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WHITE PAPER

Solar-Array Simulator Enables Small Satellite Ground Test

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Small satellites having masses up to a few hundred kilograms serve a variety of applications, most often in low earth orbit (LEO). Taking on many tasks that had been the domain of much more expensive large satellites in medium earth orbit (MEO) or geostationary earth orbit (GEO), they are serving earth observation, navigation, communication, and military reconnaissance applications, and they also find use in a variety of scientific research projects.

Small-satellite Categories

Bryce Tech, an analytics and engineering firm, cites five categories of small satellites with respect to mass:

- **Minisatellites** (201 to 600 kg)
- **Microsatellites** (11 to 200 kg)
- **Nanosatellites** (1.1 to 10 kg)
- **Picosatellites** (0.1 to 1 kg)
- **Femtosatellites** (0.01 kg to 0.09 kg)

The term CubeSat represents yet another category, although it is based on form factor rather than weight. According to NASA, a 1U CubeSat measures 10x10x10 cm up to 12U configurations.

Small Satellite Launches

NASA reports that as of its first Small Spacecraft Technology State-of-the-art report in 2013, 247 CubeSats and 105 other non-CubeSat small spacecraft with a mass less than 50 kg had been launched worldwide, representing less than 2% of the total launched mass into orbit. In its latest report, based on data from September 2023, the organization notes, "Since 2013, the flight heritage for small spacecraft has greatly increased as they have become the primary source to space access for commercial, government, private, and academic institutions."

Bryce Tech reports that 2,402 Small satellites, predominantly in the minisatellite category, launched in 2022, representing 96% of all spacecraft launched during the year and accounting for 55% of the total spacecraft upmass. The firm adds that communications satellites represented the largest share (76%) of small satellites launched in 2022, with remote-sensing satellites coming in a distant second at 10%. Looking to the future, market research firm Mordor Intelligence estimates that the global small satellite market will grow from $166.4 billion in 2024 to $260.56 billion in 2029.

Ground Tests

All these small satellites must undergo extensive ground tests before launch. During these tests, a solar array simulator (SAS) must stand in for the solar panels that each satellite will deploy in orbit. Of course, all satellites require a SAS for ground test, but the simulation requirements differ between large and small satellites.

Large satellites tend to employ shunt regulation to condition the output voltage from their comparatively large solar panels, because shunt regulation is relatively uncomplicated and reliable compared with the alternative technique—maximum power point tracking (MPPT). Small satellites, however, mainly use the MPPT regulation approach to extract the maximum possible amount of power from their smaller solar arrays, and MPPT offers higher efficiencies than shunt regulation.

I-V Output Characteristic

A SAS for satellite test must accurately mimic the actual solar array's output current-voltage (I-V) curve. For optimal performance, a SAS for MPPT should have an I-V curve with a relatively soft knee. In contrast, a SAS for shunt regulation test would have a sharper knee to help it meet a more critical specification for large satellites: fast shunt switching current recovery time.

The following equation represents an I-V curve with a relatively sharp knee suitable for large satellite shunt regulation test, based on open-circuit voltage Voc, short-circuit current Isc, and series resistance Rs:

$$V = \frac{\left(\frac{Voc\, ln\left(2 - \left(\frac{I}{Isc}\right)^{N}\right)}{ln(2)}\right) - Rs(I - Isc)}{1 + \left(\frac{RsIsc}{Voc}\right)}$$

The following equation represents the I-V characteristic for an IV curve with a softer knee suitable for small satellite MPPT test:

$$I = Isc * (1 - C1 * \left(\exp\left(\frac{V}{C2 * Voc}\right)\right) - 1)$$

In this equation, C1 and C2 are calculated from Voc, Isc, the maximum power point current Imp, and the maximum power point voltage Vmp as follows:

$$C1 = \left(1 - \left(\frac{Imp}{Isc}\right)\right) * (\exp\left(-\frac{Vmp}{C2 * Voc}\right))$$

$$C2 = \left(\left(\frac{Vmp}{Voc}\right) - 1\right) * \left(Ln\left(1 - \frac{Imp}{Isc}\right)\right)^{-1}$$

Figure 1 shows the sharper knee region of the I-V curve suitable for shunt regulation test on the left and the softer knee region of the I-V curve suitable for MPPT test on the right.

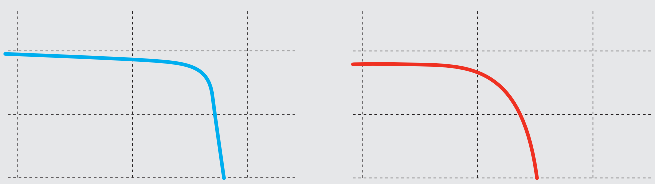

Figure 1. *These I-V curves show knee regions suitable for shunt-regulation test (left) and MPPT test (right).*

An MPPT implementation makes use of an algorithm that can locate the point on the array output's soft I-V curve at which maximum power can be extracted, and a SAS used for test must accurately represent the I-V curve of the array that will be used in orbit.

One approach to MPPT is for a satellite's power system to use dithering to alter the operating position on the I-V curve. To successfully exercise this dithering function, a SAS for MPPT simulation should have a high closed-loop bandwidth, low output capacitance, and a fast-tracking speed.

Maintaining Cost Effectiveness

In addition, a SAS tailored for the small satellite market does not require some of the features necessary for the large satellite market. These features include a fast shunt recovery response time and a rapid series switching time as extensive and expensive redundant safety functions such as programmable primary and secondary overvoltage and overcurrent protection, overtemperature protection, electronic circuit breakers, and an external interlock shutdown. A single programmable overvoltage protection function, a fixed overcurrent protection function, a fixed overtemperature protection function, and an interlock suffice as a cost-effective set of protective features for a small-satellite SAS.

Other features to look for in a SAS include a high-power density to save space in the test facility and leave additional rack space for other instrumentation. In addition, small satellites in LEO will experience extended periods of darkness, so an effective SAS can replicate a wide range of eclipse profiles. The SAS should also be controllable over a standard LAN interface, come with an easy-to-use GUI, and for maximum flexibility, be programmable using SCPI commands.

Small Satellite SAS Details

To serve the growing small-satellite market, AMETEK Programmable Power has developed the Elgar m-SAS mini-Solar Array Simulator. The Elgar m-SAS features a single channel delivering up to 840 W at 60, 80, or 150 V at 14, 10.5, or 5.6 A. Line regulation is 0.005% of rated output voltage plus 2 mV and 0.01% of rated output current plus 2 mA. The Elgar m-SAS primarily targets the minisatellite segment and heavier microsatellite categories, for which it is a sufficiently powerful and cost-effective solution.

Offering high power density, the Elgar m-SAS fits in a 1U chassis. Designed specifically for MPPT functionality, m-SAS features low output capacitance and a high-resolution I-V curve that simulates static and dynamic conditions with a 250-Hz tracking speed. On the input side, it has active power-factor correction to provide a power factor of 0.99, and inrush current is limited to 25 A.

Controlled by a digital signal processor (DSP), the m-SAS can be operated over a standard LAN interface using the AMETEK m-SAS software GUI and SCPI commands. It offers a full line of eclipse irradiance profiles that allow you to simulate any eclipse scenario, running at actual speed to 100 times actual speed for accelerated tests. Voltage output programming accuracy is ±0.2% of the maximum open-circuit output voltage, and current output programming accuracy is ±0.5% of the maximum short-circuit current.

Elgar m-SAS protection features include output overvoltage protection that is user programmable to 110% of Voc, output overcurrent protection fixed at 150% of Isc, and overtemperature protection that monitors the m-SAS's linear regulator, causing the m-SAS to shut down if the temperature exceeds 75° C. Connections to the m-SAS are via the rear panel **(Figure 2)**, which includes the AC input connector, the DC output and sense connectors, the LAN interface, a USB interface, and a 25-pin D-subminiature auxiliary output port. Overall dimensions are 1.75 in. high, 19 in. wide, and 22.6 in. deep, and the unit weighs 21 lbs.

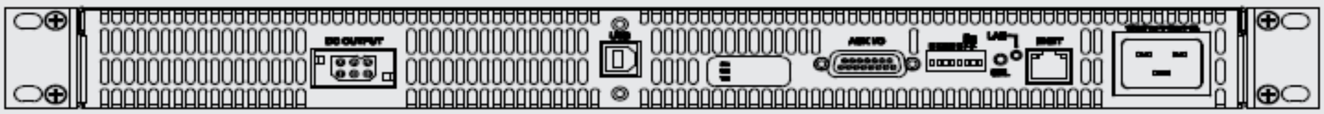

Figure 2. *The Elgar m-SAS back panel includes AC input, DC output, and output sense connectors as well as LAN and U/SB interfaces and an auxiliary I/O port.*

SAS Family

The Elgar m-SAS is the second member of AMETEK Programmable Power's NEXSIM family of space power simulation-related products. The first member is the Advanced Solar Power Simulator (ASPS) SAS, which targets the test of larger satellites. It offers a single 1,200-W channel or two 600-W channels and a Voc range of 40 to 220 V, and a shunt switching current recovery time of less than 2 µs. It offers extensive safety features, such as programmable primary and secondary overvoltage and overcurrent protection, overtemperature protection, an electronic circuit breaker, and a 10-µs external interlock shutdown. For more information, visit the Elgar ASPS product page.

In addition to the NEXSIM family, AMETEK Programmable Power offers a full lineup of standard programmable sources and loads as well as custom engineered systems, including TerraSAS terrestrial solar-array simulator. For more information view the TerraSAS product page.

Conclusion

The Small satellite market is growing rapidly with launches occurring regularly, as the small satellite form factor provides a cost-effective means for governments, universities, and commercial entities to get into space. But the satellites can remain cost-effective only if all costs can be controlled, including the cost of test. AMETEK Programmable Power's Elgar m-SAS is tailored to the needs of small satellite solar array simulation test requirements, providing the specific features needed for small satellite power systems, including the ability to effectively exercise a small satellite's MPPT function. Elgar m-SAS is the latest in AMETEK Programmable Power's lineup of reliable, easy-to-use, high power density programmable power products. For more information, visit the Elgar m-SAS home page.