WHITE PAPER

Design Satellite Power for Dynamic Orbit Realities

Lab-Based Emulation Helps to Accurately Predict Power System Performance Before Satellite Manufacturing and Launch

KEYSIGHT

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No Room for Failure in Complex Conditions

Communication satellites have evolved from simply retransmitting radio frequency (RF) signals between ground-based stations to actively participating in the network. With advanced RF systems and increased computing power onboard, modern satellites can direct and shape signal beams and process networking protocols and applications. The addition of powerful AI processing capabilities could enable satellites to serve as space-based data centers. These trends put intense stress on requirements for satellite power generation and distribution, which remain constrained by size, weight, and power (SWaP), as well as by the physical and economic limits of satellite launch vehicles.

By emulating real-world conditions in the lab, engineers can determine performance and reduce the chance of failures in increasingly complex satellite power systems. Solar arrays, for example, now typically consist of multiple panels connected in series and/or in parallel, depending on current and voltage requirements. Battery subsystems must be able to power the entire satellite during periods when illumination is unavailable or impaired, without being oversized beyond reasonable capacity margins. At the same time, power distribution systems must continuously balance solar generation with the battery state of charge to deliver reliable power to each voltage rail for payloads and control systems.

Given the dynamic, complex nature of solar array and battery behavior, testing satellite power under nominal conditions is insufficient. Solar panel performance depends on a variety of conditions experienced in orbits that are often highly kinetic, and panel characteristics typically vary from panel to panel. Battery pack performance ranges in complexity between fully charged and fully discharged states. Both subsystems require robust models and highly capable equipment to reproduce and test system behavior under dynamic conditions.

Anything But One-Size-Fits-All in Three Orbits

To understand why satellite power is getting more complex, engineers need to consider the development of many more satellites of various sizes, orbits, and mission capabilities. They are listed below from lower to higher electrical power demand:

- Low Earth Orbit (LEO) satellites, now numbering in the tens of thousands, were among the first NewSpace technologies to lower the cost of launching missions. Many of these are CubeSats, which are small, modular platforms often built from commercial-off-the-shelf (COTS) electronics modules. LEO platforms often operate in coordinated constellations for non-terrestrial network (NTN) services or, individually, run experimental missions or unique exploration. Shorter distances from Earth require less RF transmission power and yield lower latency.
- Medium Earth Orbit (MEO) platforms numbering in the hundreds offer more predictable orbits. A semi-synchronous orbit, for example, passes over the same two points on the Equator each day, which is useful for navigation. Radiation at those altitudes impacts reliability and requires mitigation. RF transmission power is also higher.

- High Earth Orbit (HEO) platforms are the largest and most complex satellites, dubbed "exquisite" by planners. Geosynchronous Earth Orbit (GEO) is common. Larger payloads enable complex missions, such as high-resolution imaging and surveillance. RF transmission power grows with larger distances to cover and more interference to overcome.

The sheer number of satellite platforms is growing, and the design cycle time is shrinking as proponents seek to launch and bring platforms online more quickly. These trends leave less time for each unique power system design and for a thorough evaluation of its performance.

Higher Power Drives Semi-Custom Designs

Breaking down satellite power system requirements reveals three common dynamic subsystems: a photovoltaic array for generation, power conversion and management, and energy storage, as shown in Figure 1. Requirements vary with satellite size, features, payload, and mission. At the low end are modular electrical power system (EPS) cards plugged into a CubeSat backplane, providing a few common voltage rails coupled with a simpler, integral-mount photovoltaic panel and a rechargeable battery or supercapacitor pack.

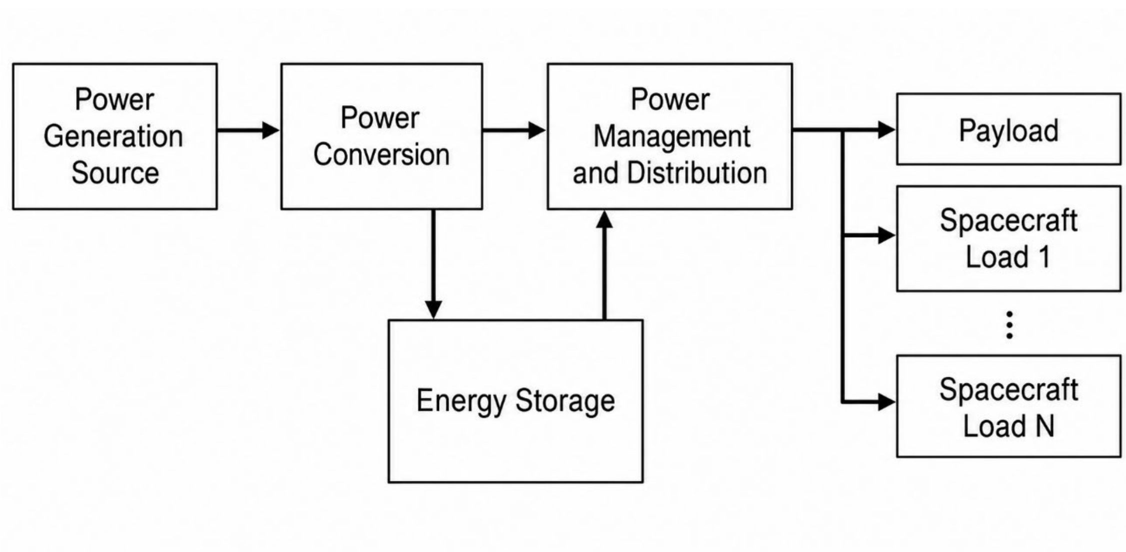

Figure 1. This graphic shows a basic satellite power system. [Credit: Dr. Frankie Zhu, Hawaii Space Flight Laboratory (HSFL)]

Higher-end LEO, MEO, and HEO platforms with more power demand may rely on multiple photovoltaic panels, possibly with orientation capability, and a power-conditioning and distribution unit (PCDU). Often, PCDUs come fully integrated with a solar panel controller, power conversion, and a battery subsystem, with packaging ready for avionics rack mounting. Whatever the configuration, PCDUs must deliver reliable system power under all conditions, maintaining full readiness to ensure proper satellite payload and actuator operation.

Thermal management is also a consideration. Current running through a system leads to power dissipation at points of conversion and switching. Pushing for smaller designs increases power density. If too much power dissipation concentrates in too small a space, however, overheating can occur and cause failures. Elevated temperatures over longer periods reduce reliability and mean time between failure (MTBF), thereby compromising the intended mission life. Designers must anticipate operating conditions and balance power density with thermal density.

Semi-custom PCDU design is common practice among satellite avionics manufacturers, typically basing new designs on a similar unit developed for another satellite program. Each design is unique in terms of the physical space and weight available on the satellite, the configuration of solar arrays and batteries, and the number of rails and the required wattage delivery. More complex PCDUs offer high-power switching, surge protection, and power sequencing.

PCDUs, whether procured or designed in-house, become devices under test (DUTs) during the integration phase. Power supplies and passive electronic loads have served as test stimuli in many design evaluation efforts. However, today's complex satellite power designs call for advanced testing under a broader range of realistic scenarios. A deeper look at solar panel and battery performance reveals why next-generation power subsystem emulation reduces overall risk and excels at system testing, yielding higher design confidence.

Inside Solar Array and Battery Performance

Given the breadth of satellite orbits and the varied approaches to power system design, it can be difficult to recreate and test the exact environmental and operating conditions an orbital platform might experience. Yet accurately recreating foreseeable conditions during the power system design phase is essential, as post-launch power outages can temporarily put satellites out of service, or worse, turn them into multi-million-dollar bricks orbiting the planet uselessly.

Many power design approaches adopt a min-nominal-max philosophy for testing and evaluation at a few operating points. However, the behavior of solar arrays and batteries is far more complex than simple models can capture, making the case for more sophisticated subsystem emulation.

Photovoltaic Array Fundamentals

Photovoltaic panels are fundamentally current sources, composed of photovoltaic cells connected in series or in parallel to achieve a desired nominal power output. Paralleling cells provides more current, while serializing cells delivers more voltage. Similarly, panels can be strung in series or parallel to form an array that provides the total power needed by a satellite. An array can have a single output or multiple outputs per panel, which can be diode-summed or handled individually at a PCDU.

A simplified equivalent circuit for a photovoltaic cell is shown in Figure 2. It contains a current source, a protection diode, a series resistance, and a shunt resistance. The current source provides current when illuminated, but several other conditions can affect the output.

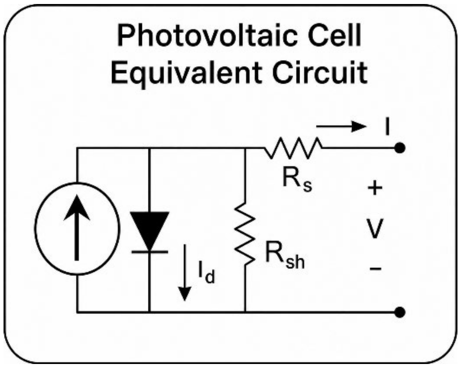

Figure 2. A current source provides current when illuminated in this photovoltaic cell equivalent circuit.

I-V Characteristics of a Panel

The current-voltage (I-V) characteristics of a solar panel follow a nonlinear curve that varies with the following:

- Irradiation
- Temperature
- Shadowing
- Reflectivity
- Absorption
- Aging

As a result, arrays under real-world conditions could range from producing an I-V curve with little output power to one with maximum output power. Each of the above conditions changes the shape of the I-V curve differently, and interaction between conditions can create a highly complex curve. A basic I-V curve is shown in Figure 3, illustrating the short-circuit current, open-circuit voltage, and maximum power point. Curves may vary slightly from manufactured panel to panel.

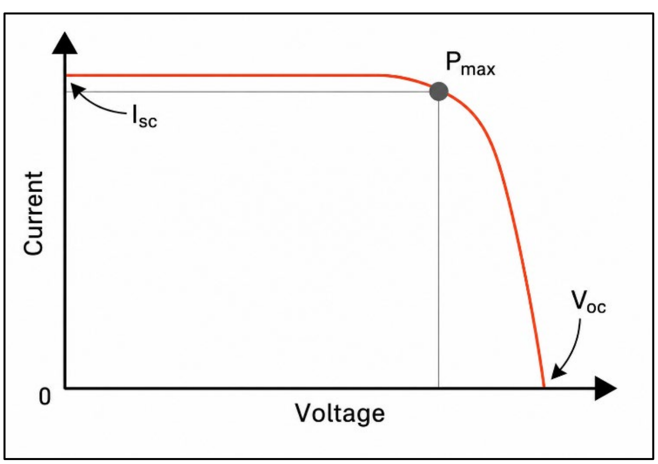

Figure 3. Shown are the basic I-V characteristics of a solar panel on an arbitrary scale.

Current Drops with Lower Irradiation

The irradiation level a panel sees depends on the sun's intensity, angle of incidence, and the panel's orientation as the satellite moves. It significantly affects the panel's output current and the corresponding power delivered, as shown in Figure 4, but has less effect on the panel's output voltage.

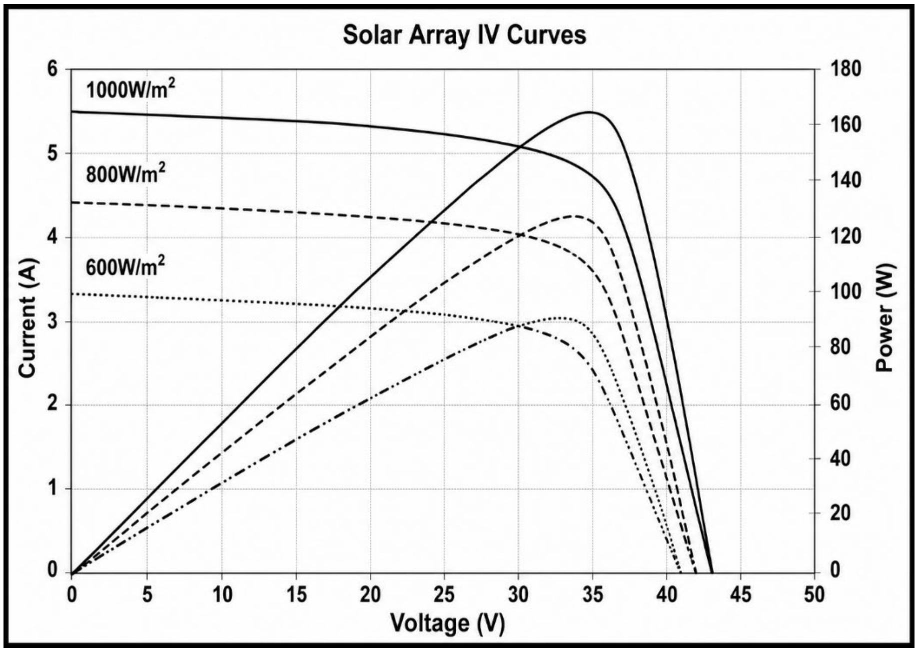

Figure 4. Shown are the effects of changing irradiation on a panel, with most of the shift in output current.

Voltage Drops as Temperature Rises

Temperature swings in space are dramatic. They fluctuate between the cold, dark "night" and the harsh light of "day," which can occur several times in an Earth solar day as a satellite orbits. Temperature primarily affects the panel's output voltage, as shown in Figure 5. It therefore impacts the power delivered, with a lesser effect on current. Cool arrays perform significantly better than hot ones.

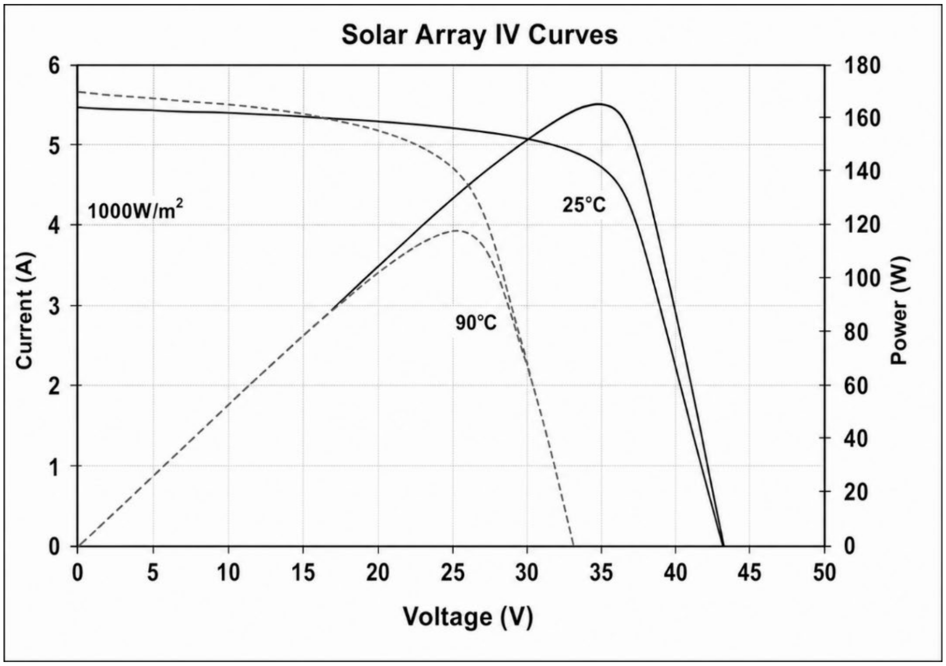

Figure 5. Effects of changing temperature on a panel show a pronounced shift in output voltage.

Shadowing Creates a Power Notch

Generally, irradiation and temperature shift the I-V curve while retaining its familiar knee shape. But shadowing a panel has a different effect. Bypass diodes around solar cells can mitigate panel power reduction due to shading. Still, shading some cells while others are in illumination creates a deformed composite I-V curve for the panel, introducing a notch where the maximum power point knee should be, as shown in Figure 6.

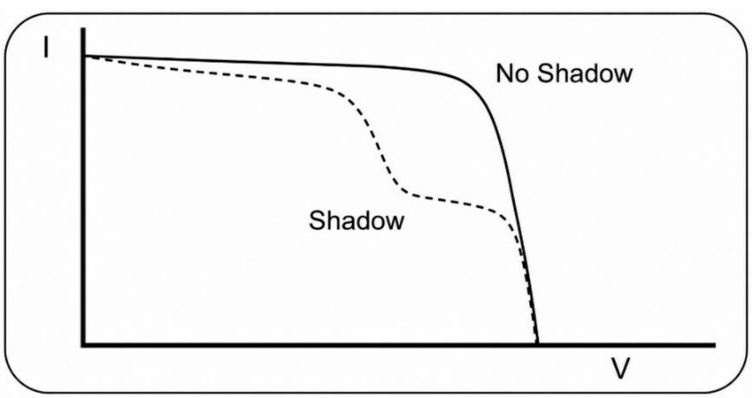

Figure 6. Effects of shadowing a panel show deformation at the knee, dramatically reducing power.

More Conditions Affecting I-V Curves

Three more operating conditions also affect panel output, though usually less dramatically than those discussed earlier:

- Solar cell coatings and protective overlays are usually imperfect and often cause changes. Higher angles of incidence can increase reflectivity, and yellowing of the coating or encapsulant can impede light absorption. Both tend to lower a panel's output current.
- Aging often reduces solar cell output, with degradation rates of 0.3% to 0.5% annually. Increased series resistance, altering both voltage and current, flattens the knee of the I-V curve, making it more difficult for a panel to operate efficiently.
- Output loading sets the operating point on the I-V curve. A resistive load forms a straight diagonal line crossing the I-V curve at the power point. Capacitive or inductive loads can cause brief transients, but the I-V curve remains unchanged.

Bus Regulation Topologies

Bus regulation extracts the desired voltage, current, and power from a solar array. Three bus regulation topologies include the following:

- Direct connection
- Sequential shunt switching
- Maximum power point tracking (MPPT)

Direct Connection

A direct connection may work for smaller, simpler satellite power systems, such as those found in CubeSats. It aims to match array output operating range to the required bus voltage, as shown in Figure 7. However, the array operates inefficiently, typically well below its maximum power point.

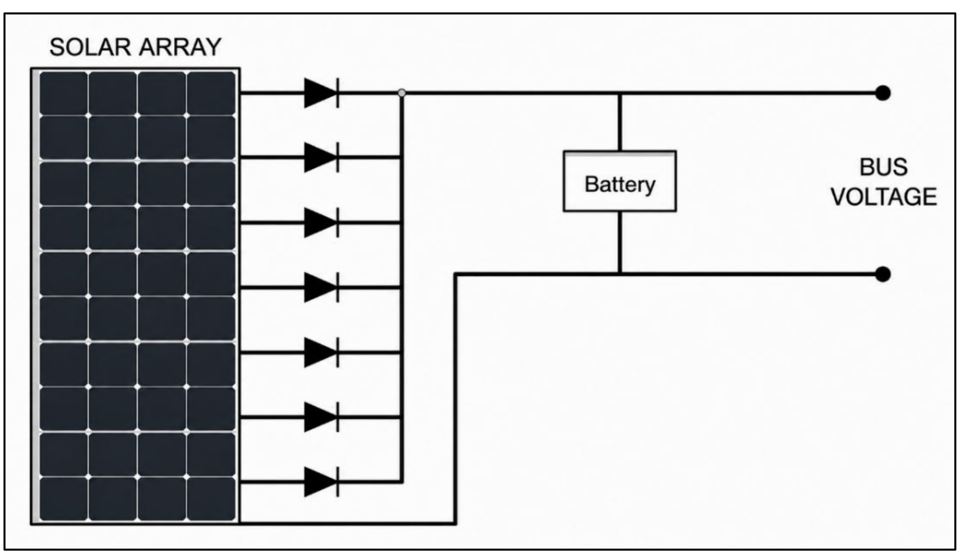

Figure 7. Direct connection of a solar array is simple but inefficient, making it suitable only for small satellites.

Sequential Shunt Switching

Sequential shunt switching adjusts which panels in the array deliver current based on power demand, shorting panel outputs when not needed, as shown in Figure 8. Essentially, this technique modulates the panel's output current to achieve regulation. The approach is simple, requiring few components and little weight, but delivers a dynamic response. However, shorting the outputs dumps thermal power into the array, causing voltage drops as the panels heat up. Efficiency is also lower because the array usually operates under its maximum power point.

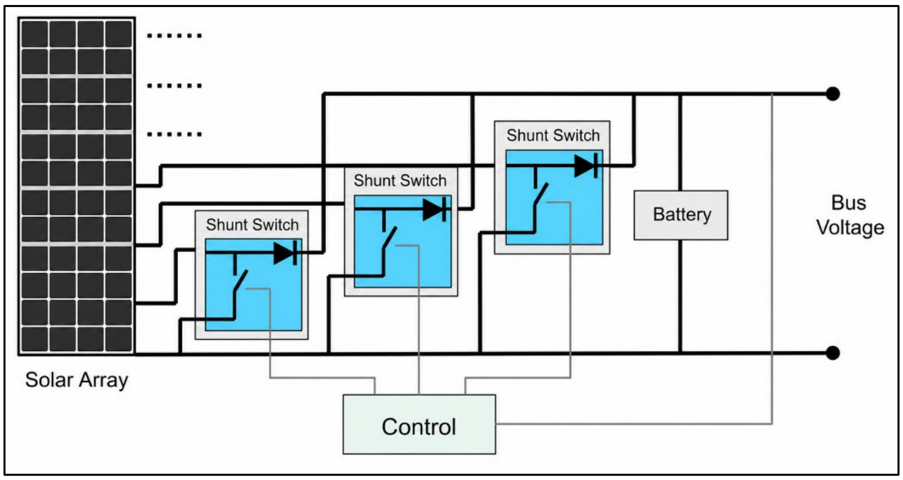

Figure 8. Sequential shunt switching brings panels online and offline as needed to maintain regulation.

Maximum Power Point Tracking

MPPT is a more nuanced, modern approach than brute-force sequential shunt switching, but it increases complexity. Two control loops, comprising a fast voltage loop and a slower MPPT loop, regulate power delivered by DC-DC converters, as shown in Figure 9. As these loops continuously seek the maximum power point for the array on a given I-V curve, they minimize conversion loss and reduce thermal loading. Added component weight is a tradeoff for improved efficiency.

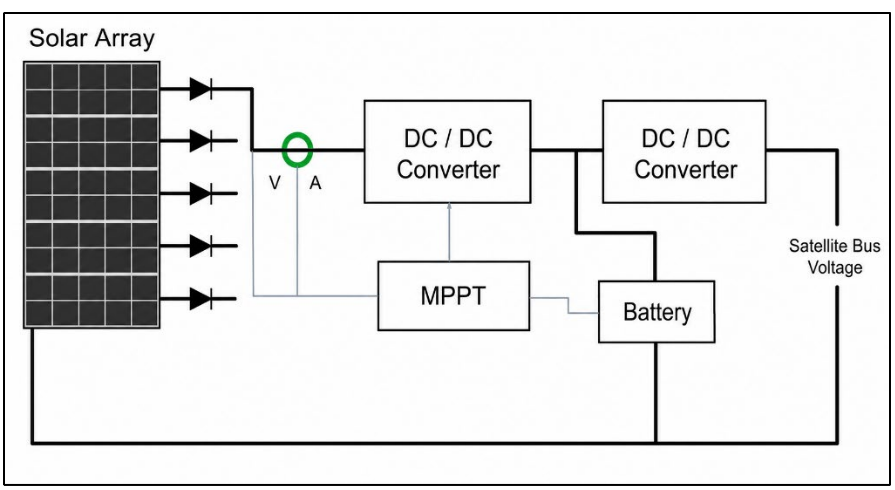

Figure 9. An MPPT implementation is more complex, but also more efficient.

MPPT can overcome many of the I-V curve effects already described, including combinations of effects. It can also deliver the maximum power possible under the conditions at the time, dynamically and continuously adjusting as conditions change.

Battery Pack Fundamentals

Satellite battery packs may comprise anywhere from a few dozen to a few hundred battery cells, depending on requirements. Like solar cells, battery cells can be connected in series for higher voltage and in parallel for higher current. Different rechargeable battery technologies with unique chemistries exhibit a variety of characteristics, but a lumped-element equivalent circuit model can approximate most cells. The simplest is the R_{int} model shown in Figure 10, which consists of a variable, ideal voltage source in series with a resistor representing the cell's internal resistance.

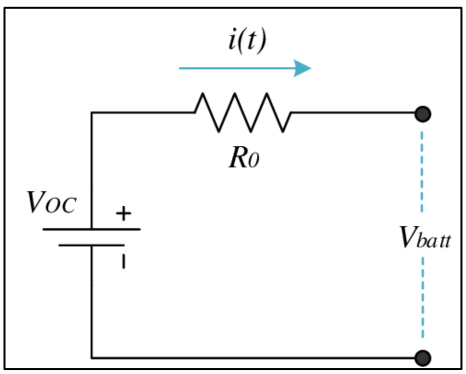

Figure 10. This graphic shows an R_{int} equivalent model of a Lithium-ion cell.

On a satellite, a battery management system (BMS) must be accurate because of the high risk of battery failure crippling the entire platform. Along with overseeing charging activity for a battery pack, a BMS estimates the following:

- State of charge or SoC
- State of health or SoH (how degraded cells are from when they were new)
- State of power or SoP (the peak energy a battery can supply or absorb safely for a short period of time)

Properly charging a Lithium-ion battery pack is a multi-step process that applies different charging phases to achieve specific BMS goals:

- The initial phase delivers as much current as safely possible to quickly raise a battery pack's SoC. Usually, the target is 80% SoC or a specific voltage. During the initial phase, the battery voltage rises steadily. In consumer devices, this phase is often called fast charging.
- The next phase begins when charging reaches the SoC or voltage target, at which point it shifts to constant-voltage mode. Because the battery pack is nearly full, it accepts less current. The constant pressure applied balances the charging levels of individual battery cells.

- The final charging phase provides a minimum voltage to prevent self-discharge, placing less stress on the Lithium-ion structure. This level keeps a battery pack saturated and ready to deliver full power.

Realistic Test and Evaluation of PCDUs

The objective of satellite power system testing in the lab is to recreate input and output conditions to validate a PCDU design. This task requires evaluating its behavior as a “black box” in accordance with requirements. PCDUs typically implement one or more of the bus regulation topologies for solar arrays, battery pack charging and management, and power conversion, distribution, and switching.

Start by considering how to model and reproduce the core behaviors of three satellite power subsystems: the solar array, the battery pack, and the electrical loads from satellite payloads and control elements. If purpose-built equipment can model behaviors with subsystem and system level fidelity, it becomes possible to devise test scenarios and sequences and accurately measure the PCDU inputs and outputs. Engineers can then observe how it responds to various conditions and confirm correct operation or identify defects.

Solar Array Behavior

The most obvious need is to emulate a photovoltaic array. Using physical solar panels would be expensive and take up valuable space in an engineering facility. Controlled lighting and temperature would be required to set precise, repeatable test conditions, adding to cost and space issues. Aging would eventually require panel replacement to maintain capability. Such a physical setup would likely reproduce only a few conditions, forcing design teams to pick and choose rather than capture all of the dynamic conditions that a satellite could encounter in orbit.

Orbital Dynamics

Common orbital dynamics alter array performance, but are difficult or impractical to reproduce in a lab using physical means. Satellites commonly change their orientation relative to the Sun as they orbit Earth. They often spin about their axes, causing panel output to fluctuate continuously, with the rate of change depending on rotational speed, as shown in Figure 11.

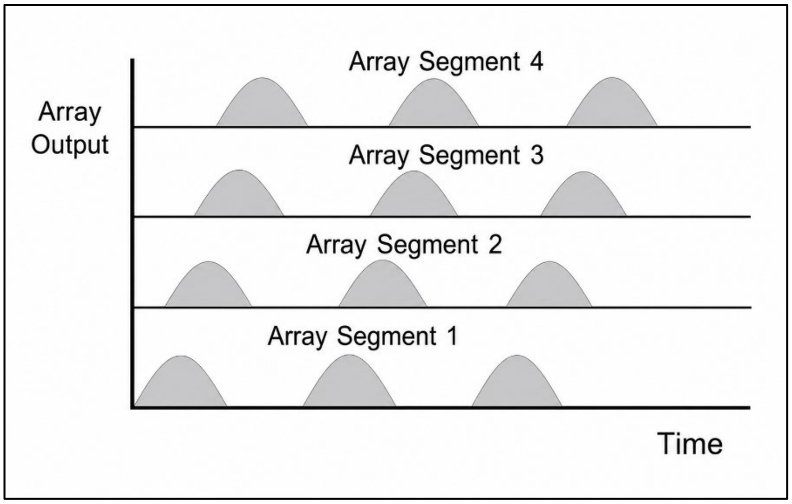

Figure 11. Fluctuations in solar panel outputs occur as a satellite platform spins around its axis.

A solar or lunar eclipse can affect an otherwise well-irradiated array, reducing or completely nullifying its output power for minutes, as shown in Figure 12. The time spent in an eclipse depends on the orbital height and plane. The rate of change through partial shadow (known as penumbra) to darkest shadow (umbra) and back depends on orbital velocity. A satellite may experience multiple impairment cycles during a single eclipse event if its orbital period is short. A simplistic eclipse-like effect might be possible to recreate in a physical array setup by controlling illumination, such as by using an array of individually controllable bulbs. This approach would increase the physical test setup cost once again, however.

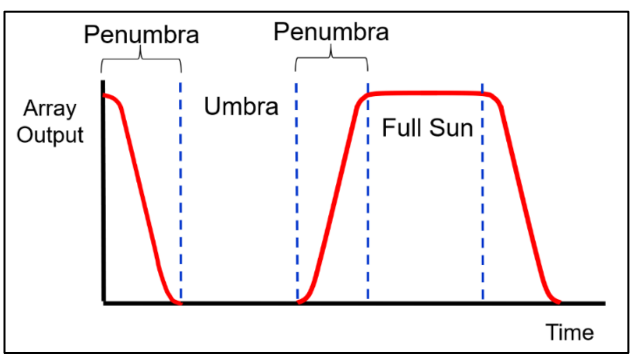

Figure 12. This simplified timeline represents solar array output during an eclipse.

Similarly, another orbiting object may cast a shadow on all or part of the array, particularly in LEO. This effect can change quickly as both bodies continue to move. It may last only a few seconds with limited impact. If a hostile satellite were intentionally deployed in an offensive configuration to disrupt operations, however, it may last longer. The duration could be sufficient to fully deplete the satellite's battery pack. Controllable shadowing with physical structures would be difficult to use for reproducing a continuously variable, repeatable effect.

I-V Curve Creation

An easier path for engineers would be to create a selection of I-V curves based on the physical panel characteristics already mentioned. While some curves represent fundamental impairments, others represent orbital-dynamic scenarios, and others a combination of effects.

Engineers can create a nominal I-V curve for a solar panel in two ways. One is to measure four parameters or obtain them from a panel manufacturer:

- Open-circuit voltage (V_{oc})
- Short-circuit current (I_{sc})
- Voltage at the maximum power point (V_{mp})
- Current at the maximum power point (I_{mp})

I-V curves can also be defined point-by-point in a custom table, with the number of points determining the resolution of the curve.

With a nominal curve in hand, scaling can reproduce impairments and scenarios with varying degrees of effect. Recalling stored curves is a matter of programming, and modifying curves for different solar array configurations is straightforward. Note that slight variations may be present from panel to panel.

Solar Array Versus Power Supply Output Characteristics

Because the output of a photovoltaic array is a current at a voltage, it might be tempting to use a power supply as a stand-in. However, conventional power supplies typically provide a near-constant voltage under varying loads, so their output offers low series resistance and high output capacitance. A photovoltaic array has nearly the opposite characteristics: moderate series and shunt resistances and little to no output capacitance, making its behavior at the load different. Another concern is output protection. Most conventional power supplies provide only basic overvoltage and overcurrent protection, which is insufficient for current spikes or thermal loads.

Battery Pack Behavior

A straightforward approach to battery pack emulation avoids numerous problems with using physical batteries for testing. Physical batteries are prone to wear from repeated charging and discharging, leading to frequent replacement. Testing full and empty is possible, but controlling the intermediate states of charge of physical battery packs for repeatable testing is difficult. To fully exercise the charging and BMS features of a PCDU, consider using a bidirectional power supply with programmable voltage and series resistance per the model in Figure 10, combined with the ability to source or sink current at variable levels on demand.

System Load Behavior

The easiest function to model and test is the loads seen by a PCDU on its output rails. Using physical payload and actuator hardware in the loop might be feasible, albeit expensive and perhaps occupying more space than is available in a lab. Passive loads might work. At the power levels involved, however, regenerative power supplies are a better option. They can emulate dynamic loads and reduce thermal energy consumption while enabling greater load capacity in less rack space. Loading programmed on demand, with controllable timing, can exercise all PCDU voltage rails, fixed or switched, together through various conditions.

Solve Power Test Challenges with Emulation

Using Keysight measurement science in high-power solar array emulators, electronic loads, and regenerative power supplies, a semi-custom PCDU can be put through its paces for a comprehensive evaluation long before launch. These solutions enable engineers to verify capabilities or reveal hard-to-spot design faults.

Figure 13 shows how three emulation units, comprising a solar array simulator, battery emulator, and load emulator, can replace physical subsystems in a lab. Together, they recreate the dynamic space conditions needed to evaluate satellite power system design earlier in the design cycle.

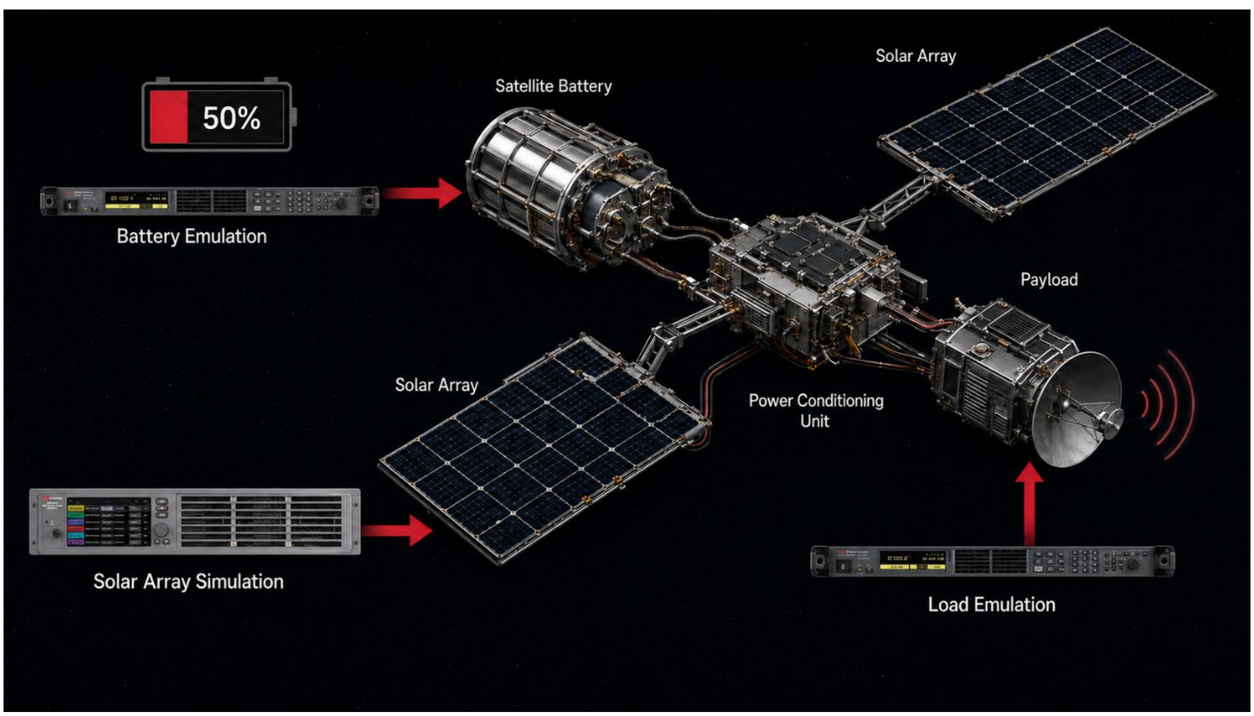

Figure 13. This simplified graphic of a satellite design illustrates how three types of emulation units could replace subsystems for more comprehensive testing.

Use Case: Multi-Scenario Stand-Ins for Solar Arrays

Here's a brief look at some relevant use cases and their primary benefits. Rather than trying to coerce a physical solar array to behave as expected under only a few irradiation conditions, a solar array emulator can provide programmed outputs with I-V curves that span irradiation, temperature, orientation, eclipse, and shadowing scenarios. This approach enables quick, repeatable state transitions during tests.

Once I-V curve models for various conditions are available, the emulator can apply them to reproduce any condition or combination of conditions. solar array emulator can provide programmed outputs with I-V curves that span irradiation, temperature, orientation, eclipse, and shadowing scenarios. This approach enables quick, repeatable state transitions during tests. Once I-V curve models for various conditions are available, the emulator can apply them to reproduce any condition or combination of conditions.

Figure 14. Shown are front and rear views of the MP4303A modular power system.

The Keysight MP4300A Series modular solar array simulator is a reconfigurable solution. It delivers up to 8.4 kW of power across six isolated outputs, each representing a panel, within a 2U rack-mount mainframe enclosure, as shown in Figure 14. Paralleling modules deliver more current. Additional mainframes in a rack can represent more panels for larger solar array configurations. Solid-state disconnect relays protect the outputs. For PCDUs without bus regulation, the emulator can run either MPPT at up to 200 Hz or sequential shunt switching at up to 20 kHz.

Three operating modes for each installed SCPI-programmable module provide flexibility:

- Fixed mode operates like a power supply, except with very low output capacitance.
- SAS mode constructs a nominal I-V curve from V_{oc}, I_{sc}, V_{mp}, and I_{mp} values.
- Table mode defines I-V curves from 1024 points, and stores up to 60 complete curves.

After a one-time effort to create I-V curve models, the MP4300A can use table mode to present a PCDU with a wide range of real space solar array output conditions. Programmable transitions can capture the dynamics of orbit in scenarios. Switching between I-V curves takes less than 8 milliseconds, and the outputs transition quickly with only 100 to 320 nF of capacitance.

Use Case: Battery Packs in Continuous Operation

Battery specifications seem simple. However, physical battery operation can be difficult to control and quantify. Battery emulation is easier to use and repeatable. It can accurately model and sweep battery characteristics, creating conditions to evaluate and quantify battery behavior as attached to a PCDU. Engineers can then test and right-size battery packs with confidence, avoiding overspecification of battery capacity and a corresponding increase in size and weight to meet specific design goals and margins.

Regenerative, bidirectional DC power supplies can serve as battery emulators, sourcing or sinking current to emulate continuous operation and supplying power to or demanding power from a PCDU. Keysight provides a family of bidirectional, regenerative DC power supplies that combine source and load functionality into a 2U to 5U rack-mount unit, handling up to 2000 V, ±800 A, and 30 kW. Two-quadrant mode allows smooth transitions between sourcing and sinking. These power supplies can continuously source or sink 100% of their rated current, with regeneration returning absorbed energy. They also provide programmable resistance up to 394 Ω to match the internal series resistance of a battery pack.

Use Case: PCDU Tests Under Combined Loads

Testing an individual PCDU voltage rail might seem trivial. Theoretically, engineers should be able to power it on, verify that it maintains its voltage at zero current and at maximum current, and move on. However, exercising multiple rails simultaneously under dynamic loading conditions can expose design flaws. If output loading varies at just the wrong magnitude and frequency, perturbations can get inside a DC-DC converter’s control loop and throw it and any voltage rails it controls out of regulation. The resulting over- or under-voltage or current spikes can damage sensitive payloads and actuators.

Programmable electronic loads can simulate a range of load scenarios and coordinate PCDU loading across multiple power rails. Keysight regenerative DC electronic loads are integrated 1U or 2U rack-mount units providing kilowatts of power-sinking capability. They return up to 95% of the energy they absorb to the grid. Regeneration keeps cooling requirements low in high-power test environments. Units provide built-in protection against overvoltage, overcurrent, overpower, overtemperature, and voltage transient drop.

Using programmable electronic loads, engineers gain the ability to present converter outputs with any desired load condition. Keysight’s loads provide several operating modes: current priority, voltage priority, power priority, and resistance priority, as well as complex modes that combine them. They can be programmed with dynamic voltage and current load behaviors, such as voltage or current steps, user-defined arbitrary waveforms with up to 65,535 data points and programmable dwell, and list capability for up to 200 steps with unique dwell times or triggering. They also offer load sequencing capability, including ramp rates for turn-on and turn-off. Built-in voltage and current measurements capture what happens instantly.

Programming load tests can step through various scenarios and take accurate measurements much more quickly than staging each test by hand. By evaluating each PCDU output rail dynamically and then looking at PCDU behavior with all rails dynamically loaded, engineers can run robust, comprehensive tests in the lab that can head off post-launch failures.

NewSpace Concepts for Megawatt Scale

The rapid success of the initial wave of NewSpace efforts is driving further efforts into satellite power system development and testing. As small satellites and reusable launch vehicles are quickly and cost-effectively launched into LEO, and larger satellites venture into MEO and HEO, the overall number of satellites is expected to grow at a rapid pace.

In a continuing quest for increased power density and reduced costs, developments in silicon carbide (SiC) and gallium nitride (GaN) semiconductor processes for power conversion continue to push switching frequencies and voltages higher. On Earth, one initiative is the 800 VDC distribution architecture shown in Figure 15, which is gaining momentum in data centers. By cutting the number of AC/DC and DC/DC conversion points, the 800 VDC architecture significantly reduces losses. Smaller-gauge wire carries lower currents, reducing weight. Next-generation battery technology, including lithium-titanate (or Lithium Titanium Oxide, LTO), and advanced solar cell technologies are also on the horizon for satellite use.

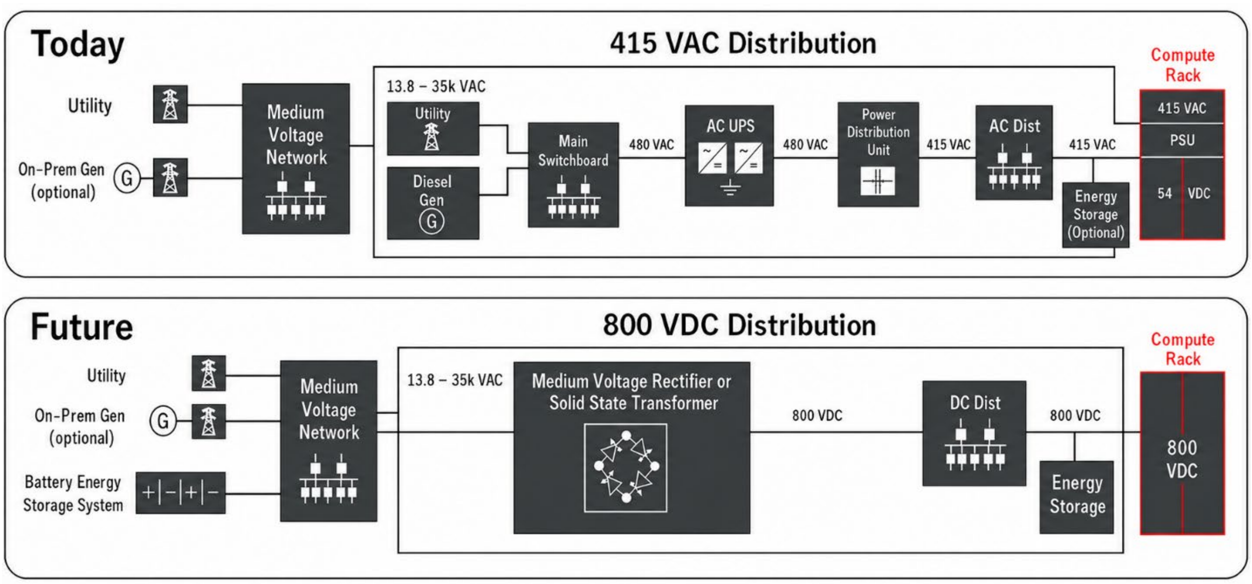

Figure 15. Shown is an example of an 800 VDC distribution architecture for data centers. (Concept courtesy of NVIDIA)

NewSpace proponents look at these ideas and the difficulties of powering and cooling terrestrial data centers and wonder whether larger satellites can host space-based data centers. Similarly, NTN proponents are working on deploying 6G network computing elements on satellites to reduce latency and improve connection quality.

So far, the thinking has been that a satellite is self-contained and self-sufficient. That will probably remain true for smaller, lower-cost satellites in lower orbits for some time. Packing more power into larger satellite platforms will make significant progress at some point. Eventually, however, power generation technology as we know it may need to evolve to keep pace with power demand.

NewSpace minds are looking even farther ahead to exotic technologies that break the boundaries of conventional satellite thinking. One idea is placing more potent energy sources, such as nuclear or fusion reactors, on orbiting platforms, but that is likely to face concerns on many fronts. Another concept is beaming microwave or optical energy around an on-orbit grid. Here, energy is generated on the ground or by large solar arrays in space. These arrays are much larger than the arrays that are practical for most satellites, being more on the scale of a manned space station. Beams carrying power are received and rectified for use on each satellite. If adopted, this energy-beaming capacity would alter the solar array subsystem in use on satellites today.

These trends are about to drive larger satellites from the kilowatt to the megawatt scale, making emulation of satellite power systems before flight even more crucial. More available power onboard may spur more creative uses in remote imaging, surveillance, and defense applications.

Cost-Effective Testing Saves Failures in Orbit

Satellite power systems should receive at least as much design and test attention as payloads and satellite control systems, as a power failure can quickly cripple an entire satellite. A setup for comprehensive satellite power emulation is reusable across multiple satellite programs, perhaps with some scaling as megawatt-ready designs appear. The time spent in lab emulation can help identify potential failures that would otherwise only appear in space, when it is too late to fix them and, in most cases, too expensive to fix by another replacement satellite launch.

Engineers have access to Keysight's expertise in power systems testing, leveraging proven equipment and software to build satellite power-emulation configurations in a lab. Keysight research teams, working with customers worldwide, have carefully thought through scenarios that affect the performance of solar arrays and battery packs when creating emulation solutions. Emulation gives engineers greater flexibility to design comprehensive tests that reproduce real space conditions and ensure systems perform as expected. With growth surging in satellite development and deployment, such capabilities boost confidence in system design and performance while supporting the test and evaluation of new approaches to satellite power systems.

For More Information

For more insights into how design and emulation can improve the performance of satellite power systems, check out the following resources:

- Application Note: Solving the Challenges of Solar Array Simulation
- Use Case: How to Simulate the Behavior of Solar Arrays in Space
- Solution Brief: Satellite Payload Testing in Aerospace and Defense
- Web Page: Elevate Your Space and Satellite Design and Test Workflow
- Solutions: High Density Power – Regenerative DC System Power Supplies and Electronic Loads
- Data Sheet: Advanced Power Application Suite