PUMPKIN™ INCORPORATED

White Paper

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To: Space Rover Designers
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Space Rover Power Supply Systems

Figure 1: NASA Opportunity rover on Mars. Credit: NASA/JPL-Caltech

Introduction

Space rovers place requirements on their power supply systems (PSS) that can be outside of the usual capabilities of PSSes for orbiting satellites. This white paper presents how Pumpkin power and energy products (both individual and working together as a system) address some of the common rover requirements, especially for lunar rovers, lunar landers and the like.

Problem: Effects of Solar String Topologies

Figure 2: CMU MoonRanger 72W solar panel

Some rovers — like NASA's Opportunity & Spirit Mars rovers and like CMU's MoonRanger lunar rover — can locate most or all of their solar cells in a single plane. This can substantially simplify the main power system, especially with all solar cell strings having the same length (and thereby, the same voltage). However, if the rover is relatively small, it may have solar cell strings of different lengths on different faces due to areal and geometric constraints. In this case, the power system must be able to handle a potentially wide range of different voltages across as many inputs as there are different solar string lengths, in order to maximize the collectable solar power.

Solution: Pumpkin worked within MoonRanger's single deployable solar panel constraints (minimum 72W and must conform to the real estate made available by the lander) to create the 72-cell solar panel shown in Figure 1. The result is a panel with seven independent solar cell strings (six at 25V and one at 30V). Two of the 25V strings are diode-OR'd inside the rover to connect to the EPSM1's six SAIs. Four temperature sensors round out the MoonRanger's EPSM1 inputs.

Problem: EPS Interfaces to Solar and Loads

Figure 3: EPSM1 250W Electrical Power System

A PSS must be efficient at collecting power from the solar arrays, distributing power to the loads, and managing the power and energy in the batteries. As mentioned above, an Electrical Power System (EPS) should be sufficiently flexible in its solar inputs to handle a wide range of potentially different solar power topologies. An EPS must also seamlessly integrate battery management so that there is efficient transfer of solar energy to the batteries when charging is required, and it must immediate transfer battery power to the loads when the loads exceed the solar array's power potential. Additionally, shunt-style regulation of solar arrays may not be in a lunar rover's best interest, as it introduces excess heat (during the lunar day) precisely when none is desired. Lastly, slow MPPTs may result in excessive dependency on batteries as the illumination on the solar array(s) changes and the solar array's contribution to overall power collapses until the MPPT can re-establish a useful operating point for power from the lit solar array(s).

Solution: With highly-efficient (>98%), single-stage GaNFET-based dc/dc converters at all of its power interfaces, the Pumpkin EPSM1 makes it trivially easy to integrate solar, EPS and batteries into a highly capable lunar rover PSS. The EPSM1 achieves this through a variety of advanced features, including:

- A wide (6-32V) voltage input range on each SAI channel.
- Six completely independent Solar Array Input (SAI) channels.

- Additional features (e.g., programmable setback recovery) on each SAI channel.
- High-efficiency (>98%) power conversion at all inputs and outputs, with 40V margins.
- An independent kHz-speed perturb-and-observe MPPT algorithm on each SAI channel.
- User-configurable maximum SAI current settings for lander power for in-transit battery charging.
- An overvoltage (OV) shunt resistor (internal or external) to handle cold solar cells and rapid load changes.

Problem: Battery Topologies & Heating

Many legacy PSSes have topologies that are fundamentally tied to a particular battery voltage. A "28V battery" may require solar cell strings that are within a few volts of the (unregulated) battery voltage, limiting options when laying out the solar panels. This is especially apparent when trying to match the typical 2.5V/cell of triple-junction space solar cells with the much lower, chemistry-driven per-cell voltage of space batteries. The resulting unregulated or regulated voltage rails can substantially frustrate the rover designer, as this can create a design requirements chain all the way from the batteries to the solar arrays, without taking the loads into account. This battery constraint (for a particular SxP battery cell configuration) may also affect physical battery integration in the rover itself. The rover design should drive the battery selection and solar array configuration, not the other way around!

Figure 4: BM2 Intelligent Battery Module

Additionally, any lunar rover that must survive the lunar night will most likely require battery heating to avoid irreparable damage to the cells. This can be done at the cells themselves, around the batteries, or in a combination of both approaches.

Solution: The EPSM1 treats batteries simply as a source of energy, and is not architecturally dependent on the battery voltage. With 16V (4S2P), 100Wh BM2s, the EPSM1 can deliver regulated output voltages up to 28Vdc and at over 200W, for any supported solar cell string voltages. Pumpkin's BM2 battery utilizes dedicated heaters in each of its 18650 cells. The battery cell heaters operate in automatic or manual modes, drawing from whatever power is available; the BM2 can self-power its heaters at any time. *In a convection test environment*, the BM2's cell heaters are adequate to maintain a cell temperature above 0C in ambient -25C conditions. In a lunar rover (without convection) at much lower ambient temperatures during the lunar night, additional secondary battery insulation and/or heaters may be required, depending on the rover's design in terms of thermal conduction and on what other heat sources may reside inside the "heart" of the rover.

Problem: Sleeping at Night

For rovers that must survive hours or days of night-time operation without solar illumination, getting down to a minimum-power mode while operating survival heaters will be required so as not to exhaust the batteries prematurely.

Solution: The Pumpkin EPSM1 and BM2 each support a sleep mode which minimizes supervisory MCU cycles and provides for a "intermittently ON" mode. This mode (with a command that specifies the duration of the sleep time) allows for scheduled wakeup to do a health check on the rover ("Are the batteries still above a minimum temperature?") driven by the only source of energy available during sleep -- the batteries themselves. This means that higher-power system elements like primary OBCs can be left OFF during sleep times, if so desired or required. Once solar power is available, the EPSM1 automatically restores power to the system. Note that the EPSM1 functions whether or not its batteries are attached and/or enabled; the EPSM1 can "wait" while batteries heat back up before it begins charging them within the cells' permitted charging temperature range. Unregulated battery power (12-16V in the BM2's case) is also available directly from the BM2 batteries independent of the EPSM1.

Conclusion

Legacy PSSes often come with a variety of inherent features that may unnecessarily complicate the design of a modern extraterrestrial rover, or hinder cleaner design solutions. Pumpkin's complete space-proven power supply system topology (one or more custom PMDSAS solar panels, the EPSM1 electrical power system and up to two BM2 batteries) provides a powerful and cost- and volume-effective solution for many common space rover requirements.