Importance of Shunt Switching Recovery Time for Solar Array Simulators

By Jim Martens

During spacecraft integration and testing activities, the solar arrays are replaced by a Solar Array Simulator (SAS), which delivers electrical power to the power management subsystem by reproducing the electrical behavior of a real solar array. A SAS needs to output power with the same characteristics as an array of photovoltaic (PV) cells.

An overall goal for a SAS is to simulate the performance of real solar cells as closely as possible, both statically (voltage and current levels) and dynamically with respect to output capacitance, response time, etc. Therefore, the response time of the SAS Module output has been identified as one of the most important design drivers.

It can be useful to look at where the SAS Module is operating on an IV curve when specifying the dynamic behavior. Figure 1 defines three areas of the IV curve; different types of power conditioning units (PCUs) normally work within only one of the three areas when steady state is reached. Systems based on shunt regulators can behave in a way that covers "Case 2" and "Case 3" when the operating point of one section jumps from Isc to MPP.

Examples of regulators working in the 3 areas are:

- Series switching devices or DC-DC converters operating in the area of "Case 1".
- Shunt regulators in the area of "Case 2".
- Shunt regulators in the area of "Case 3" when operating point of a section jumps from Isc to MPP.
- Maximum power point trackers in the area of "Case 3".

Power Regulation

The power coming from solar arrays needs to be regulated to ensure a safe and efficient power transfer. The PCU is responsible for making the incoming power usable to the rest of the system by regulating it. Due to the I-V characteristic of PV cells, the maximum power transfer is achieved somewhere in the middle of the curve. At that point, the power transfer is most efficient. If the system contains a battery, the PCU also handles the distribution of power between solar arrays and battery, and it provides the battery with an appropriate charging voltage. There are two main methods of regulating the power coming from solar arrays.

Direct Energy Transfer

With direct energy transfer (DET), excess energy is dumped using shunting resistors. When an array is generating power that is not needed, the output of that array is shorted with a shunt resistance and the shunting component radiates the extra energy as heat. Usually, string groups are shunted sequentially according to the amount of excess power. This means one group is shunted partially using pulse width modulation and the rest of the strings are either fully on or off. This technique is called sequential switching shunt regulation (S3R). The advantage of DET is that the power from the panels is transferred directly to the PCU with no complex switching regulators in between. It is very efficient with no power loss in regulating components. The disadvantage of DET is that the power being shunted needs to be dissipated as heat which can be problematic in space. An additional disadvantage in the context of simulating an array is that due to fast switching of the solar panel output, the SAS needs to have a good dynamic response to closely approximate the solar panel I-V curve at all times.

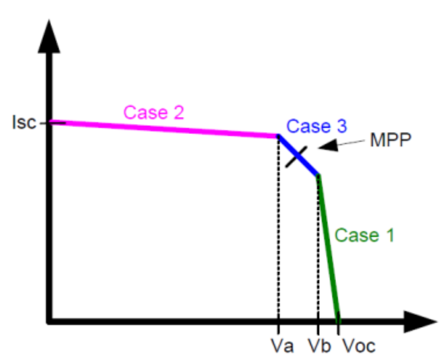

Figure 1: Working areas of the IV curve.

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Maximum Power Point Tracking

Maximum power point tracking (MPPT) is a technique where the solar array output is always kept at a voltage that gives the best power transfer from the panel to the load. This is done by using a series regulator between the panels and the rest of the system. The regulator tracks the voltage of the panel to always keep it at the maximum power point. This ensures maximum panel output efficiency but results in part of the energy being lost due to regulator inefficiencies.

The output characteristics need to be customizable to represent the specific solar cells used on the spacecraft under test. Adaptable curve parameters create more flexibility for a SAS to be utilized to test different spacecraft. In addition, the dynamic response of the SAS needs to be fast enough to keep the output on the I-V curve in all operating conditions. While this is a lesser issue with PCUs using MPPT to regulate the panel voltage, it becomes an important characteristic for spacecraft using DET methods. For example, in the case of sequential switching shunt regulation, the panel (and therefore the SAS) output can be constantly switching between short circuit and any other point on the curve. In this situation, it is important that the SAS responds quickly to any change in the load to accurately represent a real solar panel.

Solar panels have a near instantaneous response with little to no overshoot or ringing when switched from a short circuit to an operating point on the current side of the I-V curve. Typically, shunt switching regulators are operated in the 10-30KHz range. Given this switching frequency range using a 50% duty cycle, the time period that power is transferred to the main bus is between 16.5-50µseconds. With actual solar panels, nearly 100% of the power is transferred to the main power bus. The slower the solar array simulator response is, the less power is transferred to the main power bus. Remember, during shunt switching the current does not change a lot, but getting to a stable value is critical. AMETEK Programmable Power's Fast Profiling Current Source (FPCS) shunt switching recovery time is specified at 2µseconds to within ± 10% of the operating point, and a competitor's shunt switching recovery time is specified at 12.5µseconds to within 1.5A of the operating point. In the 1000W, 10A Isc worst case theoretical examples shown below the AMETEK FPCS recovers to within 1A of the operating point. Whereas the competitions' SAS recovers to within 1.5A or ±15%.

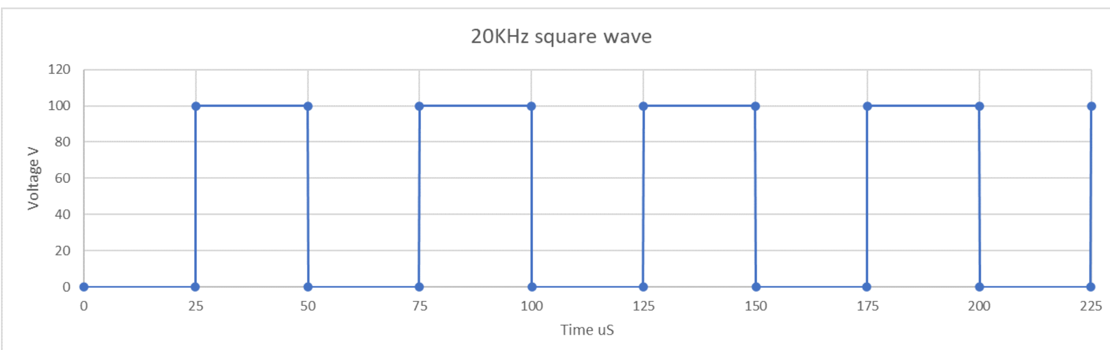

Figure 2: 20kHz square wave shunt regulation

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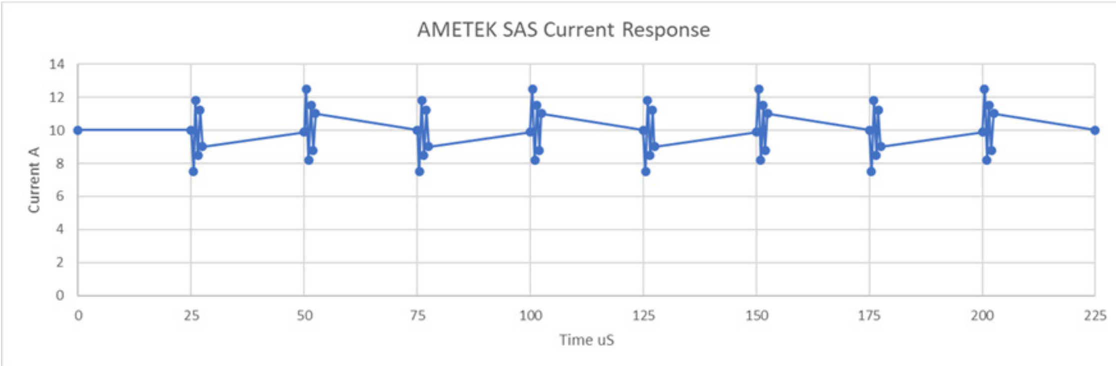

Figure 3: AMETEK Programmable Power FPCS shunt switching recovery time (theoretical)

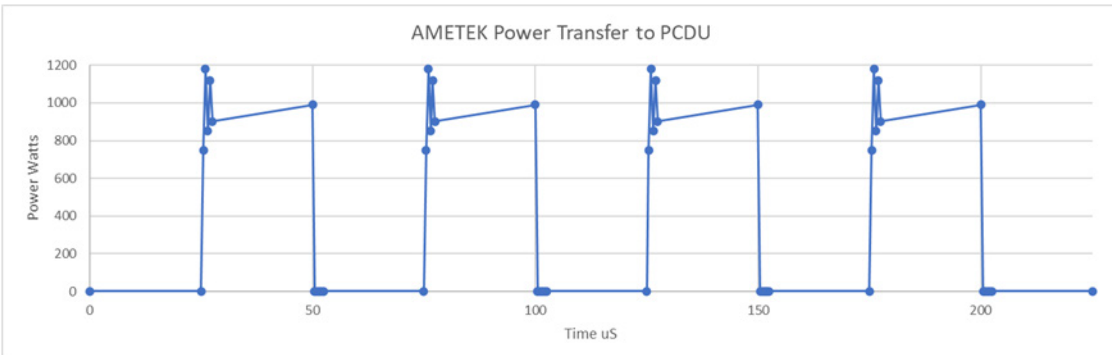

Figure 4: AMETEK Programmable Power FPCS Power Transfer (theoretical)

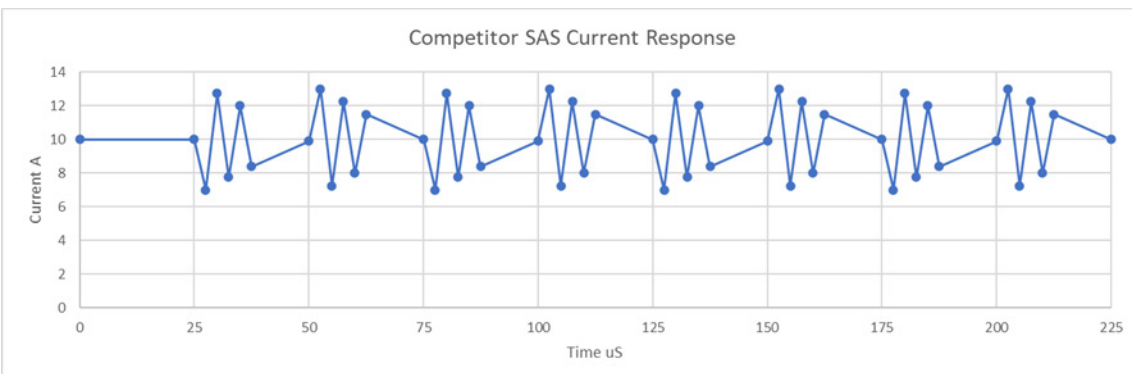

Figure 5: Competitor shunt switching recovery time (theoretical)

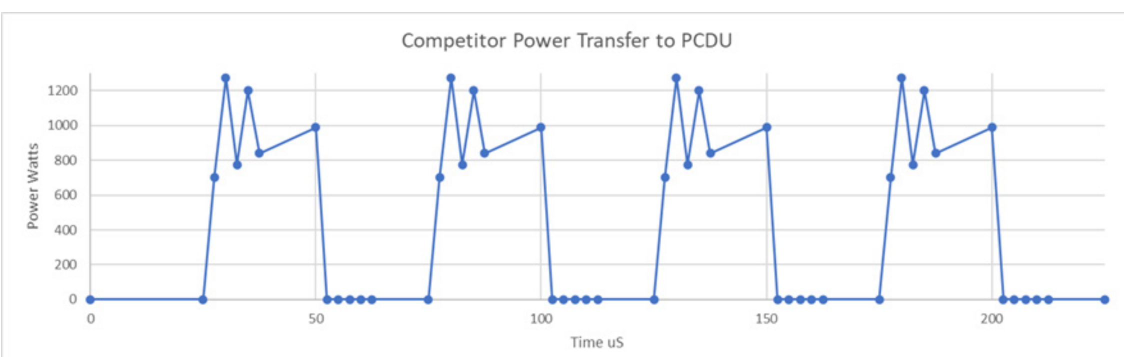

Figure 6: Competitor Power Transfer (theoretical)

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Given the waveforms above, it can be seen that the AMETEK Programmable Power FPCS theoretically provides stable power during 92% of the power transfer time at 20KHz, whereas the competitor's SAS theoretically only provides stable power during 50% of the power transfer time at 20KHz. Over the range of 10 to 30KHz, AMETEK Programmable Power's power transfer time is greater than 88%, while the competitor's can drop to as low as 24%. When a SAS does not provide the power expected by the PCU, it will change its behavior of the Pulse Width Modulation (PWM) and can result in more SAS strings being used than required.

Another factor to consider is the current spike that is generated when the switching occurs. The peak of this spike has a direct correlation to the dv/dt of the switch. The faster the switch, the greater the peak current spike. Figures 3 and 5 above do not reflect this current overshoot spike. AMETEK Programmable Power's FPCS is specified to have a current overshoot of less than 10A/500W channel or 20A/1000W channel with a 50V/µsecond dv/dt.

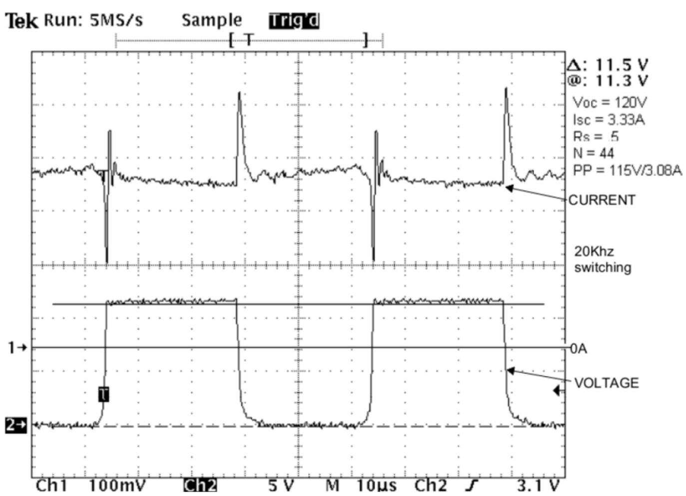

Figure 7: The waveform above shows the actual AMETEK FPCS shunt switching recovery at 20KHz.

Conclusion

A solar array simulator's main goal is to simulate a solar array as close as possible. The most important parameter is the dynamic response. AMETEK Programmable Power's FPCS comes the closest to an actual solar array with its 2µsecond shunt switching recovery time, providing the expected power to the PCU.

For More Information

To learn more about the company's programmable power sources and supplies and engineered solutions, contact AMETEK Programmable Power Sales toll free at +1 858-458-0223, or by email at sales.ppd@ametek.com. Users can also contact an authorized AMETEK Programmable Power sales representative.

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