Retrospect on Super Capacitor

Antheesh R
Department of Electrical & Electronics Engineering
SDM Institute of Technology
Ujire, Karnataka, India
antheesh@gmail.com

Dr. Rajkiran Ballal I
Professor
Department of EEE
Nitte Meenakshi Institute of Technology,
Yelahanka, Bengaluru-560064
rajkiran.dballal@nmit.ac.in

***Abstract*— Energy is the most evident factor of any power system. Utilization of this resource has to be made meticulously, as the inadequacy can direct to system failure. The prominence of Energy has given way to major research in the field of energy storage devices like battery etc., Capacitors which store the electrical energy in the form of charge, and their discharging nature supplies a lot of power to the system. Here in this paper, a comprehensive study is presented on Supercapacitors which are empowered with the potential of accommodating electric charge, hundreds of times of standard capacitors. We focus on the study of the detailed characteristics, along with the comparison with conventional capacitors, in terms of charging and discharging with different dielectric mediums depending on the energy densities and their Applications. An attempt is being made to develop Supercapacitor as the emerging storage solution for many application- specific power systems.**

***Index Terms*—Supercapacitor, Energy Storage, Filtering Application assistance, Dielectric Medium, Energy Density.**

I. INTRODUCTION

In response to the changing global landscape, energy has become a primary emphasis of the major world powers and scientific community. There has been great interest in developing and refining more proficient energy storage devices. Capacitors form one among the filtering device cum storage equipment adding an benefit over the normal storage devices like battery. Capacitors can store relatively less energy per unit mass or volume than a battery, but what electrical energy they do store can be discharged rapidly to produce a lot of power, so their power density is usually high. Capacitors stores electrical energy physically in the form of charge, no chemical reaction is tangled there by increasing the charging and discharging cycles. Due to continuous charging and discharging cycles making capacitors may rift soon so an emerging technology called Supercapacitor [1] is being invented. The supercapacitor has been matured significantly over the last decade and emerged with the potential to facilitate major advances in energy storage.

An ultra-capacitor, also called a supercapacitor or electrochemical capacitors, is an electrical component capable of holding hundreds of times more electrical charge quantity than a standard capacitor. Supercapacitors are governed by the same fundamental equations as conventional capacitors, but utilize higher surface area electrodes and thinner dielectrics to achieve greater capacitances. This allows for energy densities greater than those of conventional capacitors and power densities greater than those of batteries. As a result, supercapacitors may become an attractive power solution for an increasing number of applications.

Supercapacitor is a kind of electrical energy storage device having advantages as high power density, high efficiency, fast charging and discharging speed, long cycle life, wide operating temperature range and environment friendly. Supercapacitors have main characteristic as high capacity value and extremely low ESR's when compared to traditional capacitors. The electrodes are fabricated by high surface area, porous material having pores of diameter in the nanometre range. Storage of charge is in the micro pores at or near the interface between the solid electrode material and the electrolyte. Fabrication of Double-layer capacitor electrodes are done using carbon black and carbon aero gel and carbon cloth. When developing Supercapacitor, the electrode material and electrolyte characteristics should be considered jointly. The capacitance is dependent primarily on the characteristics of the electrode material (surface area and pore size distribution). The resistance of the supercapacitor cell is dependent on the resistivity of the electrolyte used and size of the ions from the electrolyte that diffuse into and out of the pores of the micro porous electrode particles.

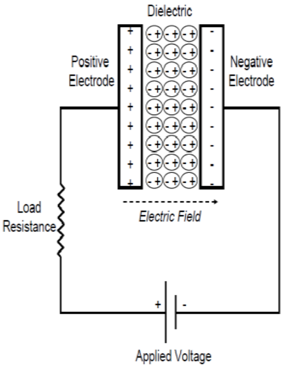


Fig. 1. Schematic of a conventional capacitor

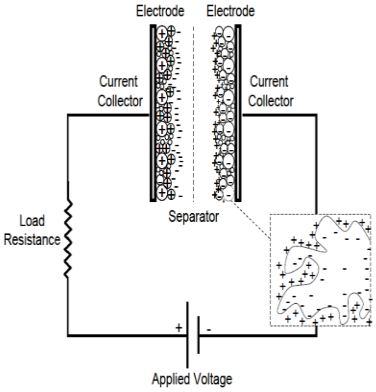


Fig. 2. Schematic of an electrochemical double-layer capacitor

Capacitors are constructed with a dielectric placed between opposed electrodes, functioning as capacitors by accumulating charges in the dielectric material. In a conventional capacitor, energy is stored by the removal of charge carriers, typically electrons from one metal plate and depositing them on another.

This charge separation creates a potential between the two plates, which can be harnessed in an external circuit. The total energy stored in this fashion is a combination of the number of charges stored and the potential between the plates. The former is essentially a function of size and the material properties of the plates, while the latter is limited by the dielectric breakdown between the plates.

Construction of Supercapacitors includes two carbon based electrodes, an electrolyte, and a separator. The charge storage principle of supercapacitor is shown in the above figure. Same as conventional capacitors, supercapacitors also store charge electro statically, and the charge will not be transferred between electrode and electrolyte. Polarization [3] occurs at electrolyte when electric field is formed. When unlike charges attracts each other, ions in the electrolyte diffuse across the separator into the pores of the electrode of opposite charge. Thus, Storage of charge is made in double layers at each electrode. Electric energy was stored into the electrical double layer which was formed at the porous solid electrode/electrolyte interface. Here separator acts as an insulator which prevents physical contact of electrodes but allows ion transfer between them.

II. TAXONOMY OF SUPER CAPACITOR

Based upon current R&D trends, supercapacitors can be divided into three general classes: Electrochemical double-layer capacitors, Pseudo capacitors and Hybrid capacitors.

Each class is characterized by its unique mechanism for storing charge. These are, respectively, non-Faradaic, Faradaic, and a combination of these two. Faradaic processes, such as oxidation-reduction reactions, involve the transfer of charge between electrode and electrolyte. A non-Faradaic mechanism, by contrast, does not use a chemical mechanism. Rather, charges are distributed on surfaces by physical processes that do not involve the making or breaking of chemical bonds.

This section will present an overview of each one of these three classes of super capacitors and their subclasses, distinguished by electrode material. A graphical taxonomy of the different classes and subclasses of supercapacitors are shown in the following figure.

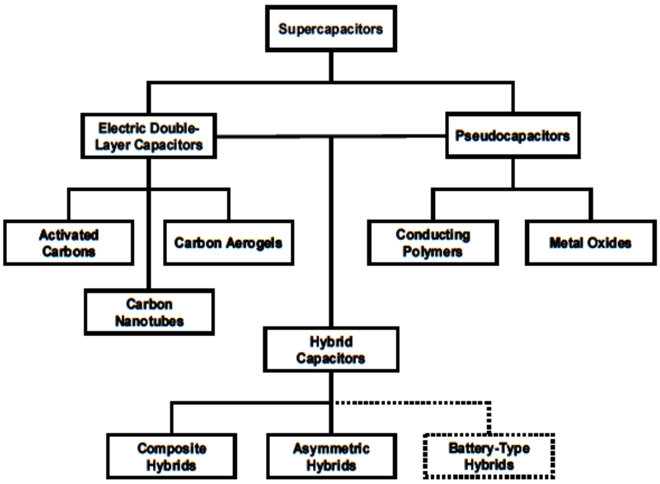


Fig. 3. Taxonomy of Supercapacitor

III. CHARACTERISTICS OF A SUPERCAPACITOR

Following provide the overview of some of the key performance characteristics and design issues of Super Capacitors.

A. Temperature effects and performance changes over time

An advantage of the Super capacitor's organic based electrolyte is its low freezing point. This enables the Super capacitors to be utilized over a wide range of temperatures, with relatively unaffected performance.

B. Lifetime

Supercapacitor life is predominantly affected by a combination of operating voltage and operating temperature. The Supercapacitor has an unlimited shelf life when stored in a discharged state. When referring to Supercapacitor life the data sheets reflect the change in performance, typically decrease in capacitance and increase in resistance. The Supercapacitor does not experience a true end of life rather the performance continually degrades over the life of the use of the product. The typical degradation behavior of the Supercapacitor resembles that of an exponential decay.

C. Cycling

From cycle testing performed, under typical conditions the product is expected to provide in excess of 1 million duty cycles with an approximate 20% reduction in rated capacitance.

D. Frequency Response

Supercapacitors have a typical time constant of approximately one second. One time constant reflects the time necessary to charge a capacitor 63.2% of full charge or discharge to 36.8% of full charge. The time constant of a Supercapacitor is much higher than that of an electrolytic capacitor. Therefore, it is not possible to expose Supercapacitors to a continuous ripple current as overheating may result. The Supercapacitor can respond to short pulse power demands, but due to the time constant the efficiency or available energy is reduced.

E. Voltage

Supercapacitors are capable of operating between their rated voltage and zero volts. Occasional spikes above the rated voltage will not immediately affect the capacitor. Depending on the frequency and duration of voltage spikes the life will be reduced.

F. Polarity

Unlike many batteries the anode and cathode of a Supercapacitor are comprised of the same material. If the positive and negative terminal and casing are also comprised of similar materials, then theoretically the Supercapacitor has no true polarity. Due to the corrosion potential it is required to maintain the polarity indicated on the products, and reverse polarity will cause accelerated life reduction.

G. Charging

Since the energy storage mechanism of the Supercapacitor is not a chemical reaction, charging/discharging of the Supercapacitors can occur at the same rate. Therefore, the rated current for the Supercapacitor applies for both charge and discharge. The efficiency of charge and discharge are in practical terms the same. A variety of methods are possible for charging of the Supercapacitors. This may be either through constant current or constant power charging via a dc source or through ac charging methods.

H. Series Connection and Balancing

Since the individual Supercapacitor cell voltage is relatively limited compared to the majority of application requirements, it is necessary to series connect the Supercapacitors to achieve the voltage required. Because each Supercapacitor will have a slight tolerance in capacitance and resistance it is necessary to balance, or prevent, individual Supercapacitors from exceeding its rated voltage.

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

Active balancing schemes are varied. This methodology will always attempt to balance two adjoining Supercapacitors based on the voltage mismatch between the two Supercapacitors. The maximum current during balancing varies by product.

Passive balancing implies no variation in the voltage regulation as a function of the Supercapacitor condition. The most typical method of passive balancing utilizes resistors in parallel with the Supercapacitors.

I. Efficiency

Unlike batteries, the Supercapacitor has the same efficiency during charge or discharge. This enables the Supercapacitor to be recharged quickly without current limiting as long as the current is within the rated current for the device. The only efficiency losses associated with Supercapacitors are due to internal resistance of the device resulting in IR drop during cycling. For high current or power pulsing the efficiency is reduced.

J. Thermal Properties

For minimum performance influence over the life of the application it is necessary to maintain the Supercapacitor core temperature within the rated temperature range of the device. The lower the temperature is maintained the better for life considerations.

Depending on the duty cycle of the application cooling can be accomplished via heat sinks (conduction), air flow (convection) or a combination of the two. Consideration should be made for the duty cycle and resulting capacitor temperature as well as the anticipated ambient temperature the device will be operating under. The combination of the two should not exceed the operating temperature for the Supercapacitor.

IV. SUPERCAPACITOR EQUIVALENT CIRCUIT MODEL

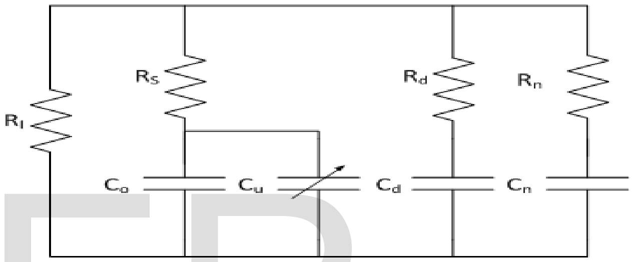


Fig. 4. Supercapacitor RC Branches model

Resistive element represents the resistivity of the electrode (carbon particles) materials of the supercapacitor and capacitive element represents the capacitance between carbon particles and electrolyte. Capacitance of the supercapacitor depends on potential differences across the material [4].

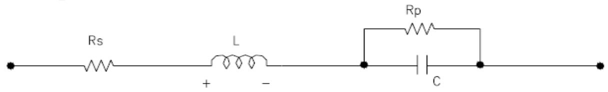


Fig. 5. First order Equivalent Circuit

The series resistance Rs which is also referred to as the equivalent series resistance (ESR). This is the main contributor to power loss during charging and discharging of the capacitor. It is also comprised of a parallel resistance Rp which affects the self-discharge, a capacitance C and a series inductor Ls that is very small as a result of the cell construction [8].

Since Rp is always much larger than Rs it can be ignored. Also, because of the porous material used on the electrode of EDLCs, they exhibit non-ideal behaviour which causes the capacitance and resistance to be distributed such that the electrical response mimics transmission line behaviour.

The voltage during discharge is determined by these resistances. When measured at matched impedance (*R* = *ESR*), the maximum power Pmax for a capacitor is given by:

$$P_{max} = (V^2 * ESR)/4$$

The above equation shows the ESR can limit the maximum power of a capacitor. Conventional capacitors have relatively high power densities, but relatively low energy densities than electrochemical batteries and to fuel cells. A battery can store more total energy than a capacitor, but it cannot deliver it very quickly, as its power density is low. Capacitors can store relatively less energy per unit mass or volume, but how much electrical energy they do store can be discharged rapidly to produce a lot of power, so their power density is usually high. Supercapacitors are governed by the same basic principles as conventional capacitors. However, they incorporate electrodes with much higher surface areas and much thinner dielectrics that decrease the distance between the electrodes.

V. ADVANTAGES AND DISADVANTAGES OF SUPERCAPACITOR

Supercapacitors are especially used as a replacement for the electrochemical battery, for standby power and memory backup devices as well as in filtering of pulsed load currents.

Advantages:

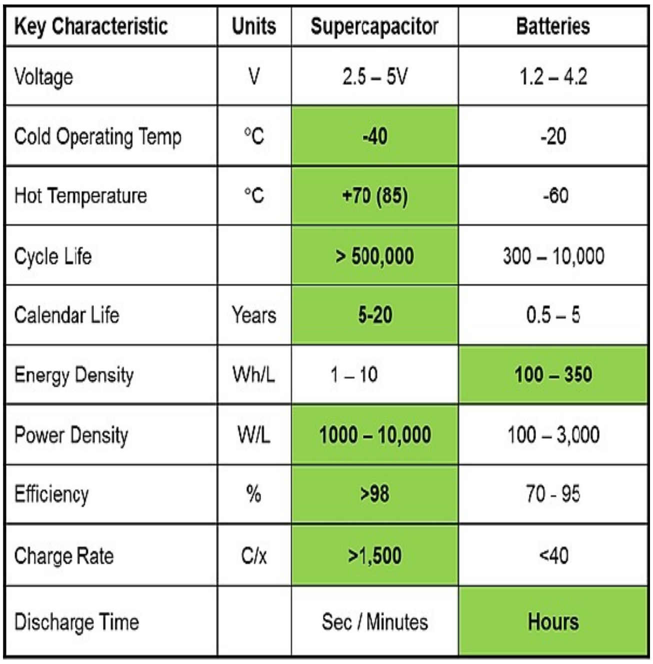
1. Unlimited cycle life; as compared to the electrochemical battery, they are not subject to the wear or aging.
2. Quick charging times
3. Low impedance; by paralleling it with a battery, it enhances the pulse current.
4. Cost effective storage; a very high cycle count compensates the lower density.
5. Low Toxicity of Materials are used.
6. High Cycle Efficiency (95% or more).

Disadvantages:

1. Low energy density; holds 1/5 – 1/10 of a battery.
2. Low voltage cells; to get higher voltages, serial connections are required.
3. Voltage balancing needed; when more than 3 supercapacitors are connected in series, the circuit needs a voltage balancing element.
4. High self-discharge as compared to electrochemical batteries.
5. Dielectric absorption of a battery is very high compared to normal capacitors

VI. COMPARATIVE STUDY

Table. 1. Comparison between Supercapacitor and Battery



Key Characteristic	Units	Supercapacitor	Batteries
Voltage	V	2.5 – 5V	1.2 – 4.2
Cold Operating Temp	°C	-40	-20
Hot Temperature	°C	+70 (85)	-60
Cycle Life		> 500,000	300 – 10,000
Calendar Life	Years	5-20	0.5 – 5
Energy Density	Wh/L	1 – 10	100 – 350
Power Density	W/L	1000 – 10,000	100 – 3,000
Efficiency	%	>98	70 - 95
Charge Rate	C/x	>1,500	<40
Discharge Time		Sec / Minutes	Hours

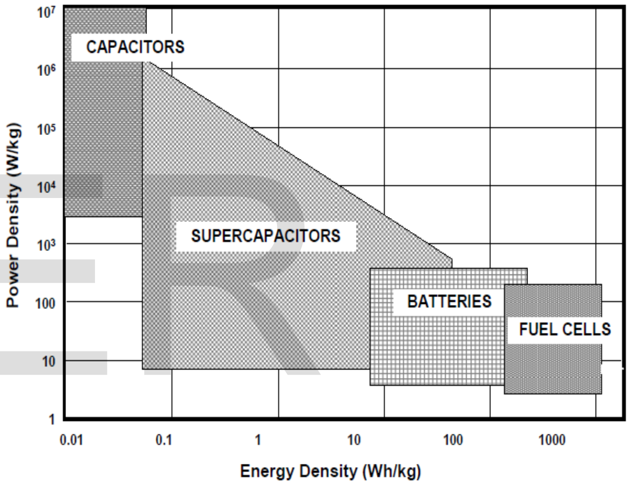


Fig. 6. Ragone Plot

Super Capacitors reside in between conventional batteries and conventional capacitors. They are typically used in applications where batteries have a short fall when it comes to high power and life, and conventional capacitors cannot be used because of a lack of energy. EDLCs offer a high power density along with adequate energy density for most short term high power applications. Many users compare EDLCs with other energy storage devices including batteries and conventional capacitor technology [7].

VII. CONCLUSION

Based upon the review of the literature described above, it seems unlikely that supercapacitors will replace batteries as the general solution for power storage. This is primarily because presently envisioned supercapacitor systems do not store as much energy as batteries [2]. Because of their flexibility, however, supercapacitors can be adapted to serve in roles for which electrochemical batteries are not as well suited. Also, supercapacitors have some intrinsic characteristics that make them ideally suited to specialized roles and applications that complement the strengths of batteries. In particular, supercapacitors have great potential for applications that require a combination of high power, short charging time, high cycling stability, and long shelf life [6].

VIII. FUTURE ENHANCEMENT

Over the last several years, supercapacitor R&D has focused upon efforts to increase the capacitance of electrode materials and to develop improved quantitative models. However, recent research trends suggest that new areas may be rising to the forefront of supercapacitor R&D.

Recently power semiconductor designers have developed a new type of device that overcomes the problems associated with safely charging a super capacitor [5]. Designers size the super capacitor to minimise the voltage drop during transmission and allow recharging during the receive phase

The main development goals will be,

- Long life time
- Increase of the rated voltage
- Improvements of the range of operating temperature
- Increase of the energy and power densities

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