Supercapacitor Technical Guide

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Introduction

Supercapacitors, also known as ultracapacitors and electric double layer capacitors (EDLC), are capacitors with capacitance values greater than any other capacitor type available today. Supercapacitors are breakthrough energy storage and delivery devices that offer millions of times more capacitance than traditional capacitors. They deliver rapid, reliable bursts of power for hundreds of thousands to millions of duty cycles – even in demanding conditions.

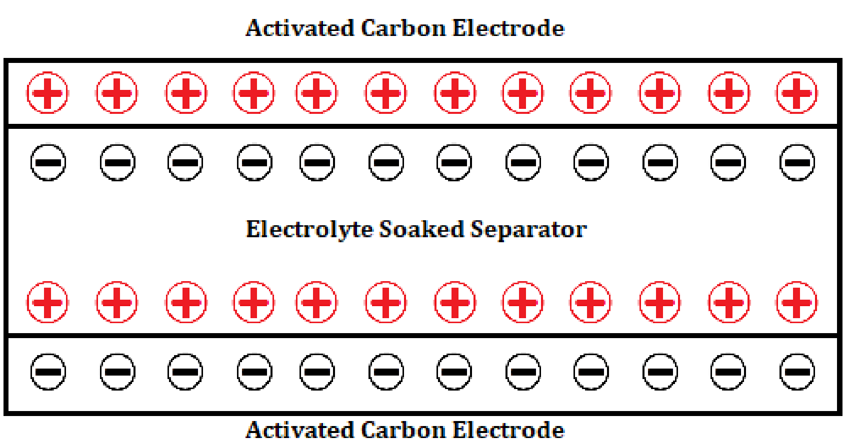
Supercapacitors are ideal for applications ranging from wind turbines and mass transit, to hybrid cars, consumer electronics and industrial equipment. Available in a wide range of sizes, capacitance and modular configurations, supercapacitors can cost-effectively supplement and extend battery life, or in some cases, replace batteries altogether.

Supercapacitor Construction

What makes supercapacitors different from other capacitor types are the electrodes used in these capacitors. Supercapacitors are based on a carbon technology. The carbon technology used in these capacitors creates a very large surface area with an extremely small separation distance. They consist of a positive electrode, a negative electrode, a separator between these two electrodes, and an electrolyte filling the porosities of the two electrodes and separators. The surface area of the activated carbon layer is extremely large yielding several thousands of square meters per gram. This large surface area allows for the absorption of a large number of ions.

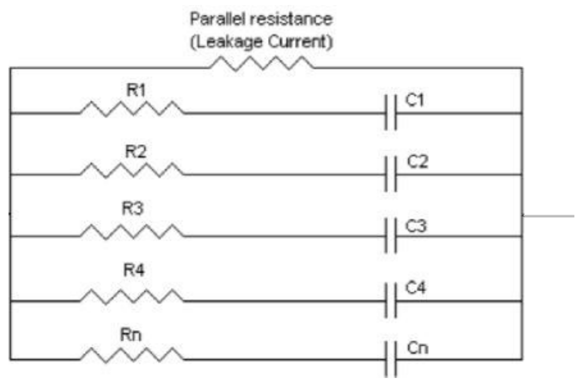
The charging/discharging occurs in an ion absorption layer formed on the electrodes of activated carbon.

The activated carbon fiber electrodes are impregnated with an electrolyte where positive and negative charges are formed between the electrodes and the impregnant. The electric double layer formed becomes an insulator until a large enough voltage is applied and current begins to flow. The magnitude of voltage where charges begin to flow is where the electrolyte begins to break down. This is called the decomposition voltage.



The double layers formed on the activated carbon surfaces can be illustrated as a series of parallel RC circuits.

As shown below the capacitor is made up of a series of RC circuits where R1, R2 ...Rn are the internal resistances and C1, C2..., Cn are the electrostatic capacitances of the activated carbons.



When voltage is applied current flows through each of the RC circuits. The amount of time required to charge the capacitor is dependent on the CxR values of each RC circuit. Obviously the larger the CxR the longer it will take to charge the capacitor. The amount of current needed to charge the capacitor is determined by the following equation:

In= (V/Rn) exp (-t/ (Cn*Rn))

Typical Applications

Cornell Dubilier supercapacitor products are offered in a full range of capacitance values and configurations. This enables utilization of supercapacitors in a variety of industries and applications for many power requirement needs. These applications span from milliamps current or milliwatt power to several hundred amps current or several hundred kilowatts power needs.

Industrial – uninterrupted power supply (UPS), wind turbine pitch systems, power transient buffering, automated meter reading (AMR), elevator micro-controller power backup, asset tracking, security, material handling, cranes, and telecommunications.

Transportation – Diesel engine cranking, security, tram power supply, voltage drop compensation, regenerative, braking, hybrid electric drive.

Military – Autonomous weapons, guidance control systems, UPS, drones and hybrid electric drive systems.

Data Storage – Server back-up, NVDIMM, SSD, and UPS.

Consumer – handheld devices, IoT, GPS, flashlights, and solar lighting.

Consideration for the various industries listed, and for many others, is typically attributed to the specific needs of the application the supercapacitor technology can satisfy.

Application Type	
Pulse Power	Supercapacitors are ideally suited for pulse power applications, due to the fact the energy storage is not a chemical reaction, the charge/discharge behavior of the supercapacitor is efficient.
Bridge Power	Supercapacitors are utilized as temporary energy sources in many applications where immediate power availability may be interrupted. Supercapacitor solutions are sized to provide the appropriate amount of ride through time until the primary backup power source becomes available.
Main Power	For applications requiring power for only short periods of time or is acceptable to allow short charging time before use, supercapacitors can be used as the primary power source.
Memory Backup	When an application has an available power source to keep the supercapacitors trickle charged, they may be suited for memory backup, system shutdown operations, or event notification. The supercapacitors can be maintained at its full charged state and act as a power reserve to perform critical functions in the event of power loss.

Determining the correct Supercapacitor for the application

Determination of the proper supercapacitor and number of capacitors is dependent on the intended application. For sizing the system correctly, a number of factors should be known. These factors include the maximum and minimum operating voltage of the application, the average current or power, the peak current or power, the operating environment temperature, the run time required for the application, and the required life of the application.

Since supercapacitors are low voltage devices, the rated voltage is generally less than the application voltage required. Knowing the maximum application voltage (Vmax) will determine how many capacitor cells are required to be series connected. The number of series connected cells is determined by:

$$\frac{V_{\max}}{V_R}$$

Next, the average current (I) in amps, the required run time (dt) in seconds and the minimum working voltage (Vmin), an approximate system capacitance can be calculated.

$$C_{sys} = \mathrm{I} \cdot \frac{dt}{dV} = \mathrm{I} \cdot \frac{dt}{(V_{max} - V_{min})}$$

The total system capacitance is comprised of the capacitance of all the series connected capacitors for achieving Vmax. For capacitors connected in series the capacitance of the individual cells is determined by:

$$\frac{1}{C_{sys}} = \frac{1}{\mathrm{C}_1} + \frac{1}{\mathrm{C}_2} + \cdots + \frac{1}{\mathrm{C}_\mathrm{n}}$$

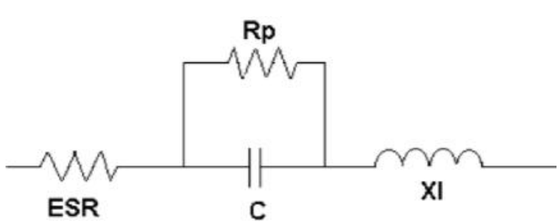
For capacitors connected in parallel to achieve the required energy, the capacitance is determined by:

$$C = C_1 + C_2 + \cdots + C_n$$

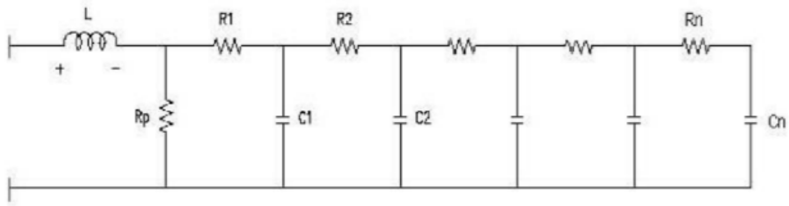
Note: There are many other items to consider for properly sizing the application. This includes the internal resistance of the capacitor to account for the sudden voltage drop associated with an applied current, the ambient operating temperature which affects the internal resistance and the capacitor life, and the life of the application. The supercapacitor performance requirement at the end of life of the application is necessary to ensure proper initial sizing of the system.

Equivalent Circuit

Supercapacitors can be illustrated similarly to conventional film, ceramic or aluminum electrolytic capacitors.



This equivalent circuit is only a simplified or first order model of a supercapacitor. In reality supercapacitors exhibit a non-ideal behavior due to the porous materials used to make the electrodes. This causes supercapacitors to exhibit behavior more closely to transmission lines than capacitors. Below is a more accurate illustration of the equivalent circuit for a supercapacitor.



Calculations

There are a couple of ways used to measure the capacitance of supercapacitors.

1. Charge method

2. Charging and discharging method

Charge Method

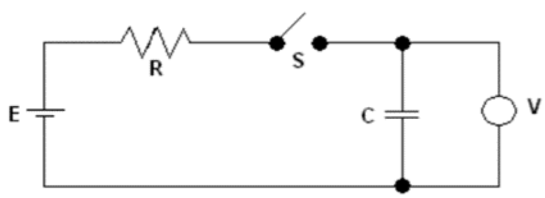
Measurement is performed using a charge method using the following formula.

Test condition

Capacitor voltage less than .05V
Ambient temperature 25°C
T1= time to reach 63.2% of the applied voltage.

C=t/R

t= .632Vo where Vo is the applied voltage.



Charge and Discharge Method

This method is similar to the charging method except the capacitance is calculated during the discharge cycle instead of the charging cycle.

Test Conditions

1. Constant current charging 10mA/F to rated voltage.
2. Constant voltage applied for 5 minutes.
3. Constant current discharge at 10mA/F down to 0.1V

Discharge time for constant current discharge

t= Cx (V0-V1)/I

Discharge time for constant resistance discharge

t= CRln (V1/V0)

Where t= discharge time, V0= initial voltage, V1= ending voltage, I= current.

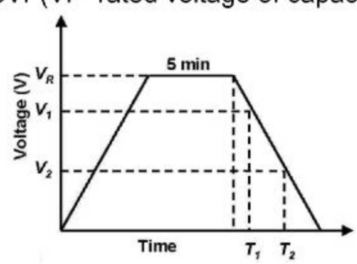
Capacitance

Supercapacitors have such large capacitance values that standard measuring equipment cannot be used to measure the capacity of these capacitors. Capacitance is measured per the following method:

1. Charge capacitor for 30 minutes at rated voltage.
2. Discharge capacitor through a constant current load.
3. Discharge rate to be 1mA/F.
4. Measure voltage drop between V_1 to V_2.
5. Measure time for capacitor to discharge from V_1 to V_2.
6. Calculate the capacitance using the following equation:

$$C = \frac{I^*(T_2 - T_1)}{V_1 - V_2}$$

Where V_1=0.7Vr, V_2=0.3Vr (Vr= rated voltage of capacitor)



Where C= capacitance in Farads
I = discharge current
V= rated voltage
V1= 80% or rated voltage
V2= 40% of rated voltage
T1= starting time of test
T2= time to reach V2

Leakage Current

Due to the extremely large surface area of the electrode the time constant of the last 0.5% of the electrode area is extremely long due to the pore size and geometry. The longer the supercapacitor is held on charge the lower the leakage current of the device. The reported leakage current is a measurement of the charging current after holding the device at rated voltage for 72 hours continuous, at room temperature. The measured leakage current will be influenced by the temperature during the measurement, the voltage in which the device is measured and the age of the product.

Leakage current and self-discharge:

Leakage current is the current that the supercapacitor will continue to draw from a source once it is at full voltage. This value decreases over time and is typically measured after the supercapacitor has been on charge for 72 hours.

Self-discharge is the rate of voltage decline when the capacitor is not connected to any circuit. The rate of self-discharge is dependent on the state of charge it was held out before being disconnected from the circuit. A part that is quickly charged then left to sit will discharge faster than one that is held on charge for many hours. The rate of discharge also changes as the voltage decreases.

ESR_{AC}

Measured using 4-probe impedance analyzer under the following conditions.

Condition: Potentiostat mode
AC amplitude: 5mV
Frequency: 1 kHz, +/-100 Hz

ESR_{DC}

1. Charge capacitor using a constant current.
2. After reaching rated voltage hold voltage for at least 1 minute.
3. Discharge capacitor at a rate of 1mA/F.
4. Measure the time it takes to have the voltage drop from V_1 to V_2.
5. Calculate ESR using the following formula:

$$ESR\ (DC) = \frac{V}{I}$$

Life Expectancy Calculation

The life expectancy of supercapacitors is similar to aluminum electrolytic capacitors. The life of supercapacitors will double for every 10°C decrease in temperature or voltage by 0.1V. Supercapacitors operated at room temperature can have life expectancies of several years compared to operating the capacitors at their maximum rated temperature.

$$L = L_1 \cdot 3.25^{\frac{T_m - T_a}{10}} \cdot 1.52^{\frac{V_r - V_a}{0.1n}}$$

L_1= Load life rating of the super capacitor (typically 1000 hours at rated temperature).
L_2= expected life at operating condition.
T_m= Maximum temperature rating of the supercapacitor.
T_a= Ambient temperature the supercapacitor is going to be exposed to in the application.
V_r = rated voltage of capacitor.
V_a = applied voltage to capacitor

Soldering Guidelines

Hand Soldering (soldering iron)

Warning. Do not touch the supercapacitor external sleeve with the soldering rod which can cause the sleeve to melt or crack.

1. When soldering supercapacitors with a soldering iron the exposure should be limited to 350°C for 3.5 seconds.
2. Circuit board thickness should be 1.6mm +/-0.5mm
3. At no time should the soldering iron come in contact with the capacitor body. Contact with the body can cause the sleeving to crack or melt.
4. To remove a capacitor from a printed circuit board, the capacitor should be pulled on gently after the solder holding the capacitor to the circuit board has sufficiently melted.

Wave Soldering

1. Supercapacitors are not to be immersed in the solder bath at any time. To do so would result in the internal pressure within the capacitor to rise, damaging the capacitor.
2. Supercapacitors are only to be mounted to the topside of the circuit board.
3. Circuit board thickness should be 1.6mm +/-0.5mm.
4. Recommended preheat – Preheat board from bottom side only, bring top of board to 100C maximum immediately before soldering. Use a maximum preheating time of 60 seconds for a PCB 0.8mm or thicker. Following the table below for wave soldering of leads only:

Solder Bath Temperature (°C)	Recommended Solder Exposure (Seconds)	Maximum Exposure (Seconds)
220	7	9
240	7	9
250	5	7
260	5	5

Reflow Soldering

Reflow soldering should **not** be used on any Cornell Dubilier supercapacitors.

Cell Balancing

Due to the low voltage characteristics of a single supercapacitor cell, most applications require multiple cells in series to achieve the voltage required. Because each cell will have a slight tolerance in capacitance and resistance it is necessary to balance, or prevent, individual cells from exceeding its rated voltage.

Balancing can be achieved through two different methods, active balancing or passive balancing:

Passive Balancing

Passive balancing implies no variation in the voltage regulation as a function of the ultracapacitor condition. The most typical method of passive balancing utilizes resistors. The concept of resistive balancing employs resistors in parallel with the ultracapacitors.

Active Balancing

Active voltage balancing is preferred for applications with a limited energy source or high level of cycling. An active circuit typically draws much lower current in steady state and only requires larger currents when the cell voltage is out of balance. The maximum current varies by product.

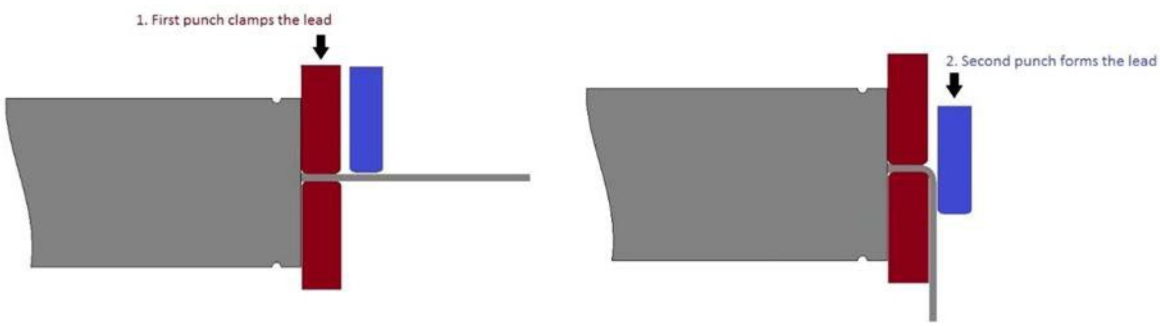
Lead Bending Recommendations

(for all radial capacitor cells)

Leads should be clamped prior to any lead bending. Clamping force should be greater than the force required to bend the leads.

- There should be a minimum clearance of 0.9mm between the bung (lead egress end of the cell) and the lead.
- Lead bending should be a two-step process (see figure following):
    1. Lead should be clamped prior to bending.
    2. Leads are formed.

Caution: Leads must be supported prior to performing lead bend. Failure to properly support the leads during bending will transfer the bending force into the capacitor enclosure and may adversely affect the integrity of the capacitor seal. It should be noted that damage of this type may lead to failures that may be detected during initial testing or may be latent and only show up in the field.



For further information on bending guidelines, please consult CDE engineering or your sales representative.

Safety Information

Cornell Dubilier supercapacitors have successfully passed UL810A testing and are UL recognized components under file number MH64760.

Individual capacitors are low voltage devices. They can deliver extremely high currents especially in short circuit situations. Handling of capacitors should be done in an uncharged state. When designing a system with higher voltages standard safety practices should be followed for the voltage levels of consideration.

Disposal

Supercapacitors are composed of aluminum, carbon, paper and an organic electrolyte. Supercapacitors contain no heavy metals or toxic materials hazardous to the environment. The organic electrolyte, Acetonitrile, is a hazardous waste per Federal regulations (40 CRF 261). Proper disposal should be done through permitted facilities. Please consult your State and local regulations and disposal requirements. In general, packaging material is recyclable. The remaining materials can be incinerated at high temperatures.

Shipping

Cornell Dubilier supercapacitor cells and modules less than 10Wh capacity comply with UN3499 regulations (including Special Provision 361 and 186) and meet all the requirements when transported as individual capacitors or modules. Supercapacitors with an energy storage capacity of 0.3Wh or less are not regulated and, therefore, are exempt from DG/HZM shipping regulations when transported as individual capacitors or modules. By meeting these requirements, all Cornell Dubilier supercapacitor cells and modules may be transported without DG/HZM restrictions, as detailed by these regulations.

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