ENERGY STORAGE USING SUPERCAPACITORS

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Abstract : In the storage process of electric energy, the supercapacitors represent a viable alternative in energy supplying and recovering energy. The paper presents the supercapacitor general technical description, the principle of operation, and their charged and discharged processing.
It is also describes the equivalents schemas for supercapacitors, with an example of two connections, serial and parallel. Among the many applications of supercapacitors there is a classical energy alimentation systems.

Keywords : Supercapacitors, Storing energy, Equivalents schemas, Applications.

1. INTRODUCTION

Electric double layer capacitors (EDLCs), which are also called electrochemical capacitors, ultracapacitors, and supercapacitors, represent one of the most interesting new developments in the field of energy storage and a good compromise between the classical electrolytic capacitors and the electrochemical batteries.
These are used as nano-tech power capacitors in environmental projects, hybrid electric vehicles, load leveling, and many more.
Many areas need a good reliability regarding the producing and the storing energy, so their introduction in to power applications is an industrial reality. For example, the Maxwell Technologies has produced in 2003 20 millions supercapacitors).
Conventional electrochemical storing systems (characterized by a great power density and low energy storage) and conventional capacitors (with great power density and low energy storage) are already developed directions. Supercapacitors lie between those two, being ideal for applications, which need peaks in short time (from 1 s to 10s).

2. PRINCIPLES AND STRUCTURE

A supercapacitors is an electric energy storing device which will be used for supplying specific consumers.
From their construction supercapacitors are build of the following components:

- two reinforcements (electrodes) – structures made from metallic plate and carbon cover lied in a technology, which enlarge the effective contact surface between the carbon grain and the electrolyte. This leads to a grown capacity of the supercapacitors. Carbon is founded in two states: powder and active fiber.
- electrolyte – with contact role, so that the double layer formed has a very low thickness, which leads to a growing capacity. There are two kinds of electrolytes: aqueous and organic.

The aqueous electrolytes are acid solutions (H_2SO_4) or basic (KOH) with carbon or with metallic oxides. Ionic conductivity is excellent, but the tension on the supercapacitors cell is limited at 1 V. To reach another level of voltage, there are more cells needed.
At the organic electrolytes the solvent is used on 90% of the supercapacitors surface, which allows a good conductivity even at low temperatures, of -30^0 C. Tension on the cell can reach 3V.

- separator – at aqueous electrolytic supercapacitors are used polyolefin filters. In organic electrolytes the separator is build from some micro porous membranes (Celgard) or from cellulosed filters.

From the physical point of view the supercapacitors can be seen like a big condenser, which stores low energy, but delivers and absorbs high power, being intermediary between the dielectric condenser and the electric accumulator.

The functioning principle is based on the formation of a double electrochemical layer at the interface of the electrolyte and the polarisable electrode, with big specific surface. Applying a potential difference at the device terminals, begins the electrostatic accumulation of electrical charges in the two interfaces electrod-electrolyt, the system behaving as if there were two serial condensers (Fig. 1).

There is considered a supercapacitors built from liquid electrode impregnated with two active carbon electrodes, separated by an inert separator.

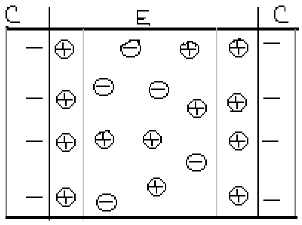


Fig. 1 Discharging state [1].

At the carbon/electrolyte interface there appears an excess charges accumulation from the electrode with electrons and from the electrode with ions. Both materials contain mobile charge carriers witch obey, at the interface, to anisotropy forces, so that they remain in the neighborhood of their origin, without moving to the adjacent medium represented by the blocked electrode. In this moment the potential of the hole cell is null, and the two interfaces behave identically.

If we measure the potential difference between the electrode and the electrolyte in dispatch to a reference electrode, we obtain an abandon potential.

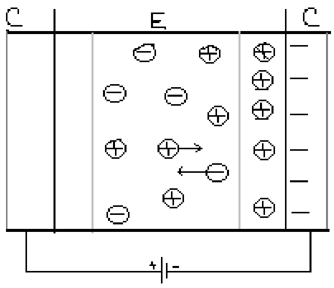


Fig. 2 Beginning of charge [1].

We apply a potential difference at the device terminals (Fig.2). The distribution of charges will be modified, cations and anions of the electrolyte will migrate in opposite directions, so that at one interface there will be a null charge potential, and at the other there will grow the charge accumulation.

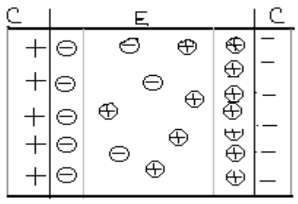


Fig. 3. Charging state [1].

If we boost the value of the applicable potential to the maximum value Umax (Fig.3.), the two double layers behave like two serial condensers and the total charge grows because of the growth of the capacity of each individual interface.

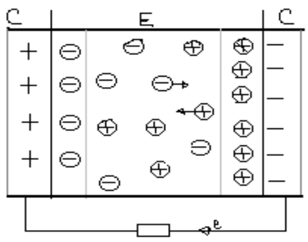


Fig. 4. Discharging state [1].

The discharge is made on a external serial resistor, R (Fig.4.). The ions and electrons take the inverse way, the electric current being used in the exterior circuit.

Compared with conventional condensers, supercapacitors have the surface of the electrodes very big, because of their structure. The thickness of the double layer has some molecular distances (tens of Mm).

In charged state the dipoles separate them selves and order them selves in a double electric layer. Characteristic for the supercapacitors is the fact that the charging/discharging process does not clamed chemicals reactions, which differentiate them from electrochemical sources.

3. EQUIVALENTS SCHEMAS FOR A SUPERCAPACITOR:

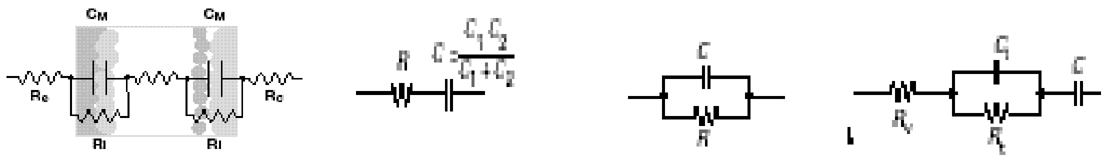
The equivalent resistance of a supercapacitor represents an important aspect to take in account. Its value must be minimized and for this there are different measurements taken, the most known being the measurement of the ohmic fall at a discharge under constant current. Also there must be taken in account the existence of other resistances like:

- the resistance of electrolyt – offers information on conductivity of electrolyt and can be measured directly through methods of impedance spectroscopy;
- resistance of electrods – varies from one material to another, electronic conductivity being different;
- interfaces resistances – they appear at interfaces electrod/electrolyt, electrod/current collector .

The equivalents schemas for a supercapacitor:

As a material for electrodes for supercapacitors there is generally being used activ carbon. Each of his particle works as a double capacity layer, with his own value for capacity. During charging, the charge is being transfered to the two resistors :

- R_e - of the carbon electrod ;
- R_c - of the collation interface of carbon.



a. b. c. d.

Fig. 5. – Electrical equivalent schemas of supercapacitors : a. - two parallel circuits RCl, made in serie; b. – serie circuit RC; c. – parallel circuit RC ; d. – serie RC circuit with parallel RC.

In fig. 5 for example, a part of the charge charges the resistance R_i of the electrolyte. There for, the equivalent circuit of the supercapacitor will be given by a combination of resistances and capacities.

4. SERIES AND PARALLEL CONNECTIONS OF SUPERCAPACITORS

The realization of supercapacitive tanks of large capacity uses a large number of individual cells, that can with advantages be operated at a high voltage level with series connection. However, the series connection of supercapacitors of not strictly equal C-values can lead to an unequal share of the cell voltages, mainly as a result of the integration of the common (series) current.

Active voltage sharing devices have been proposed, using power electronic switches with low on-state losses [5], and able to get good equalised voltage values of each individual cell. However, even when such a solution is unavoidable for reaching a full load status and to protect the supercapacitors from aging, the added price for the symmetrizing devices can lead to problematic costs for this technology.

Another possibility in order to limit the costs of the symmetrizing devices is to choose a parallel connection at each voltage level, getting naturally a better equalising of the capacitor values, and reducing so the current capability of the symmetrizing apparatus, and dividing so the total number of needed components.

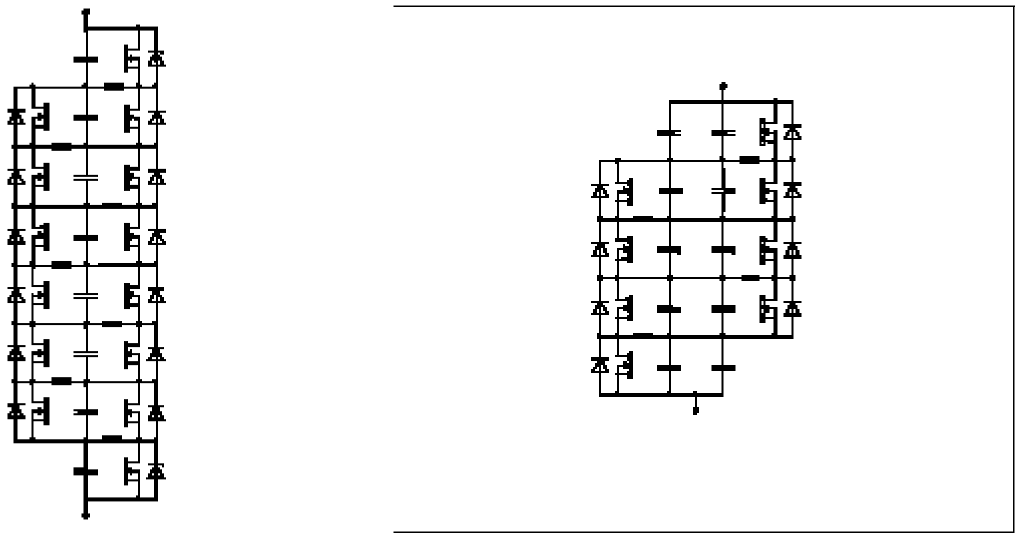


Fig.6. Organising the series/parallel connections of the cells for better voltage sharing [2].

Figure 6 shows the proposed scheme for an active symmetrized series connection of supercapacitors, and also the advantages of the reduced number of additional devices in the connection with paralleled capacitors. An optimal arrangement must be chosen by designing such a storage tank, bringing advantages in the symmetrizing costs, and simultaneously getting a sufficiently high efficiency of the needed converter for the voltage adaptation.

5. APPLICATIONS OF THE SUPERCAPACITORS

At the start supercapacitors were used in different electronically devices, under low tensions and currents ($U \leq 6V$ and $I \leq mA$).
The last studies were headed towards applications for big powers, in domains like transportation and telecommunications. At the present supercapacitors are used in hybrid systems together with other models of storing and/or producing energy, wanting for the future to become themselves autonomy resource.
Under first applications of supercapacitors are memory savings in cases of power failure, more than 80% of commercialized supercapacitors respond on this demand.
At the same time they integrate themselves too. They can also be used as primary sources in small equipments, toys.
In transportation, optimizing of supercapacitors/accumulators assembling satisfies power and energy needs of electrical vehicles. Punctual operations like: accelerating, starting, catalytic prewarming up take place through supercapacitors, rechargeable during breaking.
In telecommunications, in particular in mobile phones, supercapacitors are used for recharging between impulses of current.
In electrical networks, for their alimentation, are used big supercapacitors. There are projects for mini electrical automatic stations, in which the storing of energy should work with supercapacitors.
For a supercapacitor, the amount of stored energy is bound to the square of its voltage magnitude. Also for electrochemical batteries, the output voltage varies with the status of charge. Power supply at constant voltage level is the outgoing situation and imposes the presence of a double conversion structure, each based on associations of reversible DC-DC-Converters as shown Fig. 5.

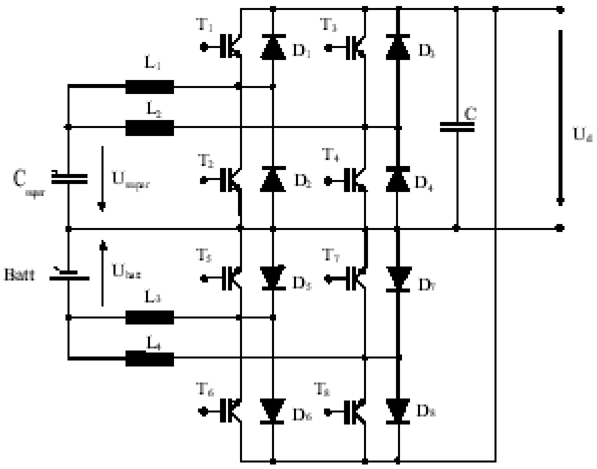


Fig. 7. Scheme for complementary storage with batteries and supercapacitors [3].

Each converter is composed of various legs. By shifted pulsing of the converters brings, a significant reduction in the current ripple of the energy sources is obtained [2]. This allows simultaneously designing the needed inductors at low values. With a strong increased number of legs, each commutation cell can be operated in so called discontinuous conduction
mode.
Designing the system for a discontinuous current mode in each individual channels brings the first advantage of the use of very small inductors. The combination of eight paralleled channels, each operating with intermittent current, results in a global current with very poor ripple [3]. The current turn-on conditions of the transistors are privilegious, due to the zero-value of the associated diode current.

6. ADVANTAGES OVER BATTERIES AND CLASSICAL CAPACITORS

Supercapacitors are well suited to replace batteries in many applications. This is because at the moment their scale is comparable to that of batteries, from small ones used in cellular phones to large ones that can be

found in cars. Even though supercapacitors have a lower energy density compared to batteries, they avoid many of the battery's disadvantages.
Batteries have a limited number of charge/discharge cycles and take time to charge and discharge because the process involves chemical reactions with non-instantaneous rates. These chemical reactions have parasitic thermal release that causes the battery to heat up. Batteries have a limited life cycle with a degrading performance and acidic batteries are hazardous to the environment.
Supercapacitors can be charged and discharged almost an unlimited number of times. They can discharge in matters of milliseconds and are capable of producing enormous currents. Hence they are very useful in load levelling applications and fields where a sudden boost of power is needed in a fraction of a second. They do not release any thermal heat during discharge.
Supercapacitors have a very long lifetime, which reduces maintenence costs. They do not release any hazardous substances that can damage the environment. Their performance does not degrade with time. Supercapacitors are extremely safe for storage as they are easily discharged. They have low internal resistances, even if many of them are coupled together.
It is presented in the Table 1 the performances of supercapacitors versus batteries and classical capacitors.

Table 1. Performances of three stocking systems [4].

	Electrolytic capacitors	**Supercapacitors**	**Batteries**
Time of charge	t < ms	1s < t < 30s	1h < t <
5hTime of discharge	t < ms		
Efficiency charge/discharge	> 94%	85% - 98%	70% - 85%
Power [W/kg]	$> 10^5$	10^4	$< 10^3$
Energy [Wh/kg]	$10^{-3} – 10^{-1}$	1 - 10	10 - 100
Life time number of cycles	10^{10}	10^6	10^3

Even though they have a lower energy density, are bulkier and heavier than an equivalent battery, they have already replaced batteries in many applications due to their readiness in releasing power.

7. CONCLUSIONS

The use of modern supercapacitors allows a complementation of normal batteries and increase the instantaneous output power. Supercapacitors show a great promise for many applications, because presents a technical maturity, a low environmental impact and high power density.

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