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A Fault Tolerant PMAD System Using Radiation Hardened Highly Integrated AFE Integrated Circuits

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Abstract

Fault tolerance of power management and distribution (PMAD) systems in a radiation environment is one of the important characteristics for the reliability of spacecrafts. Furthermore, using highly integrated ICs in the PMAD design leads to lower footprint, therefore it is advantageous to consider the design of redundant PMAD system using ICs that offer a high degree of integration.

This paper describes a PMAD topology using series MOSFETS driven by a single AFE IC that implements sense and control interfaces to the power devices. Special attention is given to the aspects of parametric drift due to radiation effects on the AFE and a method of how system design can alleviate its effect is shown. In conjunction with an FPGA, the AFE sub-system can run MPPT on multiple strings of photovoltaic modules and deliver power to the main power distribution bus. Additional protection circuits manage power distribution to loads and to and from a battery unit.

The PMAD topology

The PMAD system needs to optimally transfer power from the input sources and manage transmission of power to loads and to and from the battery system. It mainly consists of DC/DC converters, protection circuits and a power transfer and fault management function that is partly local and partly remote. In our proposed topology, the inputs are assumed PV module strings for which a fast and accurate MPPT control [1] needs to run in order to track varying angle /shading /temperature condition per string. Thus, several boost DC/DC power converters seek independently MPP per string while driving the power distribution bus. Voltages on input and output nodes and currents through each converter are monitored and used to control each DC/DC converter. Additionally, temperature is monitored at key points and AFD what is AFD? circuits are used to detect arc on each high current/voltage rail.

Control is done digitally:

- an analog front end is used to convert to digital all sense lines and to drive MOSFETs from digitally generated PWM
- an FPGA implements the DC/DC control, MPPT and power and safety management

A communication function can also be implemented for the remote function.

The connection of loads to the power distribution bus is done via individual current / SOA protection circuits that interface with the same FPGA (see figure 1).

Figure 1. The PMAD block diagram

Fault tolerant power stage control

The DC/DC boost unit converter is implemented using a series connection of two NMOS transistors for each high and low side. This way the controller can disable both high and low side paths in case of short circuit developing in one of the four MOSFETs at the expense of some converter efficiency loss (see figure 2). During regular switching periods the upper most (M11 and M21) and lower most (M14 and M24) MOSFETs are ON all the time while the mid MOSFETs (M12, M13, M22 and M23) are switching. From time to time, switching is exercising the upper most and lower most MOSFETs to verify their health state while the mid MOSFETS are turned ON continuously. If shoot-through current or inductor current sensors detect a large change when moving from mid to upper most and lower most MOSFETs a fault is identified and the power stage is disabled and a redundant power stage is enabled (e.g. Boost 11 is disabled and Boost n1 is enabled in figure 1).

The analog front end can sense both inductor and shoot through current if any. The shoot through current measure is based on a difference measurement: first the switching is done with enough dead band to guarantee no shoot through current and the peak current is measured, then, in the next switching cycle, the timing to be measured is applied and the peak current is measured again. The difference between these measurements is a measure of the timing dependent shoot through current. The controller averages this measure to eliminate input or output transient influence on the measurement. The shoot through current, together with a conversion efficiency measure (using input and output currents and voltage sense) are used by the FPGA-based controller to fine-tune the MOSFETs timing to compensate for any long term radiation induced timing drift.

Figure 2. The DC/DC boost fault tolerant power stage

Using an integrated AFE as PMAD element

Traditionally, LX7720 (see figure 3) [2] is used in motor control applications where it drives the power MOSFETS for the motor and solenoid control and acquires output currents and a resolver interface. However most of the LX7720 can be used in other power control applications. Particularly, in this PMAD system application, we use three voltage sense ADC channels (Vin1, Vin2 and Vbus see figure 2) and four current sense ADC channels are used to sense the inductor current (via Rs10 and Rs20) and shoot through current (via Rs11 and Rs21) for two fault tolerant power stages. Four high side / low side pairs of gate drivers are used to drive all 8 MOSFETS (M11-M24) required to implement the two fault tolerant power stages. The LX7720 internal charge pump is activated to turn permanently ON the upper most side MOSFETs (M11 and M21) connected directly to the rail. Additionally, the LX7720 resolver driver outputs are used to drive the primary of an isolated DC/DC converter to power auxiliary circuits for arc fault detection. A good power ground versus signal ground rejection makes this circuit operate well in this power control application.

Figure 3. LX7720 block diagram detail

Other system implementation aspects

The LX7712 [3] is a power line protection device that is used for spacecraft power distribution. It provides a means to turn on or off a DC load with current up to 5A. The LX7712 is an integrated circuit which includes a solid-state P Channel MOSET switch and catch diode (see figure 4); integration allows the temperature of the switch to trigger an optional thermal shutdown. It can be configured as a latch-able current limiter or a fold-back current limiter. Multiple devices can be paralleled in a master/slave arrangement to increase the current rating.

Figure 4. LX7712 block diagram

The full paper will describe in more detail the application of this rad tolerant power line protection device.

The FPGA implements several state machines to operate each LX7720 AFE:

- 2 PID controllers to operate the two DC/DC converters
- 2 maximum power point tracker state machines
- 2 shoot-through / timing optimizer state machines
- 2 fault detection and fault management state machines

Beside these the FPGA must run load control and communication functions to orchestrate the PMAD operation.

A more detailed description of the FPGA based control strategy will also be given.

Conclusions and future work

A new application for an IC traditionally used in actuator control is described. Based on the novel usage, LX7720 implements the analog front end of a PMAD system.

A technology demonstrator is being built and measurement results will be available by the time of publishing.

References

[1] S. A. Spanoche, J. D. Stewart, S. L. Hawley and I. E. Opris, "Model-Based Method for Partially Shaded PV Module Hot-Spot Suppression," in IEEE Journal of Photovoltaics, vol. 3, no. 2, pp. 785-790, April 2013.

[2] LX7720, Rad Hard Spacecraft Power Driver with Rotation and Position Sensing, Datasheet, Microsemi Corp. (available upon request)

[3] LX7712, Rad Tolerant Power Line Protector Device, Datasheet, Microsemi Corp. (available upon request)

Summary

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