how it works

ULTRACAPACITORS, CAPABLE OF STORING VAST AMOUNTS OF ELECTROSTATIC ENERGY, CAN SUPPLEMENT OR EVEN SUPPLANT BATTERIES IN MANY APPLICATIONS.

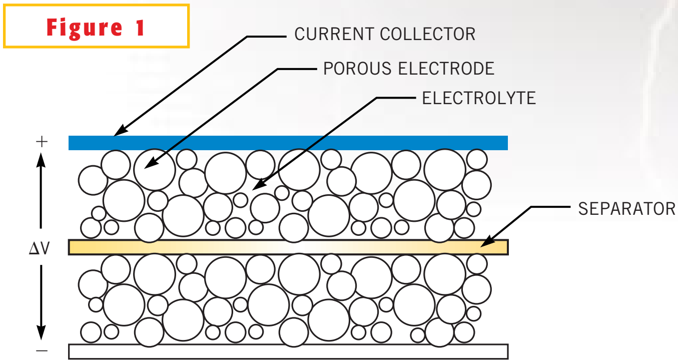
Ultracapacitors deliver jolts of power

By Bill Travis, Senior Technical Editor

A CLASS OF PASSIVE DEVICES, variously called ultracapacitors, supercapacitors, or electrochemical capacitors, are anything but passive in the wallop of power that they can deliver. They store energy in electrostatic form, unlike batteries, which use electrochemical processes. Ultracapacitors have ratings that can reach thousands of farads (*billions* of microfarads!). They don't approach the volumetric energy density of batteries, but they can deliver much more instantaneous power than a battery can provide. What's more, you can charge an ultracapacitor much faster than you can charge a battery, and the capacitor is amenable to many more charge/discharge cycles than a battery can accommodate without degradation. An ultracapacitor is environmentally safe; it uses no toxic materials, such as the lead and sulphuric acid you find in a lead-acid battery, and it emits no gasses, such as the hydrogen a lead-acid battery emits.

Figure 1 shows the construction details of a double-layer ultracapacitor. The capacitor contains two particulate-carbon electrodes formed on conductive-polymer films. An ionically conductive membrane separates the two electrodes, and a potassium-hydroxide electrolyte permeates the capacitor. The micropores in the carbon particles result in an enormous surface area, yielding extremely high capacitance values that conventional capacitors cannot attain. The ultracapacitor bridges the gap between conventional capacitors and batteries. Though its energy density is only a fraction of that of a battery, it has certain advantages over a battery:

Figure 1



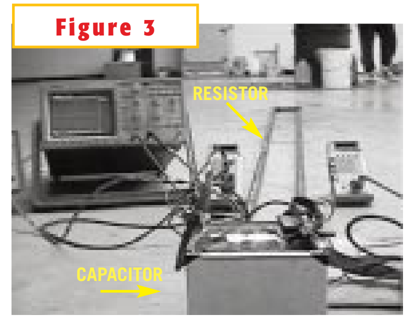
Carbon particles provide a large surface area; hence, an ultracapacitor has high capacitance values.

- You can charge and discharge an ultracapacitor almost indefinitely, whereas few batteries can accommodate 1000 cycles.
- You can charge an ultracapacitor instantaneously, whereas fast charging can damage a battery.
- An ultracapacitor can provide high discharge currents, whereas batteries suffer reduced life with frequent high-power pulses.
- An ultracapacitor requires no maintenance and is robust in severe environments.

Figure 2

This hefty ultracapacitor has a rating of 65F, 14V.

Figure 3



A length of steel pipe serves as a dummy load in the ultracapacitor tests.

- An ultracapacitor uses nontoxic and relatively inexpensive materials.

Evans Capacitor Co (www.evanscap.com) reveals some details of an ultracapacitor's construction (**Reference 1**). A MegaCap with a rating of 65F, 14V (65 million μF) contains many thin cells in the form of 0.04×5.75×5.75-in. squares (**Figure 2**). Because the voltage rating of one cell is only approximately 1V, the MegaCap cells connect in series to attain the 14V rating. The assembly then has the stacks of series-connected cells connected in parallel to attain the capacitance rating. Packaging the cell stacks to form a useful ultracapacitor presents some difficulties. The particulate-carbon electrodes need the application of pressure to provide high conductivity. A pressure of 80 psi equates to a compressive force of approximately 2600 lbs for this cell size. To keep the cells under this force, the MegaCap uses a steel sleeve capped by stiff polymer end plates and an air spring between the cell stacks and the end plates. The final product consists of five 18-cell stacks.

The MegaCap has an inherent time constant of 0.6 sec, which indicates that its effective series resistance is 9 mΩ. To test the MegaCap, Evans configured a dummy load consisting of a 20-ft, 3-in. section of ½-in. steel pipe bent into a large U shape (**Figure 3**). The connections to the capacitor and switch used large, low-resistance copper cables. With the capacitor removed from the circuit, measurements at 1, 5, and 7A revealed the total resistance of the dummy load was 7.9 mΩ. Voltage monitored across a 1-mΩ section of the load provided the current measurement. Evans used a Tektronix (www.tektronix.com) TDS 320 digital oscilloscope to record the capacitor and ammeter voltages during discharges. The scope automatically multiplied the capacitor and ammeter voltages to provide a plot of power dissipated in the load.

The test setup used a sampling rate of 500k samples/sec to observe the first millisecond of the discharge (**Figure 4**). The spikes appearing before the exponential discharge curve came from switch bounce. These spikes are narrow enough to not appreciably affect the total energy stored in the capacitor. The peak power recorded is 12.5 kW (**Figure 4**). In the results of a second test, recorded at 100 samples/sec, the power curve shows most of the discharge but doesn't have the resolution to show the initial 12.5-kW peak (**Figure 5**). The MegaCap exhibited relatively low leakage current. After an initial 24-hour burn-in charge, the measured leakage current was 2 mA at 14V. The device under test stored 6.4 kJ of energy at 14V for a calculated energy density of 2.4 J/cm^3. Evans is developing larger versions of the MegaCap, which will store more than 40 kJ of energy, with energy densities as high as 4 J/cm^3.

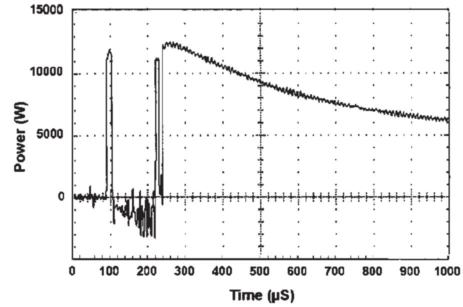


Figure 4 The MegaCap discharge produces a peak power of 12.5 kW in the load.

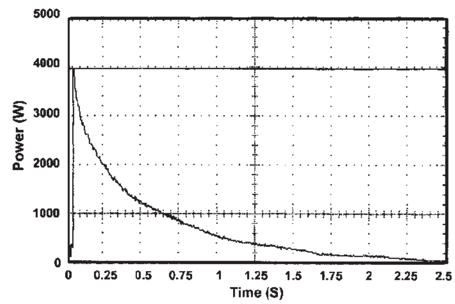


Figure 5 The area under the exponential discharge curve represents a lot of kilojoules of energy.

Some other companies make ultracapacitors with higher capacitance ratings than those from Evans. The PowerCache division of Maxwell Technologies (www.electroniccomponents.com), for example, offers a 2500F, 2.5V unit that measures 6.34×2.44×2.42 in. The capacitor caches 7.8 kJ of energy. Ness (www.ness.co.kr) makes 2.3V ultracapacitors that offer capacitance ratings as high as 3500F. NACC-Mallory (www.naccmallory.com) offers the MEC series, with capacitance ratings as high as 2000F. The MEC devices come in asymmetrical and symmetrical versions. The asymmetrical units use a somewhat different electrode configuration from the standard carbon system. You must observe polarity for these units, and you must maintain a certain minimum discharge voltage, as with a battery. The symmetrical units are nonpolarized, and you can discharge them to as low as 0V. Asymmetrical MEC ultracapacitors are available with values reaching 2000F, 12 and with energy-storage capacity as high as 144 kJ. At the other end of the capacitance spectrum is a series of ultracapacitors from AVX Corp (www.avxcorp.com) dubbed BestCap. These small units specify capacitance ratings of 0.06 to 0.2F at 5.5V.

Ultracapacitors find many useful applications. In hybrid gasoline/electric vehicles, for example, they can supplement the battery by providing bursts of instantaneous power. The ultracapacitors readily absorb large amounts of energy from regenerative braking and efficiently release this energy for acceleration. In another application, engine-starting ultracapacitors can also supplement batteries by supplying instantaneous starting power, thus extending the life of the batteries. The devices also fulfill a load-leveling function by supplying bursts of power during peak-energy periods.□

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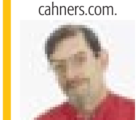

Reference

1. Blakeney, RS, "Performance of a New Line of Large Carbon Double Layer Capacitors," Application Note, Evans Capacitor.