Supercapacitors

Supercapacitors also called ultracapacitors and electric double layer capacitors (EDLC) are capacitors with capacitance values greater than any other capacitor type available today. Capacitance values reaching up to 800 Farads in a single standard case size are available.

Supercapacitors have the highest capacitive density available today with densities so high that these capacitors can be used to applications normally reserved for batteries. Supercapacitors are not as volumetrically efficient and are more expensive than batteries but they do have other advantages over batteries making the preferred choice in applications requiring a large amount of energy storage to be stored and delivered in bursts repeatedly.

Advantages over batteries
Power density
Recycle ability
Environmentally friendly
Safe
Light weight

The most significant advantage supercapacitors have over batteries is their ability to be charged and discharged continuously without degrading like batteries do. This is why batteries and supercapacitors are used in conjunction with each other. The supercapacitors will supply power to the system when surges or energy bursts since are required.

Supercapacitors can be charged and discharged quickly while the batteries can supply the bulk energy since they can store and deliver larger amount energy over a longer slower period of time.

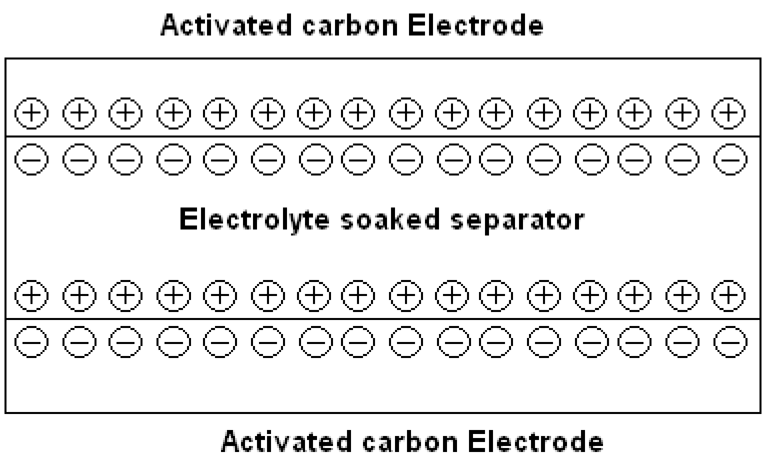
Supercapacitor construction

What makes' supercapacitors different from other capacitors types are the electrodes used in these capacitors. Supercapacitors are based on a carbon (nanotube) technology. The carbon technology used in these capacitors creates a very large surface area with an extremely small separation distance. Capacitors consist of 2 metal electrodes separated by a dielectric material. The dielectric not only separates the electrodes but also has electrical properties that affect the performance of a capacitor.

Supercapacitors do not have a traditional dielectric material like ceramic, polymer films or aluminum oxide to separate the electrodes but instead have a physical barrier made from activated carbon that when an electrical charge is applied to the material a double electric field is generated which acts like a dielectric. The thickness of the electric double layer is as thin as a molecule. 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 amount of ions.

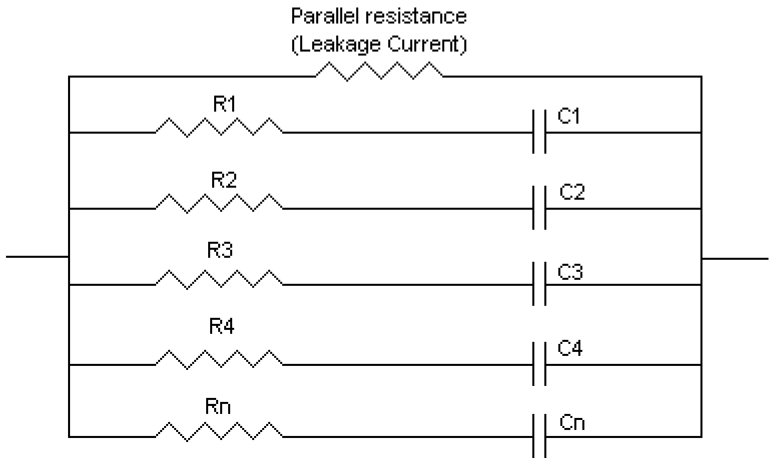
The charging/discharging occurs in an ion absorption layer formed on the electrodes of activated carbon.

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.

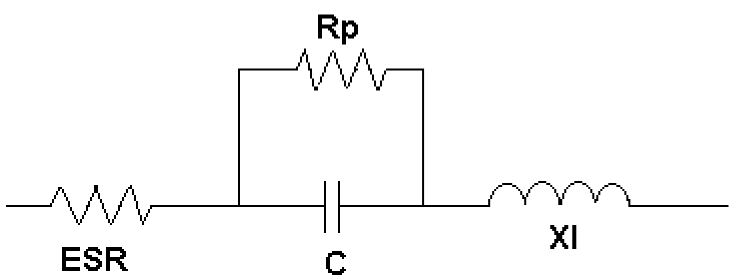


When voltage is applied current flows through each of the RC circuits. The amount of time required to charge the capacitor is dependant on the CxR values of each RC circuit. Obviously the larger the CxR the longer it will take to charge the capacitor. The amount of current needed to charge the capacitor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

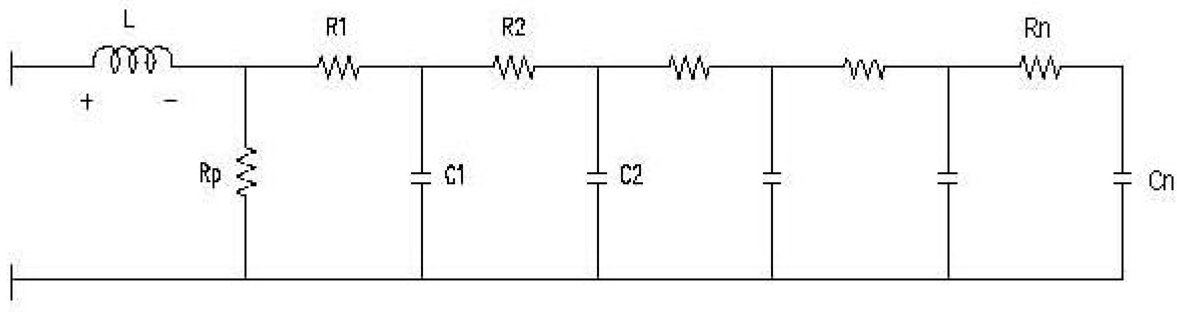
$I_n = (V/R_n) \exp(-t/(C_n * R_n))$

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.



How to measure the capacitance of a supercapacitor

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

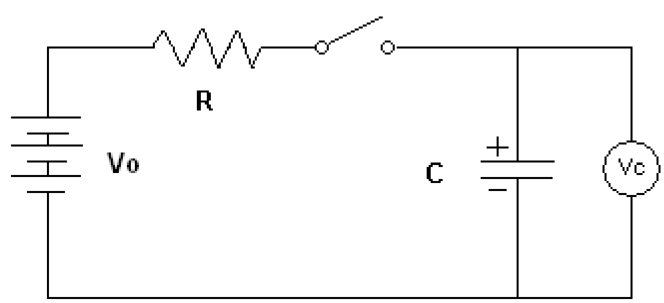
1. Charge method
2. Charging and discharging method.

Charge method

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

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.

Discharge time for constant current discharge

$t= Cx (V_0-V_1)/I$

Discharge time for constant resistance discharge

$t= CR\ln (V_1/V_0)$

Where t= discharge time, V_0= initial voltage, V_1= ending voltage, I= current.

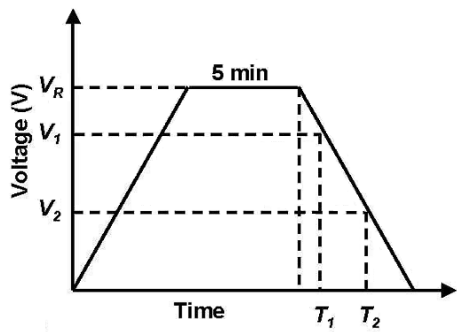
Capacitance

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)



ESR

ESR_{ac} - Measure using a 4 probe impedance analyzer at 1 kHz.

ESR_{DC} - measured using the following procedure

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

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

$$L_2=L_1*2^X*2^Y \quad X=\frac{Tm-Ta}{2} \quad Y=\frac{Vr-Va}{0.2}$$

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

Applications for Supercapacitors

Supercapacitors have found uses in:

- Computer systems
- UPS systems
- Power conditioners
- Welders
- Inverters
- Automobile regenerative braking systems
- Power supplies
- Cameras
- LED systems
- Cooking equipment
- Power generators
- Battery assist
- Smart meters
- Energy harvesting
- Medical systems
- Audio systems
- Emergency lighting
- Power generators
- Diesel engines
- Electric valves/ solenoids