Guest Editorial Special Issue on Power Electronics Systems for Aerospace Applications

AEROSPACE applications have been a major driver for the development of power electronics. The demand of light and efficient power supplies, common both for space and aeronautic applications, spearheaded the research and development efforts around switching mode power systems. Major seminal works in the field, such as those pioneered by Prof. R. D. Middlebrook, were developed under funding from National Aeronautics and Space Administration (NASA). Another example is that average current mode control or transconductance control was developed in the European Space Agency (ESA) laboratories while at the same time peak current mode control was invented in U.S. institutions.

Today, the increased importance of electronic systems in aerospace applications still pose a challenge to electronic power system designs. In aeronautical applications, the goals around the More Electric Aircraft state the needs of extreme lightweight electronic power systems in the range of several hundreds of kW and even MW. The same goals, together with the hardships of space environment are seen in space power systems. In both cases, reliability is of utmost importance, and in space applications, this is added to the impossibility of repairments once the spacecraft is in use. Together with radiation hardening requirements, these makes power electronic designs for space applications somewhat different than terrestrial ones.

This Special Issue will try to illustrate some of the challenges and solutions that power electronics systems for aerospace applications have today. There are 19 articles accepted for publication in this Special Issue, which are distributed in four topics: aircraft power systems, spacecraft power systems, motor control for aerospace, and power distribution, protections and reliability.

A. Aircraft Power Systems

The electrification of aircraft propulsion imposes a lot of challenges. A multiobjective analysis, addressing semiconductor losses analysis, dc voltage links, and magnetic design among others, of inverters is shown by Ebersberger *et al.* in [A1]. Apart of the intrinsic value of the article, its methodology can be applied to other similar challenges.

Electrical power is generated onboard from the aircraft engines, and it is generated in ac with a variable frequency which is later converted to dc. A common research topic is the minimization of passive components in input and output filter and the harmonic content minimization by active harmonic suppression strategies. In this regard, a Vienna rectifier is proposed by Xu *et al.* in [A2]. Passive element optimization is also applied to electromagnetic interference (EMI) filters as shown in [A3] by Zhao *et al.*

Finally, to close this topic, in [A4], Chen *et al.* present a general analysis tool for the analysis of power systems based in converters under component variation, such as those used in aerospace applications. Although centered in this topic it can be applied to other environments.

B. Spacecraft Power Systems

As reliability is paramount for space power systems, simplicity is a key design driver. In this regard, the so-called direct energy transfer (DET) systems are often used. DET systems directly connect a power source, typically a Solar Array, to a power bus taking advantage of the characteristics of both the solar array and the power bus to extract power. A typical DET system, in use in many ESA spacecrafts, is the sequential switching shunt regulator (S3R). These systems are not without drawbacks and some of them are addressed by Jin *et al.* in [A5].

Again, seeking for reliability analog control is favored in space applications. The different power conversion units are managed to keep the dc bus stable, so the power demand is supplied from the sources, typically solar arrays and batteries. In [A6], Yang *et al.* present a design to extend the typical approach to more power systems used either as loads or sources.

The stability of the dc bus under the load represented by motors is compensated by the use of a bidirectional dc/dc converter and a supercapacitor bank can be seen in [A7] which is written by Quin *et al.*

One of the challenges of space designs is the tolerance to radiation. In this regard, GaN devices are interesting since they have a natural built-in radiation tolerance. Compared to rad-hard Si transistors they offer a better efficiency. In [A8], Phillips *et al.* show an example of a design of a typical dc/dc converter for space application. While the topology and control methods are well known, the design process and component selection showcase the drivers for the power supply designs in space applications.

Again, having reliability as a major driver imposes several design solutions that are not typical of other applications. In [A9], Torres *et al.* analyze a well-known topology, a

Digital Object Identifier 10.1109/JESTPE.2022.3206800

multiphase buck, is analyzed in terms of the typical failures, and these failures are overcome by the use of multiple control loops and majority voters and synchronization circuitry. The application is an electrolyzer for rocket fuel production which requires a precise and reliable current control.

Another very demanding load in terms of power and controllability in space applications are electrical thrusters. The power systems in charge of managing electric thrusters are known as power processing units (PPU). Electrical thrusters require many different power sources. In typical PPU, the power is extracted in dc from the bus and then distributed to the different supplies. In [A10], Fang *et al.* propose a totally different approach, in which they present a PPU with an internal ac bus.

Factorized Bus Architecture combine regulated and unregulated dc/dc converters to distribute dc electrical power to several loads. It is often used inside computers and datacenters to provide the loads and spacecraft can benefit from its advantages as proposed by Wang *et al.* in [A11].

Finally, in a more speculative way, wireless power link could be interesting in space applications. In this regard, in [A12], Vulfovich *et al.* present a design methodology.

C. Motor Control for Aerospace Applications

Precise motor control is a topic of great research interest in aerospace applications. It is a domain that merges power electronics, which compose the driver of the motor, with control theory.

Regarding the control, in [A13], Li *et al.* propose a methodology aimed to control low-speed motors for the gimbal-controlled moment gyros used in spacecraft attitude control. Electrical motors are also important in aircraft application for substituting hydraulic, pneumatic, and mechanical power systems. In [A14], Luo *et al.* merge two different controls.

Finally, addressing the power electronics side of the topic, and although it could be used potentially for other power electronics applications, in [A15], Luo *et al.* present an analysis for the switching oscillation that appear in half-bridges employing cascodes as switching devices.

D. Power Distribution, Protections, and Reliability

Two clear distinct categories appear within this topic: space applications and aeronautical ones. The first ones show the latching current limiter (LCL) approach favored by ESA spacecrafts.

LCLs have the particularity that are designed to behave as a current source for a short period of time. This requirement and its thermal implications drive the LCL design. In this issue, two different designs exploring the use of SiC transistors as a current limiting device are presented. In the first article [A16], Garrigós *et al.* showcase the cascode combination of a SiC JFET and P-channel MOSFET. In the second article [A17], López *et al.* uses a SiC N-channel MOSFET for the same purposes.

Aeronautical applications distribute a much higher power. In [A18], Venkata *et al*. propose an example of a modular solid-state circuit breaker (SSCB) based on SCR. In [A19], Dong *et al.* present a detailed procedure for designing an SSCB based on SiC MOSFET modules and TVS.

Acknowledgment

The Editorial Team expects that these would be of interest to the reader and will inspire new research lines and applications.

A big appreciation is granted by the Editorial Team to all the authors who have contributed with their articles to this Special Issue, and reviewers who have voluntarily supported the special issues and provided constructive and timely feedback.

A special greeting is made to the following Guest Associate Editors who have contributed to the outcome of these Special Issue:

1) Andrew Forsyth, University of Manchester, U.K.
2) Enrique Maset, University of Valencia, Spain
3) Francesco Ianuzzo, University of Aalbork, Denmark
4) Alberto Castellazzi, Kyoto University of Applied Sciences, Japan
5) Cristina Fernandez, Carlos III University of Madrid, Spain
6) Rishad Ahmed, University of Nottingham, U.K.
7) Parag Kshirsagar, Raytheon Technologies, USA
8) Michael Gross, Jet Propulsion Laboratory, USA
9) Arturo Fernandez, European Space Agency, The Netherlands

Finally, the Editorial Team would like to express our gratitude to the former Editor-in-Chief, Prof. Joseph Ojo, and Editor-in-Chief, Prof. Tsorng-Juu (Peter) Liang, for their invaluable guidance during the preparation of this Special Issue.

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Appendix: Related Articles

[A1] J. Ebersberger, M. Hagedorn, M. Lorenz, and A. Mertens, "Potentials and comparison of inverter topologies for future all-electric aircraft propulsion," *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, Apr. 4, 2022, doi: 10.1109/JESTPE.2022.3164804.

[A2] Z. Xu, X. Ren, Z. Zheng, Z. Zhang, Q. Chen, and Z. Hao, "A quadrature signal based control strategy for Vienna rectifier under unbalanced aircraft grids," *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, Mar. 28, 2022, doi: 10.1109/JESTPE.2022.3162948.

[A3] X. Zhao *et al.*, “Planar common-mode EMI filter design and optimization for high-altitude 100 kW SiC inverter/rectifier system,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, Jan. 19, 2022, doi: 10.1109/JESTPE.2022.3144691.
[A4] P. Chen, L. Lu, X. Ruan, and N. Liu, “A testing tool for converter-dominated power system: Stochastic electromagnetic transient simulation,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, Jan. 25, 2022, doi: 10.1109/JESTPE.2022.3146231.
[A5] X. Jin, H. Lin, W. Yao, and Z. Lu, “Sequential switching shunt regulator with improved controller to suppress the influence of double-section phenomenon,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, Apr. 12, 2022, doi: 10.1109/JESTPE.2022.3166820.
[A6] Q. Yang, Y. Yang, R. Li, Y. Dou, B. Dong, and A. Yang, “An analog-device-based five-domain control method and distributed system configuration for high-power spacecraft power systems,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, Dec. 8, 2022, doi: 10.1109/JESTPE.2021.3133875.
[A7] C. Qiu, Z. Li, Q. Tan, J. Huang, and D. Wang, “Hybrid model linearization predictive control for DC bus stabilization in spacecraft combined power system,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, Feb. 10, 2022, doi: 10.1109/JESTPE.2022.3150784.
[A8] A. Phillips, T. Cook, B. West, and B. M. Grainger, “Gallium nitride efficacy for high reliability forward converters in spacecraft,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, May 17, 2022, doi: 10.1109/JESTPE.2022.3175934.
[A9] C. Torres, J. M. Blanes, A. Garrigós, D. Marroquí, and J. A. Carrasco, “Single point failure free interleaved synchronous buck converter for micro satellite electrolysis propulsion,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, May 11, 2022, doi: 10.1109/JESTPE.2022.3174358.
[A10] M. Fang, D. Zhang, and X. Qi, “A novel power processing unit (PPU) system architecture based on HFAC bus for electric propulsion spacecraft,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, Jun. 10, 2022, doi: 10.1109/JESTPE.2022.3182029.
[A11] L. Wang, D. Zhang, Y. Yang, and H. Li, “Two-stage factorized power architecture DC–DC converter for spacecraft secondary power supply system,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, Jan. 5, 2022, doi: 10.1109/JESTPE.2022.3140431.
[A12] A. Vulfovich and A. Kuperman, “Design space of sub-resonant frequency controlled series-series compensated inductive wireless power transfer links operating with constant output current under frequency constraints,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, Jun. 2, 2022, doi: 10.1109/JESTPE.2022.3179724.
[A13] H. Li, Y. Wang, B. Han, and X. Chen, “High precision composite control based on dual-sampling-rate extended state observer for ultra-low speed gimbal servo system,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, Jul. 4, 2022, doi: 10.1109/JESTPE.2022.3165628.
[A14] Y. Luo, X. Zhang, and S. Niu, “A hybrid two-stage control solution for six-phase PMSM motor with improved performance,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, Jan. 7, 2022, doi: 10.1109/JESTPE.2022.3141487.
[A15] B. Luo, G. Luo, and S. Li, “Quantitative modeling and analysis of switching oscillations of cascode GaN devices in half-bridge converters,” *IEEE J. Emerg. Sel. Top. Power Electron.*, early access, May 6, 2022, doi: 10.1109/JESTPE.2022.3173007.
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