SuperCapacitors – Advantages when combined with Starter Batteries

By Bob Gell

Typical cylindrical SuperCap design

Capacitors store electrical charge. Because the charge is stored physically, with no chemical or phase changes taking place, the process is highly reversible and the discharge-charge cycle can be repeated over and over again, virtually without limit. Electrochemical Capacitors (ECs), variously referred to by manufacturers in promotional literature as "SuperCapacitors" or "Ultracapacitors," store electrical charge in an electric double layer at the interface between a high-surface-area carbon electrode and a liquid electrolyte. Consequently, they are also quite properly referred to as electric double layer capacitors (ELDCs) or simply double layer capacitors (DLCs).

A simple EC can be constructed by inserting two conductors in a beaker containing an electrolyte, for example, two carbon rods in salt water (Figure l). Initially there is no measurable voltage between the two rods, but when the switch is closed and current is caused to flow from one rod to the other by a battery, charge separation is naturally created at each liquid-solid interface. This effectively creates two capacitors that are series-connected by the electrolyte. Voltage persists after the switch is opened-energy has been stored. In this state, solvated ions in the electrolyte are attracted to the solid surface by an equal but opposite charge in the solid.

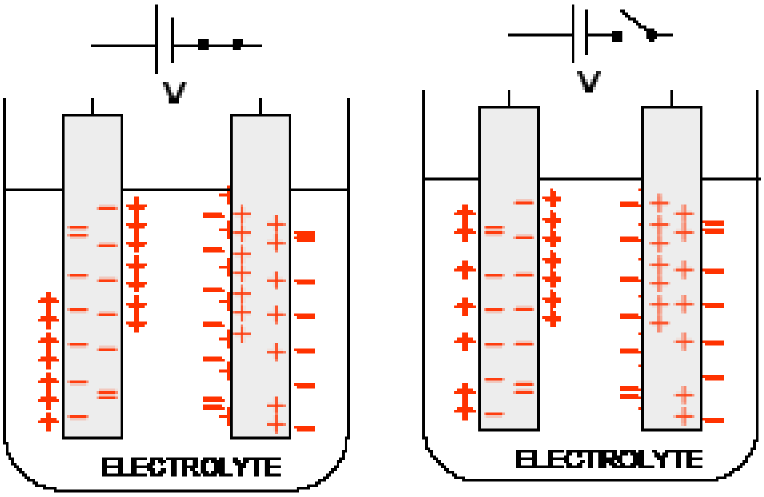

Figure 1: Electric double layer capacitor constructed by inserting two electrodes in a beaker and applying a voltage. The voltage persists after the switch is opened (right), creating two series-connected capacitors. Charges in the electric double layer are separated by only about lnm.

These two parallel regions of charge form the source of the term "double layer." Charge separation is measured in molecular dimensions (i.e. few angstroms), and the surface area is measured in thousands of square meters per gram of electrode material, creating five-thousand-Farad-size capacitors that can be hand held.

SuperCapacitors are therefore not suited to energy storage (like a chemical battery) over long periods of time, but rather they are very good at short term storage and delivery at around 98% of the charge placed in them. The chart illustrates the capability of the SuperCapacitor to deliver high cranking power.

The operating voltage of an electrochemical capacitor is limited by the breakdown potential of the electrolyte (typically 1 to 3 v per cell) and is generally much lower than that of conventional electrostatic and electrolytic capacitors. In many practical applications, therefore, electrochemical capacitor cells must be series-connected, similar to batteries, to meet operating voltage requirements.

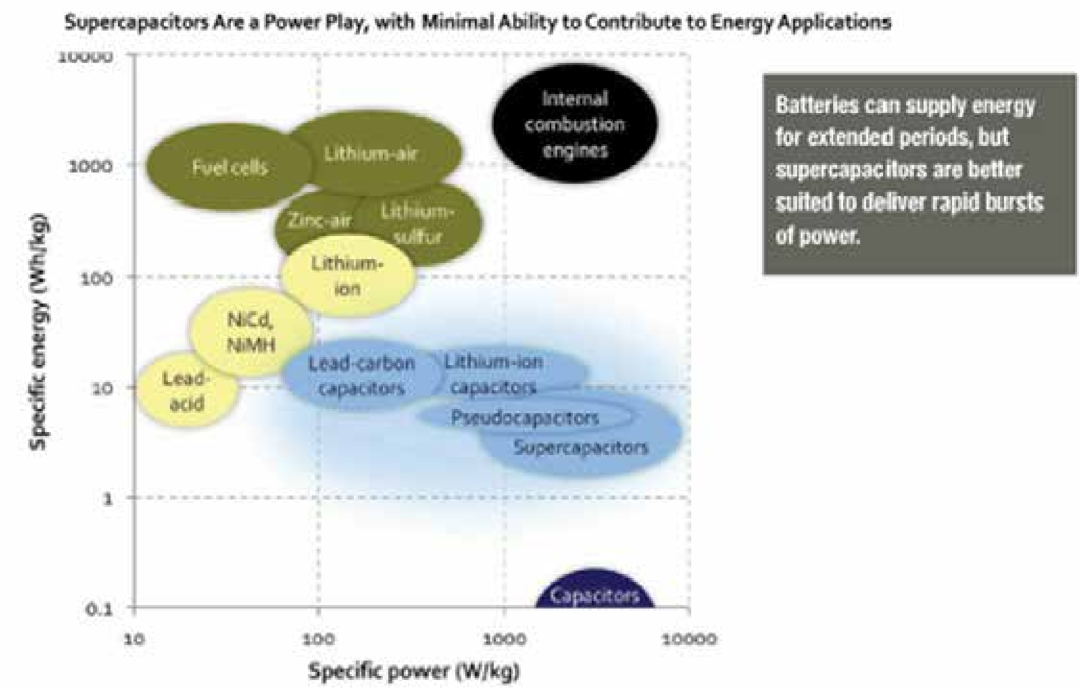

Table T - Comparison of properties of secondary batteries and electrochemical capacitors

PROPERTY	BATTERY	ELECTROCHEMICAL CAPACITOR
Storage mechanism	Chemical	Physical
Power limitation	Electrochemical reaction kinetics, active materials conductivity, mass transport	Electrolyte conductivity in separator and electrode pores
Energy limitation	Electrode mass (bulk)	Electrode surface area
Output voltage	Approximate constant value	Sloping value - state of charge known precisely
Charge rate	Reaction kinetics, mass transport	very high, same as discharge rate
Cycle life limitations	Mechanical stability, chemical reversibility	Side reactions
Life limitation	Thermodynamic stability	Side reactions

To illustrate the major differences between secondary (rechargeable) batteries and electrochemical capacitors, important fundamental properties of each are compared in Table T.

The fundamental difference between batteries and electrochemical capacitors is that the former store energy in the bulk of chemical reactants capable of generating charge, whereas the latter store energy directly as surface charge. Thus the battery has much more energy in a given volume than a capacitor. Battery discharge rate and therefore power performance is limited by the reaction kinetics as well as the mass transport, while such limitations do not apply to electrochemical capacitors constructed with two activated carbon electrodes, thereby providing capacitors with exceptionally high power capability during both discharge and charge.

Most batteries exhibit a relatively constant operating voltage because of the thermodynamics of the battery reactants; as a consequence it is often difficult to measure their State of Charge (SOC) precisely. And for a capacitor, its operating voltage changes linearly with time during constant current operation so that the SOC can be exactly known. Furthermore, the highly reversible electrostatic charge storage mechanism in ECs does not lead to any volume change like observed in batteries with electrochemical transformations of active masses. This volume change limits the cyclability of batteries generally to less than 2500 cycles whereas ECs have demonstrated from hundreds of thousands to many millions of full charge/discharge cycles.

Table TT compares state of the art commercial starting-lighting-ignition (SLI) battery technology with electrochemical capacitor technology in several important ways. Cost figures were based on today's product prices for capacitors and batteries in large quantities, each normalized to mass using dc energy values and power levels at which charge/discharge efficiency is at least 90%.

Table TT: Comparison of some important characteristics of state of the art SLI batteries and electrochemical capacitors.

Characteristic	State of the Art SLT Battery	Electrochemical Capacitor
*Charge time	0.5-6 hour	0.3-2 second
*Discharge Time	I0-30 minutes	0.3-2 second
Cycle life	200-700	>500,000
Specific Energy (Wh/kg)	25-40	I-5
Specific power (kW/kg)	0.I-0.3	5-I0

*** Time for discharge and charge of the useable total energy stored in the devices**

It is clear that the charge/discharge times and the cycle life of capacitor and SLI lead acid battery technologies are quite different at present, and it is expected that this situation is not likely to change in the foreseeable future. Even the most advanced lithium ion battery technology available today offers charge/discharge times >3-5 minutes, specific power levels <1 kW/kg, and operation <5000 cycles.

Hence the suitability of each technology for particular applications is now and will remain markedly different regardless of likely advances that may be made in either of the technologies. Thus, capacitors are expected to remain the technology of choice in applications requiring very high power performance, like in engine cranking. It is just not possible to overcome the fundamental limitations of battery technology to have them effectively compete with the performance of capacitors for engine cranking.

SuperCapacitors are a viable addition or alternate to the starting pulse power requirements for SLI batteries as used today in motor vehicles, and particularly suited to the current rapidly emerging Micro-Hybrids for the Idle Stop Start (ISS) functionality.

Vehicles with 42 V electric systems:

The electric power consumed by various loads in the modern vehicle (electric heating of seats, windows, mirrors, air conditioner, electric windows, electrically heated catalyst, power steering, active suspension, audio system, etc.) has risen to several thousand Watts and keeps increasing growing.

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Providing these power levels with the existing 12 V electric system is becoming difficult due to high current levels. In response, the International Automotive industry has decided that it will start a step-by-step transfer to a new 42V electrical system.

One of the variants under review is a combined power source comprising SuperCapacitor and battery. The battery will supply power to long low current loads (audio systems of standard power, key-off period lighting, etc.), while the SuperCapacitor will act as a floating power source providing and taking powerful short-term pulses for engine starting, vehicle speedup and braking energy recuperation.

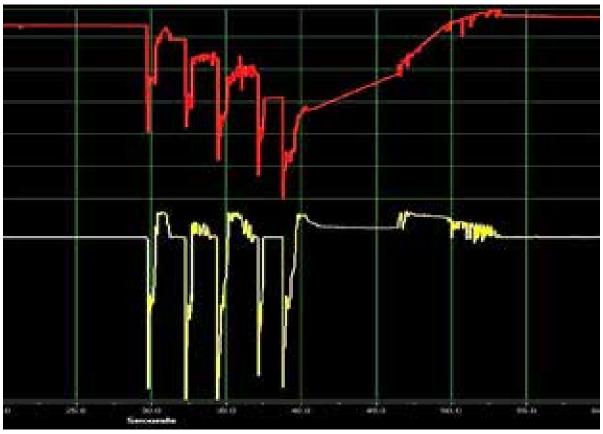
Such application requires the floating power source to have high maximum power and cycling capacity, wide operating temperature range and high reliability. A storage device based on asymmetric SuperCapacitors meets all the above requirements.

Capacitor modules for vehicles with 42 V electrical systems:

One manufacturer is well advanced with SuperCapacitor development – particularly for the new 42 volt vehicle operating systems. The table indicates module operating parameters.

Capacitor module	Operating voltage window, V	Maximum power, kW	Energy stored in operating voltage window, kJ	Internal Ohmic resistance at +25 ^{0}C (-30 ^{0}C), mOhm
30EC104 H	45-12	28	100	18 (32)
30EC402 H	45-12	56	310	9 (12)
30EC405 H	45-12	34	370	15 (22)
30EC501 H	45-12	56	180	9 (14)

Information courtesy Maxwell Capacitors



SuperCapacitor Discharge – Cranking an ICE:

The chart indicates a typical SuperCapacitor discharge capability, when deployed to crank an Internal Combustion Engine. The data shows 5 cranks to full start condition over a period of 10 seconds. Note the very quick – 12 second - full recovery time.

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Some article content provided courtesy of Dr. John Miller Ultracapacitor Applications, Maxwell Capacitors, CAP-XX Australia, BEST Magazine. Author Research.

Toyota & Denso Form New Company

Toyota (Japan) and DENSO have established a new company, (Yantai Shougang TD Automotive Compressor Co), to manufacture AC compressors in response to the growing Chinese market and plans to produce 2 million compressors in 2015 alone.

Hybrid

And in other news, Denso and Hino have jointly developed the world's first electric refrigerator system for heavy-duty trucks using a hybrid unit.

With the combination of Hino's hybrid powertrain system technology and DENSO's electric refrigerator system technology, the two companies have developed a high-quality refrigerator system that helps improve fuel economy, improves refrigeration performance, and is quieter when operating.

Hybrid trucks conventionally use energy generated from hybrid systems to assist the vehicle's driving. However, this new truck uses energy from hybrid unit only for the new electric refrigeration system, which saves fuel.

The newly developed electric refrigerator system uses energy generated while driving or regenerated energy from the hybrid unit to operate the refrigerator's compressor. This substantially reduces the amount of fuel normally used to drive the engine to operate the compressor, thus reducing CO_2 emissions as well.

Compared to refrigerated trucks that use an auxiliary engine to operate the compressor, the new system is quieter, and contributes to an approximately 150kg weight reduction because it does not need an auxiliary engine.

Trucks with main engine-driven compressor systems need to have separate refrigerator components in the engine compartment, under the floor panel, and in other places. However, the new truck uses a new integrated refrigeration unit that includes an electric compressor, condenser, and other devices. This simplified structure uses fewer tubes and wires and also is easier to maintain.