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Overview of Supercapacitor

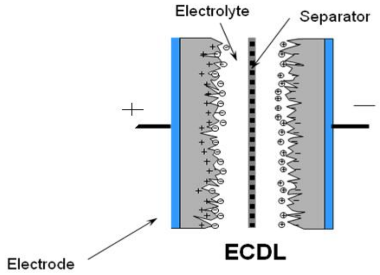
Amol Yadav *
Electronics Dept. BVDUCOE
India

Prof.Brig.R.M.Khaire
E & TC. Dept. BVDUCOE
India

Abstract— ***In this paper, we present a brief overview and applications of supercapacitor. Also, we discuss short review of recent supercapacitor technology. First we will see the architecture of the supercapacitor and current technology used for integrating & manufacturing supercapacitor. Then we will see the applications of supercapacitor in various fields.***

Keywords--

I. *Supercapacitor basic architecture*



It consists two electrodes separated by one separator which is made by porous carbon.The Electrolyte is carbon arogel material which has High surface area and electrodes are made by activated Carbon.

II. Classification of Supercapacitor

II. A-Double layer capacitors:

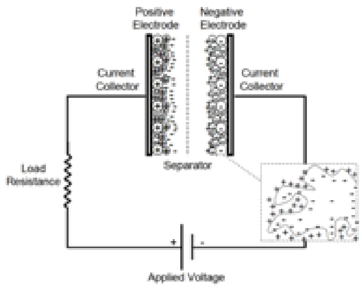


Figure.2 -Schematic of Double layer capacitor

Electrochemical double-layer capacitors (EDLCs) are constructed from two carbon-based electrodes, an electrolyte, and a separator. Figure 3 provides a schematic of a typical EDLC. Like conventional capacitors, EDLCs store charge electrostatically and there is no transfer of charge between electrode and electrolyte. EDLCs utilize an electrochemical double-layer of charge to store energy. As voltage is applied, charge accumulates on the electrode surfaces. Following the natural attraction of unlike charges, ions in the electrolyte solution diffuse across the separator into the pores of the electrode of opposite charge. However, the electrodes are engineered to prevent the recombination of the ions. Thus, a double-layer of charge is produced at each electrode. These double-layers, coupled with an increase in surface area and a decrease in the distance between electrodes, allow EDLCs to achieve higher energy densities than conventional capacitors.

Because there is no transfer of charge between electrolyte and electrode, there are no chemical or composition changes associated with non-Faradic processes. For this reason, charge storage in EDLCs is highly reversible, which allows them to achieve very high cycling stabilities. EDLCs generally operate with stable performance characteristics for a great many charge-discharge cycles, sometimes as many as 10^6 cycles. On the other hand, electrochemical batteries are generally limited to only about 10^3 cycles. Because of their cycling stability, EDLCs are well suited for *applications that involve non-user serviceable locations, such as deep sea or mountain environments.*

II.B- Pseudocapacitor:

In contrast to EDLCs, which store charge electrostatically, pseudo capacitors store charge faradaically through the transfer of charge between electrode and electrolyte. This is accomplished through electrosorption, reduction-oxidation reactions, and intercalation processes. These Faradic processes may allow pseudo capacitors to achieve greater capacitances and energy densities than EDLCs. There are two electrode materials that are used to store charge in pseudo capacitors, conducting polymers and metal oxides.

Conducting Polymers:

Conducting polymers have a relatively high capacitance and conductivity, plus a relatively low ESR and cost compared to carbon-based electrode materials [5]. In particular, the n/p-type polymer configuration, with one negatively charged (n-doped) and one positively charged (p-doped) conducting polymer electrode, has the greatest potential energy and power densities; however, a lack of efficient, n-doped conducting polymer materials has prevented these pseudo capacitors from reaching their potential [6, 7]. Additionally, it is believed that the mechanical stress on conducting polymers during reduction-oxidation reactions limits the stability of these pseudo capacitors through many charge-discharge cycles. This reduced cycling stability has hindered the development of conducting polymer pseudo capacitors.

Metal Oxides:

Metal oxides have also been explored as a possible electrode material for pseudo capacitors. The capacitance of ruthenium oxide is achieved through the insertion and removal, or intercalation, of protons into its amorphous structure. In its hydrous form, the capacitance exceeds that of carbon-based and conducting polymer materials . Furthermore, the ESR of hydrous ruthenium oxide is lower than that of other electrode materials. As a result, ruthenium oxide pseudo capacitors may be able to achieve higher energy and power densities than similar EDLCs and conducting polymer Pseudo capacitors.

II.C-Hybrid Capacitor

Hybrid capacitors have relative advantages and the relative disadvantages of EDLCs and pseudo capacitors to realize better performance characteristics. Utilizing both Faradaic and non-Faradaic processes to store charge, hybrid capacitors have achieved energy and power densities greater than EDLCs without the sacrifices in cycling stability and affordability that have limited the success of pseudo capacitors. There are three different types of hybrid capacitors, distinguished by their electrode configuration: composite, asymmetric, and battery-type respectively.

Composite:

Composite electrodes constructed from carbon nanotubes and polypyrrole a conducting polymer. It is integrated on carbon-based materials with either conducting polymer or metal oxide materials and incorporates both physical and chemical charge storage mechanisms together in a single electrode. The carbon-based materials facilitate a capacitive double-layer of charge and also provide a high-surface-area backbone that increases the contact between the deposited pseudo capacitive materials and electrolyte. The pseudo capacitive materials are able to further increase the capacitance of the composite electrode through Faradaic reactions.

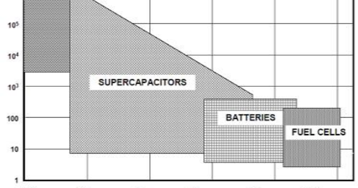
Asymmetric:

It combines Faradaic and non-Faradaic processes by coupling an EDLC electrode with a pseudo capacitor electrode.

Battery-type:

It couples two different electrodes; however, battery-types are unique in coupling a supercapacitor electrode with a battery electrode. This specialized configuration reflects the demand for higher energy supercapacitor and higher power batteries, combining the energy characteristics of batteries with the power, cycle life, and recharging times of supercapacitor. Research has focused primarily on using nickel hydroxide, lead dioxide, and LTO ($Li_4Ti_5O_{12}$) as one electrode and activated carbon as the other. Although there is less experimental data on battery- type hybrids than on other types of supercapacitor, the data that is available suggests that these hybrids may be able to bridge the gap between supercapacitor and batteries. Despite the promising results, the general consensus is that more research will be necessary to determine the full potential of battery-type hybrids.

III. Performance Characteristics:



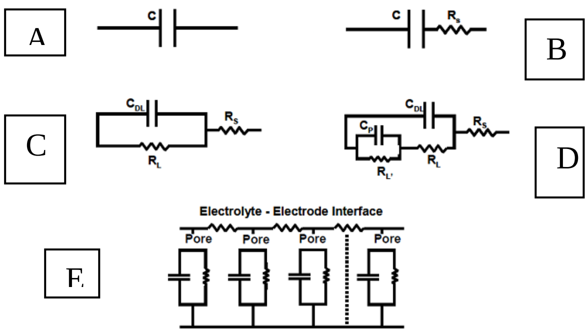
Power Density (w/kg) Vs Energy Density (wh/kg)

This graph termed a "Ragone plot." This type of graph presents the power densities of various energy storage devices, measured along the vertical axis, versus their energy densities, measured along the horizontal axis. In above figure it is seen that supercapacitors occupy a region between conventional capacitors and batteries. Despite greater capacitances than conventional capacitors, supercapacitors have yet to match the energy densities of mid to high-end batteries and fuel cells. Thus, much of the literature surveyed for this overview focuses on developing improved types or classes of supercapacitors to make their energy densities more comparable to those of batteries.

IV. Equivalent Circuit Model:

It employs mathematical models of fundamental electric circuit component such as resistors and capacitors, to model complex electrochemical processes. Simple equivalent circuits have long been used to predict the performance characteristics of porous electrodes. These equivalent circuits primarily have been applied to attempt to capture the behavior of the double-layer at the interface between the electrode pores and electrolyte solution.

The hierarchy of equivalent circuits used to model porous electrodes is presented in Figure 4. This hierarchy begins with a simple capacitor (4A) and adds components one at a time to arrive at the complete equivalent circuit for a porous electrode (4E). In this final equivalent circuit (4E), which is known as a transmission line, the distributed resistances represent the ESR intrinsic to each pore as the ions from the electrolyte diffuse towards the electrode. The distributed capacitances represent the non-Faradaic double-layer capacitance of each pore.



Here,
A- *Capacitor.*
B- *Capacitor with series resistance.*
C- *Capacitor and leakage resistance parallel with series resistance.*
D- *Simple pseudo capacitor circuit*
E- *Transmission line model for porous electrode.*

V. Relation between distance, surface area and capacitance:

$$C = \varepsilon_0 \varepsilon_r \frac{A}{D}$$

Here,
C ---- Capacitance.
D ---- Distance between two electrodes.
A ---- Surface area.
ε_0 *---- Dielectric constant of free space.*
ε_r *---- Dielectric constant of material used between electrodes.*

VI. Future of the supercapacitor research and development:

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. In particular, R&D efforts concerning hybrid capacitors, equivalent series resistance, electrolyte optimization, and self-discharge are likely to expand and enable major performance advances in supercapacitor

Equivalent Series resistance:

Determining how to lower the ESR of supercapacitors is becoming an important area of R&D. Several methods for reducing the ESR already have been developed, including polishing the surface of the current collector, chemically bonding the electrode to the current collector, and using colloidal thin film suspensions. In addition, there has been research in defining the relationship between pore size and ESR in electrode materials and determining the intrinsic ESR of various electrolytes.

.Electrolyte optimization:

It has been emphasized consistently as the critical step towards improving supercapacitors [2, 3-4]. While the resistance of an electrolyte can limit power density, its ion concentration and operating voltage can limit the energy density of a supercapacitor. Despite the impact of electrolyte properties on supercapacitor performance, R&D efforts towards improving electrolytes have yet to become as rigorous or to be as fruitful as the comparable R&D efforts towards improving electrodes. However, the authors believe that, due to the importance of electrolyte optimization and the emphasis upon that in the literature, it is necessary to encourage more R&D efforts to refine electrolytes and improve the synergy between electrolyte and electrode.

Self discharge:

There are a number of different mechanisms for self-discharge, but they commonly result from uncontrollable Faradaic reactions, such as the reduction and oxidation of impurities in the electrode material. Thus, improving material purity has been identified as one way to decrease the rate of self-discharge in supercapacitors. A step that needs to be taken for supercapacitors to fulfil their promise is their tendency to self-discharge. Because charged supercapacitors are in a higher state of potential energy than discharged supercapacitors, there is thermodynamic pressure for a supercapacitor to discharge.

VII. Applications:

VII.A- Cordless Screwdriver:

It is first supercapacitor powered cordless tool which charges within 90 seconds. It is named as Flash cell.

VII.B- Public Transport:

China experimenting a new form of electric bus that runs without power lines using power stored onboard large supercapacitor, which are fast recharged when electric bus stops at any bus stop, and gets fully charged at terminus. A few prototypes being tested in Shanghai in 2005.

VII.C- Wind Turbine Pitch System:

Modern wind system consists of three bladed variable speed turbines. Independent electromechanical propulsion units are used to control and adjust the rotor blade. Each pitch system equipped with an ultracapacitor emergency power supply. It has some advantages such as enhanced level of safety, high reliability, efficiency and scalability.

Following switch box included 2600F Supercapacitors.

VII.D- Small Cell Applications:

Digital cameras, AMR, Actuators, Memory boards etc.

VII.E- Electric Rail Pack:

Regerative braking energy recaptured for diesel engine starting called traction.

***VII.F- A bank of capacitor** releases a burst of energy to help a crane heave its load aloft; then they capture energy released during the descent to recharge.*

***VII.G- Ultracapacitor**s functions well in temperatures as low as -40 degree centigrade, they can give electric cars a boost in cold weather; when batteries are at their worst.*

VII.H- Fuel cell powered fork lift:

VII.I- Application with a single energy storage component:

Applications in which little total energy is required (i.e. memory backup), Possibly used with other energy sources, Short duration, high power (i.e. pulse transmit).

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