# More Than Just a DC Load

*by Tom Lecklider, Senior Technical Editor*

Electronic loads present a varied current path to ground. For a simple constant resistance (CR), the relationship between voltage and current is linear. However, other types of loads also exist, such as constant voltage (CV), constant current (CC), and constant power (CP). The most sophisticated loads have complex dynamic current profiles.

Electronic loads are used to simulate real loads and typically comprise an array of MOSFET power transistors, a heatsink, and control circuitry. All electronic loads are constrained to operate within a safe operating area (SOA) similar to that shown in **Figure 1**, bounded by maximum power, voltage, and current limits.

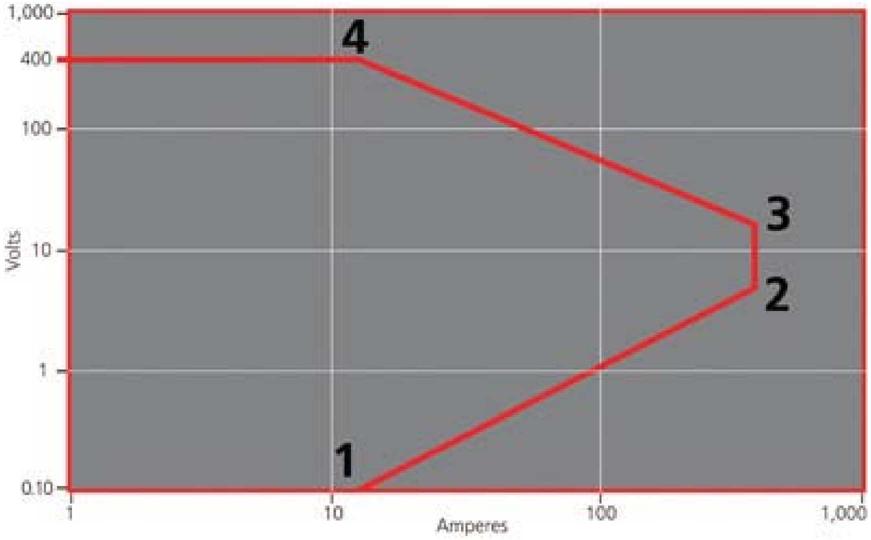

**Figure 1. Typical Electronic Load Single-Quadrant Safe Operating Area**
***Source: Kepco***

Corner 1 of the SOA characteristic is determined by the minimum voltage at which the load will operate. This depends on the load's design but typically is a few tenths of a volt. In Figure 1, it's shown as 0.1 V. Even with several large MOSFETs and heavy copper bus bars and terminals, a load will have a minimum resistance of at least a few milliohms. This resistance multiplied by the load's maximum rated current defines corner 2 of the SOA.

Increasing the voltage at the maximum current eventually causes the maximum power limit to be reached at corner 3. If the current is reduced, the voltage simultaneously can be increased to maintain the same maximum power dissipation. This results in the slanted line in the upper part of Figure 1 and eventually hits the maximum voltage limit at corner 4.

**Performance Details**

Operation is allowed at any I-V combination within the SOA and can be controlled in real time. For example, according to Kepco, the EL Series Electronic Load can use test patterns from an arbitrary waveform generator via the external analog input.[1]

AMETEK Programmable Power's recent catalog includes a very good introduction to electronic loads that highlights the dynamic characteristics of the Sorensen brand loads. According to the company, there are many applications that require either fast, random slew rates or an AC signal on top of the DC level. These are encountered when developing rechargeable battery controllers, fuel cells, and magnet control. These applications require both a high bandwidth electronic load and the capability to generate an arbitrary waveform.

The company's SL Loads have a 20-kHz bandwidth full scale across all DC models and up to 40 to 50 kHz for small signal AC on a DC setpoint. These frequencies can be applied through analog control from either an arbitrary waveform generator or a signal generator depending upon the waveform desired. In fuel cell testing, a high-frequency, low-amplitude current can be drawn to perform electrochemical impedance spectroscopy for characterization of cell impedances.[2]

Wiring resistance and inductance both affect performance, resistance causing undesirable voltage drops and inductance potentially leading to control instability. Resistance is minimized by using the heaviest wire that is practical and keeping the leads as short as possible. Nevertheless, it's difficult to avoid adding several milliohms to the load's internal resistance value.

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Particularly with today's low-voltage, high-current logic circuitry, this can be a problem. Lead resistance also contributes to power loss and must be added to the power dissipated in the electronic load to determine the total DUT power.

Some electronic loads include an auxiliary supply to offset the increased voltage drop. This approach allows operation down to 0 VDC even at maximum current, but the load's dynamic characteristics will depend on the load design as well as that of the additional supply.

Load size varies greatly from 200 W or less in Keithley Instruments, Agilent Technologies, and National Instruments source-measure units (SMU) to more than 250 kW in the Amrel and Chroma electronic loads. Size matters because a load's intrinsic resistance usually is lower for high-current models. Some SMUs, such as Keithley's recently introduced Model 2651A, support much greater pulsed power ratings, in this case 2 kW vs. the 200-W DC limit.

AMETEK advises selecting a load with a higher current rating than required. For example, the SLH-60-120-600 load will sink 120 A @ 0.5 V. However, if the SLH-60-240-1200 load is selected, a load of 240 A could be supported at the same 0.5-V. This method retains the full programmability and bandwidth of the load.[2]

AMETEK acquired Amrel's Power Division including its electronic loads in 2010. Sorensen brand loads handle up to 1,800 W and can be paralleled for higher power operation. Amrel loads start at 60 W and range up to higher than 250 kW.

Amrel's Eric Turner, product marketing manager, discussed the company's FCL Series of DC loads. "This is our product line for testing fuel cells and can be used down to 0 VDC at full operating current. It also has an embedded frequency response analyzer, making it a single-box solution for testing not only electrical specifications but additionally a fuel cell's dynamic operation up to 20 kHz," he explained.

Remote voltage sensing also is offered by some loads, which allows the load to compensate for the voltage drop in the connecting wires. This means that the load will monitor voltage at the DUT terminals, not the voltage at its own input.

Inductance involves the physical routing of the connecting wires as well as their length. Twisting them together and keeping them short minimize inductance because the oppositely directed magnetic fields mostly cancel.

Saul Kupferberg, Kepco's vice president of sales and marketing, explained how the company's EL Series loads minimize inductance and avoid instability or oscillation. "Each of the Power MOSFETs is part of an individual loop with five variable slew rate adjustments to compensate for the Miller effect inherent in any MOSFET," he said.

"The overall load control loop has seven different user slew rate adjustments which allow the user to fine-tune the load response characteristics to the environment in which it is operating. The load high-current circuits are constructed with laminated bus bars to reduce inductance to the maximum extent possible," Mr. Kupferberg concluded.

Chroma Systems Solutions' Larry Sharp, applications engineer, said, "There are two techniques used in Chroma's electronic loads to reduce oscillations and overshoot. In the 63800 Series AC loads, we use adaptive bandwidth adjustment and soft damping control. For the other series, passive RC damping circuitry is used."

Some of the Chroma loads feature constant impedance (CZ) operation in addition to the more usual CC, CV, CR, and CP modes. You can specify the values of a series R and L as well as a shunt R and C. The object is to make the loading current more realistic. In this mode, the minimum loading current transient time is 400 µs. The company's 63800 Series AC and DC Electronic Loads can simulate rectified AC loads with a special RLC mode.

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**Applications and Constraints**

*Power Supply Transient Response*

An electronic load provides a convenient way to test power supply transient response. Not only can the load switch the current demand quickly, but the levels can be easily controlled. This means that switching from full to half load is as easy as switching between any other two levels or among a programmed sequence of levels.

James Hsu, product manager at Instek America, said, “The sequence function in the PEL-2000 Series DC Electronic Loads allows each channel to change its load sink according to a predefined sequence at a rate of up to 100 µs per step. Under the dynamic load mode, the load current or load resistance pulses between two preset levels at a predefined speed up to 25 µs per step.”

B&K Precision’s James Schada, product marketing engineer, described similar applications for his company’s loads. “Our electronic loads can be used to measure voltage, current, and power in the various CV, CC, CP, and CR modes,” he said. “We provide software that allows users to create dynamic load sequences, monitor and log measurement data, and characterize and graph battery discharge profiles. Additionally, you can set up a transient condition where the electronic load toggles between two levels.”

*Hardware in the Loop*

Simulating the behavior of a system component or subassembly often is more practical or convenient than dealing with the actual thing. Hardware-in-the-loop (HIL) testing is a good example of a technique that mixes software and hardware parts of control systems. A typical automotive development scenario might use the power stages from a real electronic control unit (ECU) but allow engineers to easily alter the software algorithms. Electronic loads are used to simulate the loads the ECU power stages ordinarily would drive.

A paper on battery management system testing from Arsenal Research described an HIL simulation of a four-wheel drive hybrid electric vehicle (HEV). Software modules within the Dymola Dynamic Modeling Laboratory tool were used to calculate the loads seen by a real Li-Ion battery. A power supply and an electronic load were used to charge and discharge the battery. Other than the battery, the dynamic mechanical and electrical behavior of the HEV was simulated as the New European Drive Cycle was executed.[3]

As shown in **Figure 2**, negative current pulses correspond to acceleration when the electronic load is draining power from the battery, and positive pulses result from regenerative braking when the power supply is charging the battery. The combination of 480-V maximum voltage, 600-A charge, and 750-A discharge with 96-kW peak power necessitated separate power supply and electronic load units.

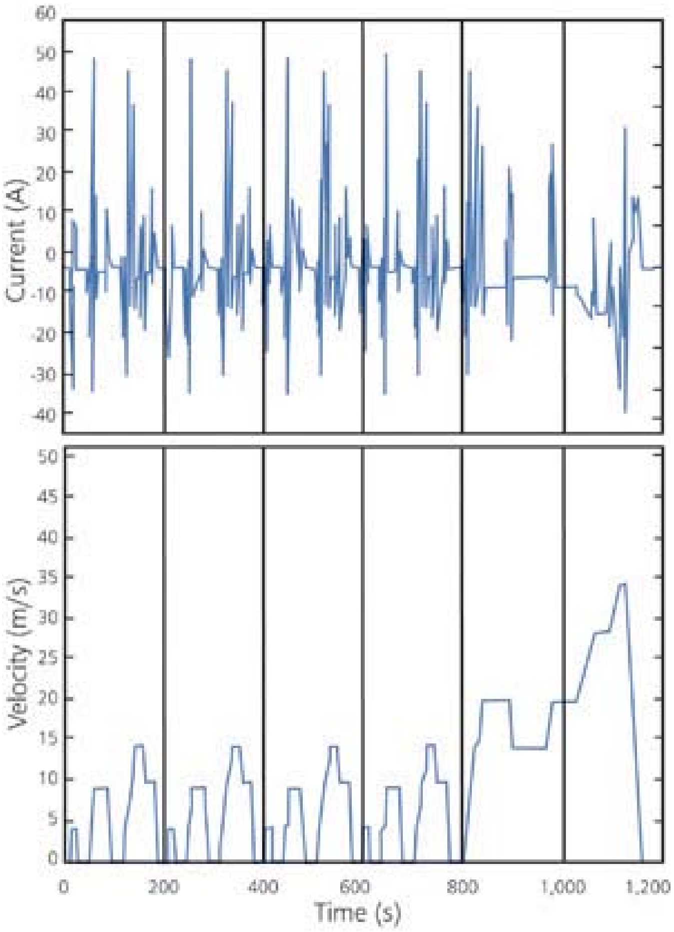

**Figure 2. Battery Charge/Discharge During HIL Simulated Vehicle Test**[3]

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Two- or four-quadrant SMUs are available that both source and sink power but at these levels are specialized test systems rather than general-purpose instruments. For example, AeroVironment™ Power Cycling and Test Systems capabilities range from the 30-kW Model MT-30 rated at ±500 A and up to 120 V to the Model AV-800 at ±1,000 A and 800 V. The operating envelopes for several models are shown in **Figure 3**. These two-quadrant test systems have similar constraints as enumerated in Figure 2, but because the scaling in Figure 3 is linear rather than logarithmic, the lines of constant power are hyperbolic.

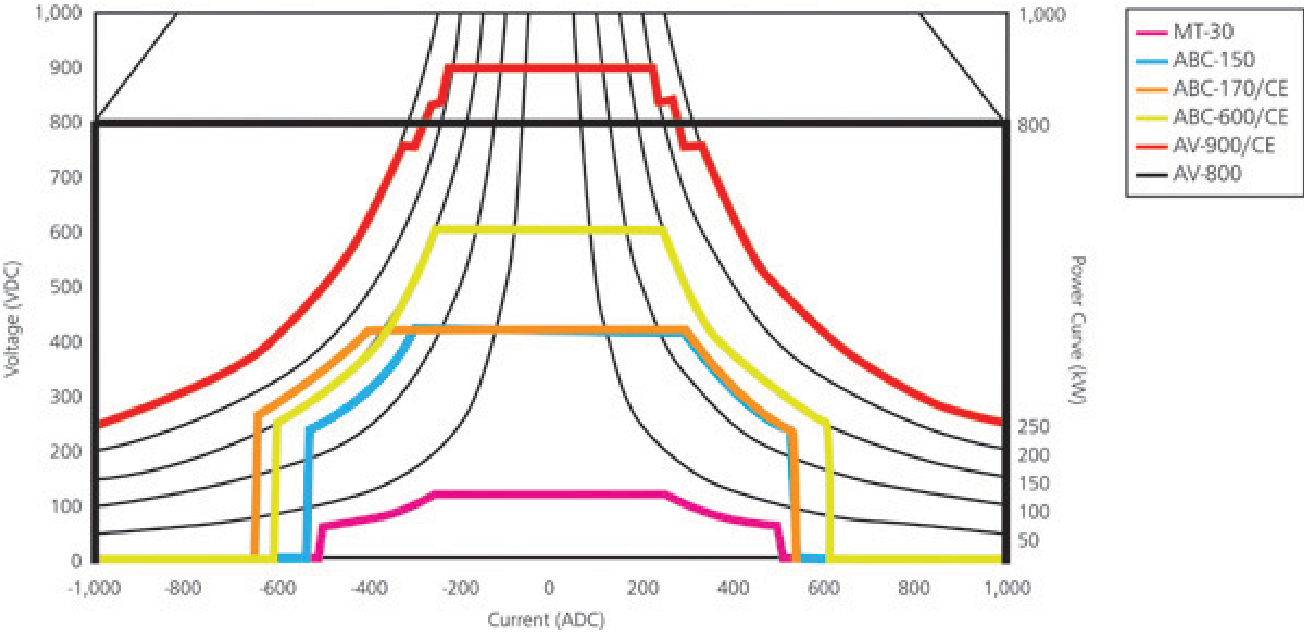

**Figure 3. Linear Plots of Two-Quadrant Safe Operating Areas**
***Source: AeroVironment***

*Circuit Deactivation*

The popularity of portable personal electronics devices has focused a great deal of attention on the batteries used to power these products. Several SMUs and special battery emulator power supplies are available with programmable output resistance to simulate a battery's internal resistance. These instruments have high bandwidth voltage regulation to cope with the fast switching load often presented by personal electronics products.

For a device like a cell phone, inactive circuitry runs in a background sleep mode as much as possible to save power and extend operating time. Because of this, the battery current exhibits a large dynamic range. At one extreme, only microamps are being drawn while the phone is in a standby condition. At the other extreme, two or three amps are required when transmitting in bursts. An electronic load used to simulate a phone's loading must change its power demand as fast and over the same range as the actual unit.

In a recent article about electronic loads and current measurement, Agilent Technologies' Bob Zollo explained that not only are accurate measurements difficult to make at high speed, but range changing also may be involved. Several current measurement schemes are discussed in the article, which concludes that none of the common ones such as shunts or current probes is ideal.[4]

However, Agilent's N6705 DC Power Analyzer can measure current directly down to 1 µA and has an 18-bit digitizer to support a wide measurement range. Similarly, the company's N6781A, a two-quadrant SMU optimized for battery drain analysis, supports glitch-free and seamless current measurement with a 200-kHz sample rate. There are four current ranges: 10 µA, 1 mA, 100 mA, and 3 A. The N6781A also includes an auxiliary voltage measurement capability. This means that as the load monitors the battery current, simultaneous battery voltage readings can be recorded.

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*Solar Array Characterization*

In this application, the object is to determine a solar panel's I-V characteristic. By stepping the electronic load through a succession of current levels from 0 A to an appropriate upper limit, sets of panel I-V data can be acquired. Typical photovoltaic (PV) I-V curves plot current as the dependent variable along the Y axis and voltage as the independent variable on the X axis. The familiar I-V shape will be developed by plotting the sets of points even though they were acquired by controlling current instead of voltage.

This application is relatively straightforward but easily can provide misleading data. Although not immediately obvious, speed is very important. This type of test often is done on completed PV installations to confirm that design goals have been met. This means that results depend on the actual irradiance available when the test is run. By quickly cycling the load through the successive current values, there's less chance that variations in light intensity will affect the test.

Electronic loads also are used to optimize the maximum power available to a PV inverter. Some form of a perturb and observe (P&O) algorithm often is used to ensure operation at a PV panel's maximum power point (MPP). Periodically, the output voltage may be increased and the power measured. If it has increased, the I-V load characteristics are changed accordingly. If the power has decreased, then the algorithm would decrease the voltage and compare the power under that condition to the power previously available. Clearly, an easily controlled electronic load is a great advantage when working with P&O algorithms.

Chroma has developed the Solar Application Soft Panel, a software tool used in conjunction with the company's 63600 Series DC Loads to generate PV panel I-V curves and track their MPP. The software continually adjusts the load's current to maintain PV panel operation at the MPP.

*Power Dissipation*

Chroma's regenerative Coolburn® Loads are intended for use during DC-DC converter burn-in and can recover up to 75% of the power. The recovered power is added to the bulk DC supply at the proper voltage level to drive the converters being burned in.

Very high power loads, such as the AeroVironment Test Systems, invert the DC current and return power to the AC grid. This not only reduces operating costs but also minimizes the peak load the grid must deliver. Kepco's high-power BOP Series Bipolar Operational Power Supplies operate in all four quadrants and return a portion of the load current to the AC grid.

TDI Power offers the WCL Series of high-power water-cooled loads with dissipation up to 120 kW. This approach doesn't reduce the net amount of power used but does improve equipment density. A complete 120-kW system consisting of 10 12-kW units in parallel fits in one 62" high 19" rack. Most loads that dissipate several kilowatts are air cooled and occupy a larger volume. For example, Kepco's EL Series Loads are 7" high and dissipate a maximum of 5 kW. The TDI WCL master load is 5.25" high, and slave loads are 3.5" high. Both dissipate 12 kW.

According to an example that focuses on the Kepco EL, a 60-kW load was configured from one EL master and 11 slaves. For the same 60-kW capacity, one WCL master and four slaves would be required. The ratio of volumes occupied is approximately 4.36:1. Of course, the TDI Power solution requires 10°C cooling water at a rate of 3 gpm per 12-kW load. Against this, the combined Kepco loads will have 36 fans exhausting the 60-kW dissipation into a space that must provide adequate cooling. Any Kepco load can function as a master or a slave, providing more flexibility than specialized masters and slaves when reconfiguring test systems.[1]

Your application may not require both the maximum voltage and current at the same time. By understanding in detail the way the load is going to be used, you can specify the least expensive model that will do the job. For example, you may need to accommodate 30 A and 12 V but not simultaneously. If only 5 A is drawn at 12 V and 3 V developed at 30 A, then a 90-W load could be used rather than the 360-W unit suggested by multiplying the maximum ratings.

Obviously, the greatest part of the dissipation is caused by the DC current through the load. This is only partially true for two-quadrant instruments such as the AeroVironment test systems that typically source as much power as they can sink. Even for the smallest MT-30 System, the AC input is rated three-phase 240 V with 380, 400, 440, and 480 V available as options. Maximum input current is 130 A at 240 V, so power considerations are vastly different if operation in quadrant 1 as well as 2 is needed.

## Conclusion

Selecting the most appropriate electronic load for your application no doubt is possible given the wide range of available loads. On the other hand, having so many loads to choose from can make the job appear daunting.

If you haven't previously used electronic loads, start the selection process by outlining the test requirements you already know about in detail. How might they be extended in the future in terms of voltage, current, and power? What additional features such as voltage and current readback would simplify testing? Finally, do you need only a load, or would a two- or four-quadrant SMU be a better solution?

The answers to these questions will narrow the choices. Before making a final selection, be sure to discuss your requirements with vendors whose products are on your short list. Most of the time, an electronic load's capabilities aren't challenged in simple test applications. But for anything a bit unusual, a wealth of information is available from the relevant technical support staff.

## References

1. *Series EL Electronic Loads Brochure*, Kepco, 2010.

2. *Programmable Power Supplies and Electronic Loads Catalog*, AMETEK Programmable Power, 2010, pp. 259, 260.

3. Ebner, A., et al., “Rapid Validation of Battery Management System With a Dymola Hardware-in-the-Loop Simulation Energy Storage Test Bench,” *World Electric Vehicle Organization Journal*, Vol. 1, 2007, pp. 205-207.

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