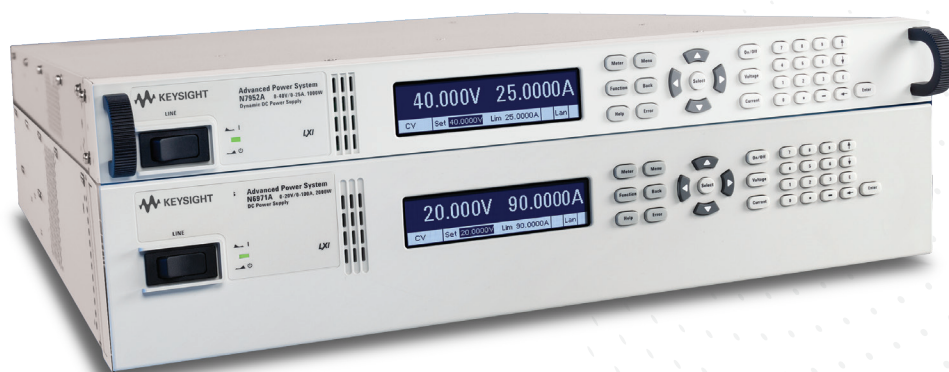


Conquering the Multi Kilowatt Source/ Sink Test Challenge



Introduction

Satellites, hybrid electric vehicles (HEVs), uninterruptable power supplies (UPSs), alternate energy power sources, and a number of other modern power systems supply power when it is opportune. They rely on bidirectional and regenerative energy systems and devices for storage in order to provide a continuous supply of power on demand.

Examples of these systems and devices include:

- Rechargeable batteries
- Super capacitors
- Motor-generator systems
- Bidirectional DC/DC converters
- Battery management systems (BMS)
- Regenerative braking systems

Many of these systems and devices operate at multi kilowatt power levels. When you develop and manufacture these systems, you need the ability to source and sink at kilowatt and greater power levels, which presents a formidable challenge for test engineers. The most common approach is to use separate instruments for sourcing and sinking, because of their availability. But this approach has shortcomings that can be overcome only by having the sourcing and sinking functions fully integrated in a single instrument or system.

Two-quadrant versus Four-quadrant operation

Test engineers sometimes misunderstand about what is needed for sourcing and sinking power for testing bidirectional and regenerative energy systems and devices. Bidirectional is often interpreted as bipolar, suggesting a bipolar power source is required for test purposes. These are actually two different things. A unipolar, bidirectional power source is one that operates in quadrants I and II of a four-quadrant I-V (current-voltage) plot, as shown in Figure 1. It can source and sink current but only with positive voltage. It operates as both a DC source and electronic load. It is a two-quadrant DC source.

In comparison, a bipolar power supply can transition through zero volts and operate with either positive or negative voltage. It can source power in quadrants I and III and sink power in quadrants II and IV.

As these bidirectional and regenerative energy devices and systems source and sink current and have unipolar voltage, a unipolar two-quadrant DC source is almost always adequate, and often preferable, for testing them. It is important that the two-quadrant DC source has fully regulated continuous operation when used as an electronic load in quadrant II. Simple downprogrammer current sinking is not sufficient for adequately testing these bidirectional energy systems and devices.

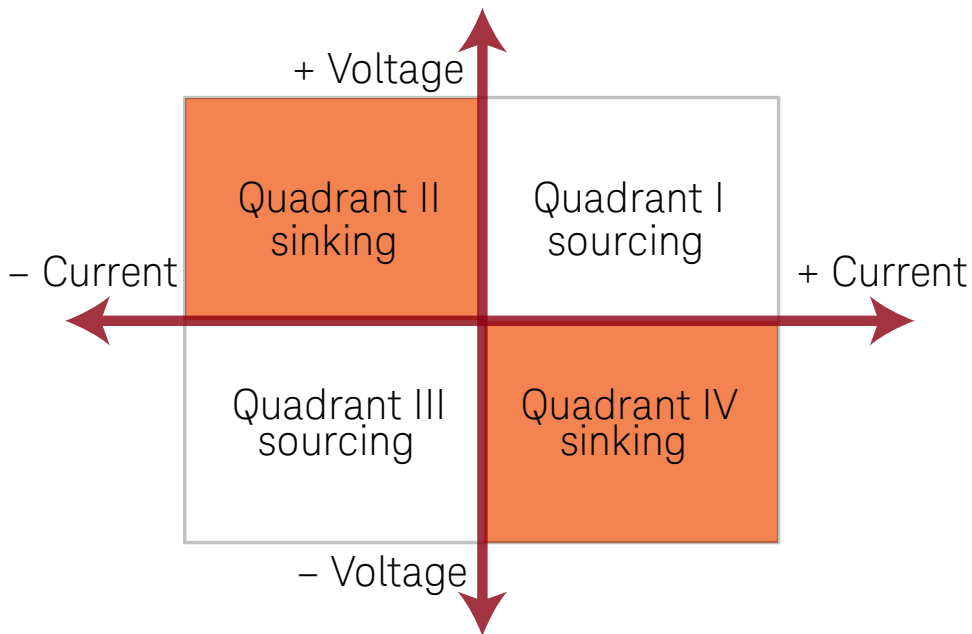
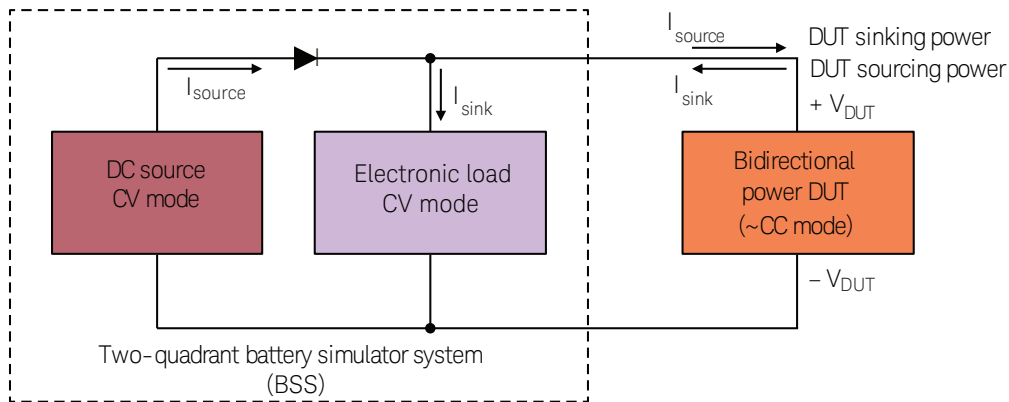


Figure 1. The four quadrants of an I-V plot

Separate DC source and electronic load with deadband, for source-sink operation

The selection of suitable two-quadrant DC sources at multi kilowatt power levels is extremely limited. Engineers often resort to using separate DC sources and electronic loads to provide the combined power sourcing and sinking needed for testing their bidirectional regenerative energy systems and devices. Independently, the DC source and electronic load are well suited for continuously sourcing and sinking power while providing good DC accuracy, stability, and fast dynamic response, regardless of the DUT. This kind of performance is needed, as these DUTs are active and dynamic, alternately sinking and sourcing power, depending on their status and operating conditions.

One arrangement for combining a DC source and electronic load for source-sink operation is depicted in Figure 2, often used as a battery simulator system (BSS).



$$V_{e-load} > (V_{DC\ source} - V_{diode})$$

DUT sinking power, DC source active: $V_{DUT} = (V_{DC\ source} - V_{diode})$

DUT sourcing power, electronic load active: $V_{DUT} = V_{load}$

Figure 2: Common DC source and electronic load arrangement for a battery simulator system (BSS)

A BSS is predominantly a voltage device; both the DC source and the electronic load normally operate in constant voltage (CV) mode. Their voltage is offset to provide a deadband so that they do not overlap in operation, with the electronic load's voltage being set slightly greater than that of the DC source. Most often the DUT being tested with a BSS is a battery management system (BMS), but this set up is applicable for a variety of DUTs that need to be tested with a unipolar two-quadrant DC source. When the DUT is drawing or sinking power, the voltage is maintained by the DC source. When the DUT is generating or sourcing power, the voltage rises, the DC source cuts off, and the electronic load becomes active operating in CV mode, clamping the voltage at a slightly higher level. A blocking diode at the output of the DC source is often required to isolate and prevent any reverse current from flowing back into the DC source when the DUT is actively sourcing power. With this configuration, the source current is then directly read back from the DC source while the sink current is directly read back from the electronic load. There are a number of performance compromises with this approach:

- The DC source needs to be used with local voltage sensing as the blocking diode will destabilize it if remote sensing around the diode.
- The deadband between sourcing and sinking is high impedance.
- Voltage-level programming commands need to be sent to both the DC source and electronic load so that they track each other as the BSS voltage level is changed.
- A much higher level of complexity in general is needed for coordinating the activities of the DC source and electronic load during test.
- The electronic load has to transition between cut-off and active CV mode, compromising its dynamic performance.
- The voltage drop of the blocking diode is variable based on current levels and temperature, leading to the need to use a substantial deadband voltage of a few hundred millivolts between the DC source and electronic load voltage levels.

In particular these last two items limit the two-quadrant flexibility, accuracy, and general performance of this configuration to static operation. To compensate for the deadband voltage under static operation, the BSS voltage can be programmatically brought up or down as needed, to within a reasonably close voltage level. However, the deadband voltage step is inherent for dynamic transitions, further compounded by the electronic load's CV mode transient cross-over, as depicted in Figure 3.

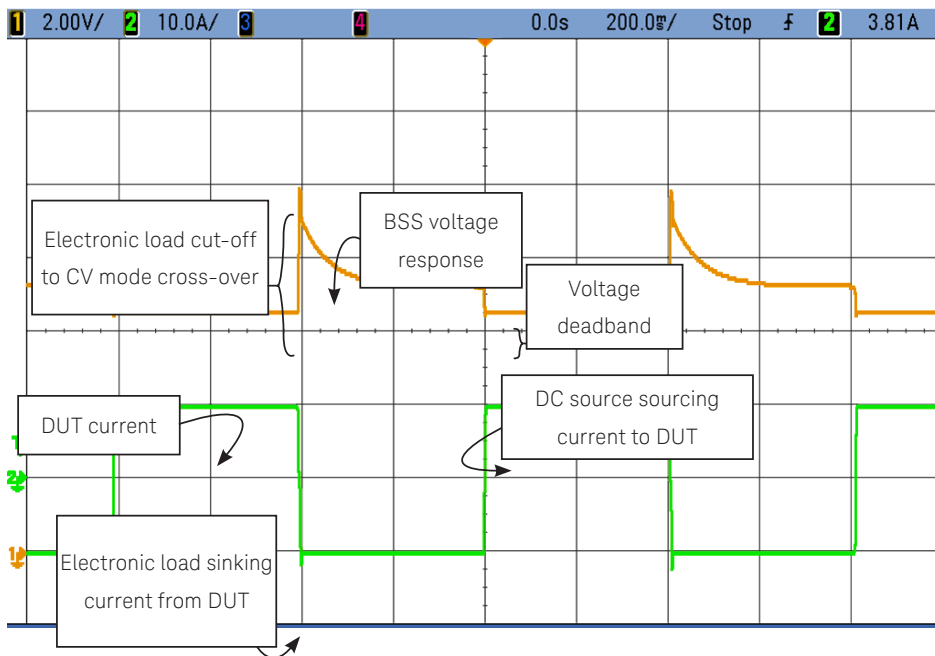


Figure 3. Source-sink transition for separate DC source and electronic load with deadband

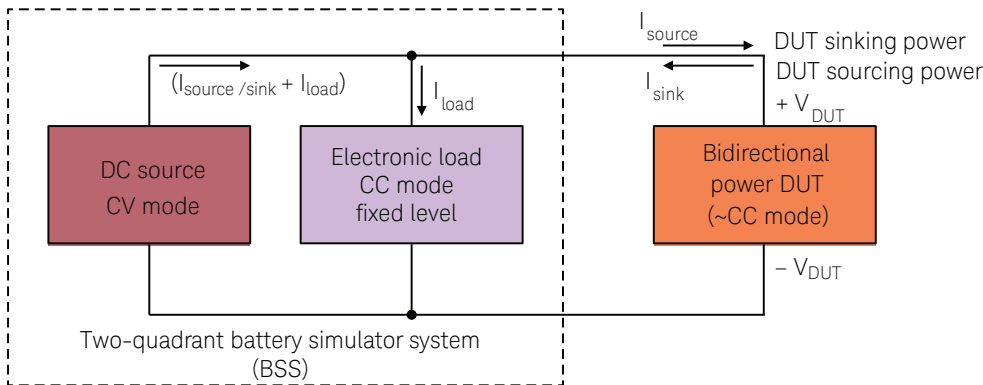
Separate DC source and electronic load with overlapping source-sink operation

Fully overlapping operation can be used to avoid many of the problems associated with non-overlapping operation as previously described. A DC source and electronic load configured for fully overlapping operation is depicted in Figure 4. Now the electronic load operates in CC mode instead of CV mode. The electronic load's current setting is fixed at a value in excess of the maximum value expected to be sourced from the DUT. This way the electronic load always remains in CC mode, drawing a fixed level of current and power. The electronic load no longer has to contend with any mode cross-over issues. The DC source always remains in CV mode and is always sourcing current. Because of this, the blocking diode is no longer required. As a result, this BSS configuration is always in CV mode throughout the entire range of sourcing and sinking, free of the electronic load mode cross-over and the deadband voltage transients affecting the BSS configuration that has non-overlapping operation. There are a few drawbacks as a result:

- The DC source needs to be considerably larger so that it can furnish both the maximum current and power required by the DUT plus the full amount that the electronic load continually draws. As one example, the DC source needs to be more than twice as large for 100% current sinking.
- The electronic load is constantly dissipating full power, which is considerable for a large system.
- Measurements require reading back both the DC source and electronic load currents and taking the difference, often of two large values to get one small value. Measurement accuracy suffers as a result.

Integrated source-sink solutions

The disadvantages of configuring a power sourcing and sinking solution with separate DC source and electronic load are mitigated when the sourcing and sinking functions are integrated into a single instrument. When integrated, these functions operate under closed-loop control to provide seamless, transient-free cross-over between sourcing and sinking current and power. There is no need to constantly dissipate large amounts of power to accomplish this. DC accuracy and dynamic performance are now optimized instead of compromised. Measurement performance is greatly improved by having a single measurement system for all currents. The main challenge has been a lack of instruments available that adequately address the test needs of today's bidirectional and regenerative energy systems and devices, leaving engineers no choice but to use separate DC sources and electronic loads.



$$I_{load} > (I_{sink-max}), \text{ fixed value}$$

$$V_{DUT} = V_{DC \text{ source}}$$

$$\text{DUT sinking power: } I_{DC \text{ source}} = (I_{source} + I_{load})$$

$$\text{DUT sourcing power: } I_{DC \text{ source}} = (I_{sink \text{ (negative)}} + I_{load})$$

Figure 4: DC source and electronic load with overlapped operation for a battery simulator system (BSS)

Keysight Advanced Power System (APS) N6900/N7900 DC power supplies featuring integrated sourcing and sinking

The APS N6900A/N7900A DC power supplies, pictured in Figure 5, are tailored for the test needs of today's bidirectional and regenerative energy systems and devices. Notable features include:

- Energy efficient 1U-tall, 1-KW models and 2U-tall, 2-KW models provide high power in minimum space.
- 10% current and power sinking integrated capability is built in. Easily increased to up to 100% sinking with the optional N7909A Power Dissipator Unit.
- Wide selection of output voltages addresses the diversity of today's DUTs and applications.
- Voltage- and current-priority operation give greater sourcing and sinking test flexibility, regardless of the DUT's nature.
- Two-quadrant measurement system for accurate voltage, current, power, charge, and energy measurements.
- Advanced sourcing and measurement capabilities in the APS N7900 dynamic DC power supplies can be used for creating dynamic output events, making transient measurements, continuously logging voltage, current, and power, and more.
- Advanced trigger signal routing with configurable logic for creating application-specific controls, triggers, and protection features, useful for easily solving particularly challenging test problems.
- Unique modular architecture for easily scaling integrated source-sink systems of up to 10-kW, for testing higher-power DUTs.



2-kW power sourcing in 2U



1-kW power dissipation in 1U



1-kW power sourcing in 1U

Figure 5. Keysight APS family

APS N6900A DC Power Supply			APS N7900A Dynamic DC Power Supply	
	1000 W	2000 W	1000 W	2000 W
9 V	100 A	200 A	100 A	200 A
20 V	50 A	100 A	50 A	100 A
40 V	25 A	50 A	25 A	50 A
60 V	17 A	33 A	17 A	33 A
80 V	12.5 A	25 A	12.5 A	25 A

Table 1. Keysight APS N6900/N7900 models

APS integrated sourcing and sinking for seam- less operation

When you use separate DC sources and electronic loads, you don't have access to built-in power sinking. The APS units, however, feature 10% power sinking built in. This can be effortlessly increased up to 100% integrated sinking capability with the simple addition of one or two 1-kW N7909A Power Dissipator Units, depending on the APS unit's power rating. All that is required is to connect a power cable and a control cable between the two units to provide truly integrated operation, as shown in Figure 6. As you can see in Figure 7, even with 10X greater voltage resolution, an APS and N7909A provides seamless, stable voltage performance while transitioning between sourcing and sinking, when tested under conditions comparable to the separate DC source and electronic load BSS setup shown in Figures 2 and 3.

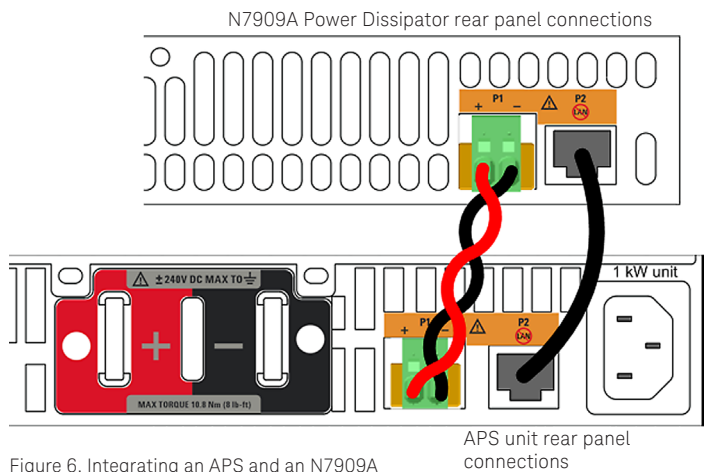


Figure 6. Integrating an APS and an N7909A

APS unit rear panel connections

APS advanced measurement performance

Making accurate voltage, current, power, charge, and energy measurements is a necessary part of testing bidirectional and regenerative energy systems and devices. These measurements are complicated and problematic when you use a separate DC source and electronic load as a basis for a source-sink test solution. As a minimum, separate currents read back from the DC source and electronic load have to be managed and assimilated. In all likelihood the DC source and electronic load will not have adequate capabilities for making accumulated charge and energy measurements, requiring you to add external logging measurement capability with its associated complexity and issues.

The APS's integrated two-quadrant measurement system fully complements its integrated sourcing and sinking capability. Making accurate voltage, current, power, charge, and energy measurements is a simple matter when you use APS. As one example, Figures 8 and 9 depict the current, voltage, and energy sourced and then subsequently recovered on a super capacitor when using an APS and N7909A Power Dissipator Unit for charging and discharging the super capacitor while capturing its voltage, current, and energy.

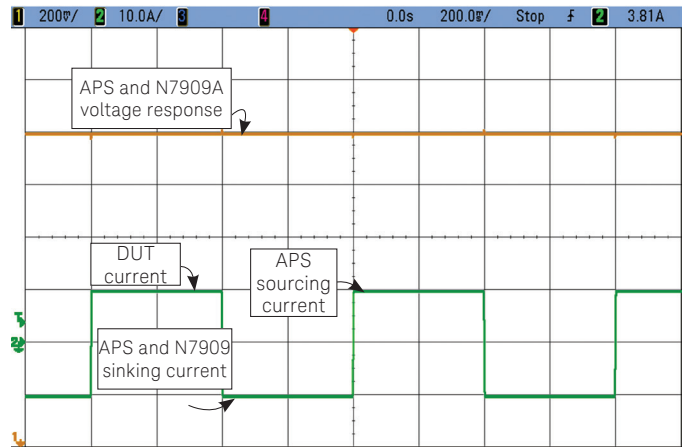


Figure 7. APS and N7909A seamless source – sink response

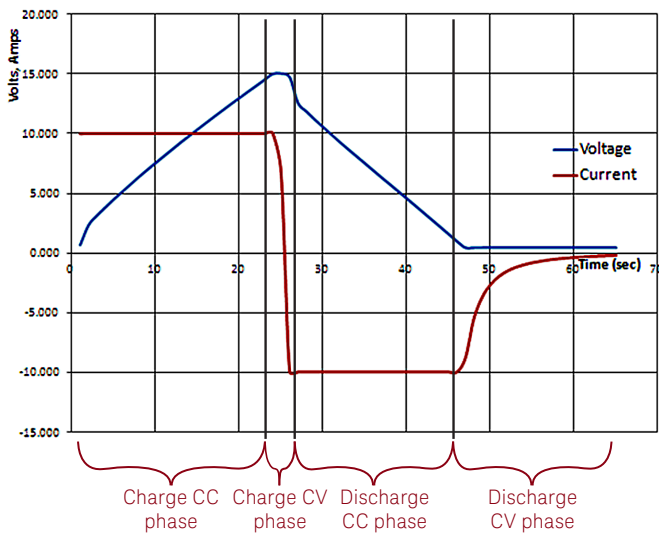


Figure 8. Super capacitor charging and discharging voltage and current

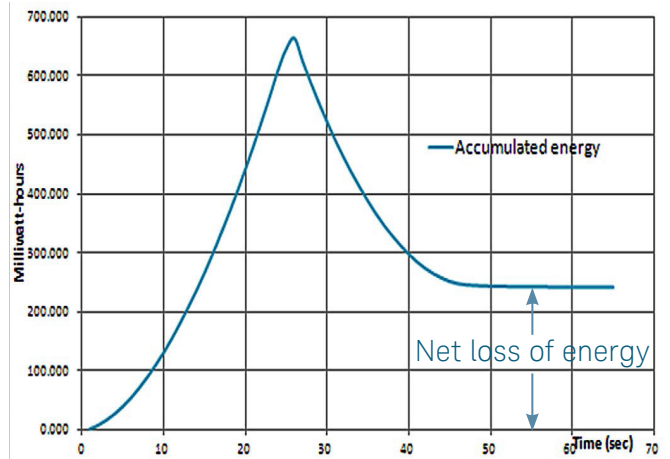


Figure 9. Super capacitor charging and discharging energy

Summary

Satellites, hybrid electric vehicles (HEVs), uninterruptable power supplies (UPSs), alternate energy power sources, and a number of other modern power systems rely on bidirectional and regenerative energy systems and devices. Many of these bidirectional energy systems and devices operate at multi kilowatt power levels. Accordingly, development and manufacturing of these systems and devices dictates having the ability to source and sink at kilowatt and greater power levels, which is a formidable challenge for test engineers.

The most common approach is to use a separate DC source and electronic load for sourcing and sinking. However, this leads to a number of issues and compromises in practice because the sourcing and sinking are independent. Only when sourcing and sinking are truly integrated into a single system can they provide optimum, seamless performance.

The Keysight Technologies APS N6900/N7900 DC power supplies feature integrated sourcing and sinking capability tailored for the test needs of today's bidirectional and regenerative energy systems and devices. As a result, the Keysight APS N6900/N7900 DC power supplies overcome all the challenges of creating a high-power source-sink test solution, providing optimum performance that only an integrated solution can do, freeing up test resources to tackle other challenges needing conquering!

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