency and architecture.

A. Electrical Power System Architecture

The basic components of the EPS are the energy source, energy conversion, power regulation and control, energy storage, and distribution [1].

Figure 1. shows a simple block diagram of these components. The primary energy source for nearly all cubesats is the sun. Solar arrays are used to convert the solar energy to electrical energy. High efficiency converters are used for regulation and control. Secondary or rechargeable batteries are used for energy storage. Electronic switches or relays are used to distribute the power to the loads. Other implementations of these basic components can be, and are, used for cubesats.

The focus of this thesis is the power regulation and control block and how it can be optimized for both efficiency and utility in cubesat or Nanosat implementations.

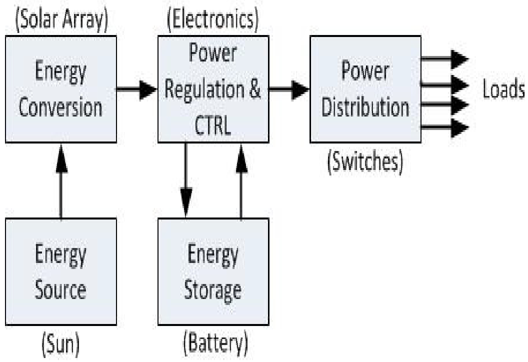

Fig. 1. Spacecraft EPS standard block diagram.

There are many different variants of the regulation and control block. However, most can be lumped into two categories: Direct Energy Transfer (DET) and Peak Power Tracking (PPT). The DET architecture connects the solar array directly to the load(s). This style requires that the solar array, loads, and battery be voltage matched. When optimized, and under the right conditions, this is ultimately the most efficient since there are no other intermediate components to dissipate power. Since conditions are seldom ideal, especially over long mission durations, the Peak Power Tracking (PPT) architecture is often used. The PPT architecture inserts a series regulation device between the solar array and the loads. The regulator regulates the current extracted from the array such that it maintains the solar array at its peak power point. Advantages of this architecture are that the solar array can be decoupled from the load, allowing simpler array designs. The PPT architecture does not rely on matching the array to the loads, and as such, optimization is obtained over a much broader set of conditions. The down side of the PPT is the added complexity of the controlling electronics. Under many conditions, it is debatable if peak power tracking wastes more power, with the added circuitry and complexity, than is saves.

Regardless of what type of energy transfer architecture is selected, the power must ultimately be distributed and regulated to the 4 required voltages for each spacecraft component.

II. CUBESAT POWER SYSTEM

The power system is necessary for the other CubeSat subsystems, such as the microcontroller and communication, to function. The design objectives of the power system include: providing sufficient power to the electrical subsystem, minimizing power drain from the batteries, ensuring efficient recharging of the batteries, and minimizing weight and volume. In addition, Satellite Solutions hopes to improve upon Sub-Orbital-Technologies' power system.

The preliminary design of Satellite Solutions' CubeSat power system implemented various power generation methods, a DC-to-DC boost converter, a battery charger, rechargeable batteries, and a DC-to-DC converter. Parts for that power system have been ordered; however, due to a back order of 8-14 weeks, a redesign of the system was necessary to provide parts faster. As a result, the power system has multiple design options due to different component specifications. Some of the design options change battery configuration (series or parallel) and the method of power delivery to the CubeSat subsystems. The redesign of the system also resulted in a new design strategy that examined the power system from the load to the source. The strategy is based on the idea that each component is dependent upon the component from which it receives power.

The following discussion presents a final design review of the power system by Satellite Solutions. First, the general operation and problems of the CubeSat power system are given. Next, the CubeSat power system is divided into three main areas, which include: power generation, storage, and distribution. A general layout of the power system is presented in Figure 2, which provides a road map for discussing the areas of interest.

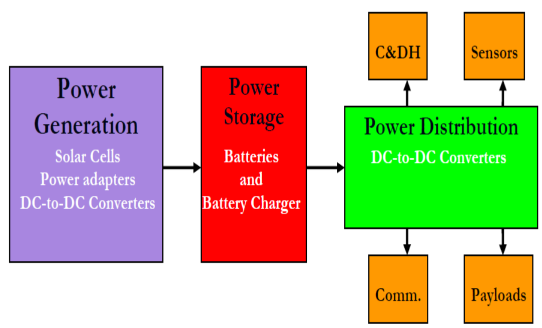

Fig. 2. General Layout of the CubeSat Power System.

III. DISTRIBUTED DESIGN ANALYSIS AND COMPARISION

This section outlines and describes a distributed EPS with point-of-load converters. Parts of this design have been built and tested as isolated components. Most of the design is still just paper. This design targets the DICE spacecraft described in Chapter 1, Section B.2. This distributed design attempts to provide all of the same voltages generated on the DICE spacecraft card sets. If a complete redesign were to take place, further optimization could likely be realized. However, for the sake of analysis and comparison, the original design loads have been used. To evaluate the impact of charge pumps, an attempt will be made to incorporate them into this distributed design. Efficiency will be given precedence over other parameters. However, if a charge pump can be used, it will be evaluated.

A. EPS Analysis and Comparision Approach

The goal of the comparison is to show that an optimized distributed EPS can be realized such that the efficiencies of the distributed design are not significantly different than the centralized system efficiencies with its inherently non-optimized converters. If the design can be shown to be at least equal, or close to equal, then the advantages of the single voltage, distributed bus will allow for the sought after high degree of utility, and reuse, in the EPS design.

The analysis and comparison of power systems performed by the students at the University of Aalborg resulted in a distributed architecture except they did the regulation all local to the EPS card. The regulated buses were distributed to the downstream electronics. The assumption is that subsequent regulation took place locally at the point-of-load. Their analysis looked only at the initial stage of the power conversion chain and did not include all of the secondary and later stages. Looking at the entire spacecraft power system helps provide perspective not available by just looking at the first stage.

The comparison mechanism will use power converter models, assembled in MatLab Simulink. The approach is to model the existing DICE power architecture and the distributed EPS design using measured efficiencies from the actual converters and data sheet values provided by the manufacture. Both architectures will be modeled using the same loads and local voltages. The differences will be in the architecture and the ability to optimize the distributed system.

B. Power Generation- Power Storage

It is not within the scope of this thesis to go into detail on the power generation and storage blocks other than a brief description. This design will assume photovoltaic power generation and lithium-ion batteries for power storage.

The solar arrays are constructed using high efficiency triple junction solar cells. There are two primary vendors in the United States that both make similar cells. The Emcore BTJ and the Spectrolab UTJ cells each provide about 28% efficiency at beginning of life. The standard cell size is 26.6 cm2 and nominally produces 1 watt per cell. The DICE spacecraft reference design uses four 1.5U solar array panels, each populated with three solar cells. This results in power generation of three watts per panel assuming direct illumination and a normal sun vector to the panel. Greater power can be generated if more than one panel is being illuminated at the same time depending on the axis tilt of the spacecraft.

The battery selection is much greater. Lithium-polymer, due to its high energy density and thin shape, has become the battery type of choice for cubesat applications. Standard lithium-ion cells are also frequently used. The DICE reference design uses the lithium-polymer cell manufactured by Varta. This is a 1.3 A-h battery cell. The DICE reference design uses four cells configured as 2S2P, providing a 2.6 A-h battery at 8.26 volts maximum.

For the analysis, both the battery and the solar array will be assumed constant, and modeled as ideal DC sources. The intent is to remove the effects of these components from the architecture comparison.

C. Battery Charge Regulator

The battery charge regulator used in the DICE reference design is manufactured by Clyde Space Ltd. This regulator has been independently characterized for efficiency by measurements in the laboratory. The measured efficiencies are used throughout this analysis. The BCR used for the distributed EPS design is assumed to have the same performance characteristics as the Clyde Space device. The BCR effects will be the same for both designs forcing the differences to be due primarily to architecture, and downstream component optimization to highlight the effects of point-of-load converters.

D. Distributed EPS Design Detail

The primary feature of the distributed EPS is the single battery dominated bus. This bus is sun regulated; meaning that it is regulated to a fixed voltage during the sunlit portion of the orbit or once the battery end of charge voltage is reached. The bus is unregulated during the eclipse portion of the orbit. The battery state of charge determines the bus voltage for this time period. The orange block represents Line Regulators. Linear regulators were used in noise sensitive areas where the voltage ripple of a switching regulator was not acceptable. Figure 5.2 shows the block diagram for the distributed configuration equivalent.

For this configuration, three additional converters are required. A 3.3V converter and a 5.0V converter generate the voltage rails previously provided from the DICE EPS. One additional 3.3V buck converter is used for the Global Positioning System (GPS) for load optimization.

The GPS 3.3V load is approximately 300mA and is too great for the local board regulator to handle. In an ideal world, the GPS would provide its own point-of-load conversion directly from the battery input. Since it does not, it is provided here. The DICE design used a solid state relay to switch 3.3V power to the GPS. The new point-of-load 3.3V regulator can be considered as replacing that relay since it has a shutdown feature. From a board real estate point of view, the regulator is larger than the solid state relay, but not significantly.

For this analysis, and simplicity, we will assume a constant voltage. The battery dynamics can be added later to the model for increased fidelity. However, the battery dynamics are not required to compare the first order impact of the distributed EPS to the centralized approach and are omitted in this analysis. Figure 3 shows the block diagram for the DICE (centralized) power delivery system for the Attitude Determination and Control System (ADCS) Interface Board. This board is used as an example of the difference between the centralized design and the distributed design. Note that all three buses, battery and the two regulated buses are used on this board. The battery bus is further regulated to obtain an analog plus and minus rail. The 5.0V and 3.3V rails are used directly on the card. The green blocks represent switching converters.

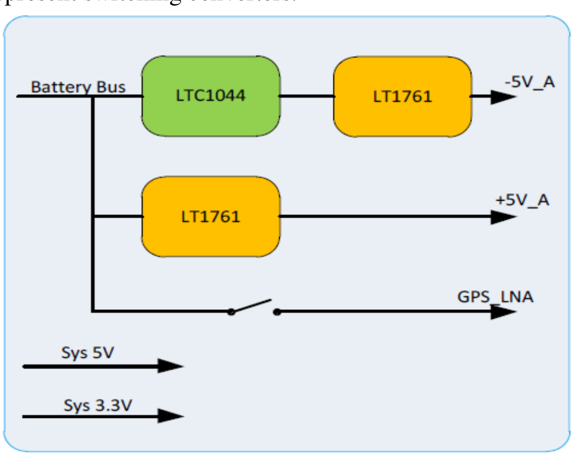

Fig. 3. DICE ADCS power block diagram.

For the analysis, a power block diagram, similar to ADCS, was generated for each card in the DICE design. A second block diagram was then generated that showed the power implementation assuming a single distributed bus

E. EPS Analysis Models

There are three main Simulink models that include a DC-DC converter, a linear regulator, and a load cell. Each of these models is configurable so they can be made to represent many different components. The components are connected together in the same configuration as the block diagrams outlined in the previous section. In addition to the three custom model components, typical SimuLink source, sink, and interconnecting components are used.

IV. ANALYSIS RESULTS

In the analysis, an attempt to match the DICE power loads was performed. The power load for each DICE card was measured at each voltage bus. The sum of these loads was then considered to be the card power load. For the analysis, constant power loads were selected for each voltage rail, such that the power load of the card, including converter efficiency, matched the measured DICE load. While the matching is not exact, the same loads are used throughout the analysis to allow for a good comparison.

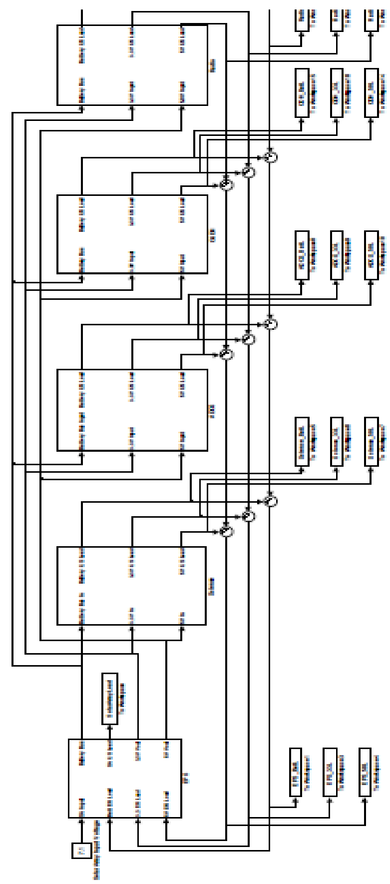

Fig. 4. DICE centralized power system design.

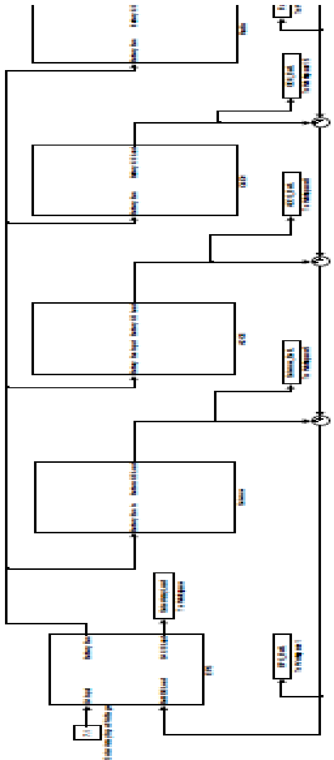

Fig. 5. DICE distributed power system design.

Table 1. is a summary of the Simulink analysis for the DICE centralized design loads. Table 2 is the summary for the DICE distributed analysis. The first column, top section, lists the different cards. In the case of the Radio and the Science board, the power loads are divided because there is a significant change depending on what is powered. The next column, Fixed Load, is the load that the local power system on each card sees. In other words, it is the load downstream of any local power supplies. Where no power supplies exist on a particular bus voltage, for the given card, this column is the power for the specified power rail.

The next five columns, Case 1 through Case 5, are the individual power draws for each card based on the simulation. Where the value is "OFF," it indicates that the card or the function is turned off. The "Total System Load" row is the sum of each of the columns and represents the total load seen by the EPS card for that case. This value does not include the EPS card loads and inefficiencies. The next line, Solar Array Load PWR, is the total power required for the entire spacecraft. In the real system, the battery would begin to provide power to the power loads for the high load cases. For this analysis, all of the power is brought out to the solar array for comparison.

Table 1: Dice Centralized Design Card Power Summary.

	Fixed Load (W)	Case 1 Load (W)	Case 2 Load (W)	Case 3 Load (W)	Case 4 Load (W)	Case 5 Load (W)
C&DH	0.065	0.065	0.065	0.065	0.065	0.065
ADCS	0.158	0.198	0.198	0.198	0.198	0.198
GPS	1.022	OFF	1.022	OFF	OFF	OFF
Comm Tx	10.271	OFF	OFF	OFF	10.271	10.271
Comm Rx	0.117	0.117	0.117	0.117	0.117	0.117
Science Digital	0.12	0.193	0.193	0.193	0.193	0.193
Science Analog	0.175	OFF	OFF	0.338	OFF	0.338
Total System Load	12.045	0.573	1.595	0.911	10.844	11.182
Solar Array Load PWR		2.961	4.277	3.337	14.42	14.8248
BCR Efficiency	Pct.	83%	84%	84%	84%	84%
3.3V Efficiency	Pct.	87%	88%	87%	88%	88%
5.0V Efficiency	Pct.	15%	15%	15%	88%	88%

Table 2: Dice Distributed Design Card Power Summary.

	Fixed Load (W)	Case 1 Load (W)	Case 2 Load (W)	Case 3 Load (W)	Case 4 Load (W)	Case 5 Load (W)
C&DH	0.065	0.068	0.068	0.068	0.068	0.068
ADCS	0.158	0.207	0.207	0.207	0.207	0.207
GPS	1.022	OFF	1.099	OFF	OFF	OFF
Comm Tx	10.271	OFF	OFF	OFF	10.323	10.323
Comm Rx	0.117	0.125	0.125	0.125	0.125	0.125
Science Digital	0.12	0.154	0.154	0.154	0.154	0.154
Science Analog	0.175	OFF	OFF	0.252	OFF	0.252
Total System Load	12.045	0.554	1.653	0.806	10.877	11.129
Solar Array Load PWR		1.984	3.124	2.188	14.12	14.422
BCR Efficiency	Pct.	83%	84%	84%	84%	84%

Accounted for locally on the boards. However, for the science board this is not the case. This is because the science board converters are oversized and not operating efficiently. In the distributed design, different converters were used that resulted in better efficiency, up to 86 mW less power consumption.

The second reason is the EPS board regulated voltage efficiency. Both the 3.3V and the 5.0V converters are high efficiency converters, but they require a relatively high amount of load current before they reach their peak efficiency. Even in the peak power mode for the system, the 5.0V converter has still not reached its peak efficiency. This is one of the primary flaws of a centralized design that is not optimized for a specific mission. If the EPS design would have been designed for this specific mission, it likely would have done better.

However, since it is a common design, used for multiple cubesat missions, it has to be designed for the highest loads. It is therefore inefficient for missions that have lighter loads. For most of the DICE mission, the 5.0V converter efficiency is at a dismal 15%. From this analysis, it is fair to assume that even if the 5.0V converter was optimized for the maximum load requirement of the DICE mission, the efficiency still would not be as good as dedicated point-of-load converters. The load spread between the high load state and the low load state is great enough that it is difficult to find a converter that can cover the spread evenly at its peak. The 3.3V converter is better utilized but even it could benefit from point-of-load optimization.

One of the initial goals of the research was to determine if charge pumps could be effectively used in the distributed design. For the distributed DICE design, only one charge pump was used. The DICE mission uses a 7.2V nominal bus. At this voltage, commercially available charge pump options are few. The other issue is that charge pumps are better suited for non-regulated applications where the output only depends on the input. High efficiency charge pumps are available but mostly for inverter or doubler applications. For the DICE mission, the science board specifications for the low level regulated voltages required linear regulation for the analog components. This eliminated the charge pump from several applications. If these requirements were relaxed, then the charge pump could have been used to increase the efficiency over the linear alternatives.

A lower bus voltage was initially considered for the distributed design. This would have enabled more opportunities for charge pumps. However, the decision was made to keep the bus the same as the centralized DICE design to enable better comparison. For a single bus voltage distributed design, a decision for what that bus voltage should be will have a large impact on available converters. It will also have an impact on what kind of efficiencies can be obtained at the point-of-load. The process of selecting the point-of-load converters, and generating efficiency data, showed that the lower the delta between the converter input voltage and output voltage, the greater the efficiency. Assuming lithium-ion battery chemistry for the distributed bus, the voltage rail options grow in increments of 3.6 volts. Based on the design and subsequent analysis, the recommended bus voltage is either 7.2 +/- 1.2 volts. Further work should be done to come up with the optimal cubesat bus voltage. A review of the different loads would shed more light on the optimal bus voltage.

VI. CONCLUSION

The distributed EPS design is very flexible with a high degree of utility. The efficiency of the distributed design can be shown to be equal or close to that of an optimized centralized design. In the case of the reference design used in this analysis, the distributed design efficiency is better. The use of small, efficient, point-of-load converters, both charge pumps and inductor based converters, enables single bus voltage architectures for cubesat or Nano class satellite applications. This architecture is the same as that used in larger small sat applications, and is the key to a cubesat or Nanosat EPS design that can be used across multiple platforms and varying missions.

The cubesat industry almost entirely relies on centralized EPS designs. Most EPS designs have been custom designs. There are a few manufactures that make their designs available for commercial use. Most of these designs conform to the most common standard that uses three distributed buses. A single distributed bus would increase the EPS utility and allow its use in more cubesat designs.

Point-of-load converters are efficient and small. The down side of the distributed EPS is that more board space is required for voltage regulation on each card. To mitigate the impacts of more converters, small monolithic converters can be used, and require very little board space.

Standard inductor converters have an advantage over charge pumps in regulated applications. Their efficiency is usually greater and there is a much greater selection available over a wider array of input voltages. When charge pumps are used, they are easier to configure since there is one less energy storage element to size. For inverting or doubling applications, the charge pump is a good choice and is easier to configure than the inductor based counterpart.

It is very insightful, for EPS designs, to perform full power system analysis. Looking at the power performance from the solar array down to the last converter before the load, gives you a very complete look at all of the power dissipation. It allows for identification of problem areas where further optimization can be made. Building a prototype design for each converter, with representative loads, allows you to completely characterize the performance of the selected converter. It helps identify issues early in the design process. Ultimately, if a distributed design is implemented, optimization can be done at a lower level.

A series connected, two cell lithium-ion battery was used in this analysis. The research would indicate that an 8.4 volt (two series cells) battery bus is the most common. While, it is still not clear what the optimal bus voltage is, based on the research, the optimal bus voltage recommendation would be 8.4 volts for all cubesats 2U and smaller. It appears that 12.6 volts (3 series cells) is a better choice for cubesats larger than 2U.

A review of cubesat loads would be useful to help determine the optimal voltage. For example, the DICE radio initially required a higher bus voltage. They initially wanted greater than 9 volts. The requirement was subsequently lowered to accommodate the DICE battery bus voltage. Using a higher bus voltage would reduce the number of boost converters required in a system. However, the higher the bus voltage, the lower the converter efficiency is when that voltage is converted to low level regulated voltages. For this reason, voltages above 12.6 volts are not recommended. If a standard voltage can be selected, then the greatest utility can be realized.

Full power system modeling is extremely insightful and useful for analyzing the power system performance. Further development of the EPS system level models to include system level dynamics would be valuable. The inclusion of a solar array model and a battery model would help perform reference mission EPS simulations to validate solar array and battery sizing. Further work in this modeling arena could provide a very valuable tool for the EPS designer in not only evaluating the EPS architecture and optimizing the system, but it could be very useful in performing mission simulations for the power system. Battery voltages could be modeled. Bus switches could be implemented and controlled based on mission scenarios. MatLab Simulink®appears to be a good tool for doing these types of dynamic modeling cases. MatLab allows for the inclusion of actual SPICE models into MatLab models when the proper tool packs are made available.

REFERENCES

[1] M. Patel, *Spacecraft Power Systems.* Boca Raton, FL: CRC Press, 2005.

[2] C. Barrett. (2011, May, 30). The Importance of Global Standards. (interview) [Online]. Available: http://www.intel.com/standards/execqa/qa0904.htm

[3] *User Manual: CubeSat 1U Electronic Power System and Batteries,* Clyde Space LTD., Glasgow, Scotland, 2010.

[4] *CubeSat Design Specification, Rev 12*, Cal Poly SLO, Aug 2009.

[5] W. C. Boncyk, "Developing a Distributed Power and Grounding Architecture for PnPSat," in *Aerospace Conference, IEEE*, p. 1–9, 2008.

[6] C. McNutt, R. Vick, H. Whiting, and J. Lyke, "Modular Nanosatellites - Plug-and-play (PnP) CubeSat," presented at the 7th Responsive Space Conference, Los Angeles, 2009.

[7] M. Thomsen, "Michael's List of Cubesat Satellite Missions," *Michael's List of Cubesat Satellite Missions*, 2009. [Online].Available: http://mtech.dk/thomsen/space/cubesat.php.

[8] M. Long et al., "A cubesat derived design for a unique academic research mission in earthquake signature detection," in Proceedings AIAA Small Satellite Conference, Logan, 2002.

[9] I. Bland. (2011, May, 30). *Cal Poly EPS and Side Panels (California Polytechnic State University)* [Online]. Available: http://polysat.calpoly.edu/CP2_docs.php

[10] G. J. Wells *et al.*, "Canada's Smallest Satellite: The Canadian Advanced Nanospace eXperiment (CanX-1)." Space Flight Laboratory University of Toronto Institute for Aerospace Studies., Toronto, Canada [Online]. Available: http://www.utias-sfl.net/docs/canx1-ssc-2002.pdf

[11] K. Sarda et al., "Canadian advanced nanospace experiment 2: Scientific and technological innovation on a three-kilogram satellite," *Acta Astronautica*, vol. **59**, no. 1-5, p. 236–245, 2006.

[12] A. Scholz and J. Giesselmann. (2005, November, 5). *Compass-1 The first Pico Satellite Project at the Aachen University of Applied Sciences* [Online]. Available: http://www.raumfahrt.fh-aachen.de/compass-1/download/18_RFK_COMPASS-1_final.pdf

[13] "Cute-1.7 + APD - Sub Systems > EPS -." [Online]. Available: http://lss.mes.titech.ac.jp/ssp/cute1.7/cute1.7-1/subsystem_eps_e.html.

[14] "Delfi-C3 - EPS (Electrical Power Subsystem)." [Online]. Available: http://www.delfic3.nl/index.php?option=com_content&task=view&id=28&Itemid=42.

[15] Y. K. Chang et al., "Design and development of HAUSAT-1 picosatellite system (CubeSat)," in *Recent Advances in Space Technologies, 2003. RAST'03. Proceedings of International Conference*, (2003) p. 47–54.

[16] P. Thirion, "Design and Implementation of On-board Electrical Power Supply of Student Nanosatellite OUFTI-1 of University of Liege," MS thesis, Electrical Engineering, University of Liege, Wallonia, Belgium, 2009.

[17] M. Blanke, "DTUsat-1: Power Supply," *DTUsat Project.* [Online]. Available: http://dtusat1.dtusat.dtu.dk/group.php?c_gid=9&PHPSESSID=d5b7a0b93364dbe2a30cf3a21105913b.

[18] M. Balan et al., "GOLIAT Space Mission: Earth Observation and Near Earth Environment Monitoring Using NanoSatellites," in 60th IAC B4. 13th Small Satellite Missions Symposium, Daejon, Korea, 2009.