SUPERCAPACITOR ENERGY STORAGE SYSTEM- BASICS AND APPLICATION

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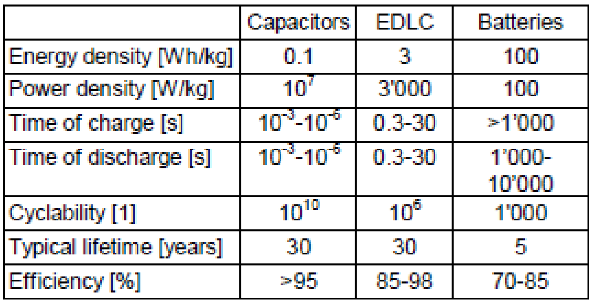
Abstract: A new technology, the Supercapacitor, has emerged with the potential to enable major advances in energy storage. Supercapacitors are governed by the same fundamental equations as conventional capacitors, but utilize higher surface area electrodes and thinner dielectrics to achieve greater capacitances. 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. While energy storage technologies do not represent energy sources, they provide valuable added benefits to improve stability, power quality, and reliability of supply. The latest technology developments, some performance analysis, and cost considerations are addressed. This paper concentrates on the performance benefits of adding energy storage to power electronic compensators for utility applications.

Keywords- Battery energy storage, Supercapacitor, Electrostatic Resistance (ESR), Capacitor.

I. INTRODUCTION

Supercapacitors are energy storage devices with very high capacity and a low internal resistance. In a supercapacitor, the electrical energy is stored in an electrolytic double-layer. Therefore such energy storage devices are generally called electrochemical double-layer capacitors (EDLC). ECDLs or supercapacitors (i.e.supercaps) are also known as ultracapacitors. Supercapacitors are attractive for their high energy and power densities, their long lifetime as well as their great cycle number. In addition to the high specific power the energy storage in supercapacitors is reversible in contrast to conventional batteries .The electronic applications need passive components to store the electrical energy in volume and weight as small as possible. The choice of the storage device type depends in particularly on the speed of the storage process, in other words on the power required by the application.

Actually, while the slower storage processes may be performed with batteries, the faster ones have to be done with capacitors. In general the electrical energy storage devices are of 3 types: faradaic batteries, electrostatic capacitors and magnetic inductors. The situation may be well summarized by the following so-called Ragone plot. The energy density in a battery may rise to 150 Wh/kg. This is about 10 times higher than the highest expected value of a supercapacitor. The power density in a battery has difficulty to reach 200 W/kg and is therefore about 20 times smaller than the expected supercapacitor performance. The batteries suffer from several weaknesses, which exhibit a rapid decrease of their performances. The origins may be the fast charge-discharge cycles or the cold environmental temperature. The batteries have also a limited lifetime and require expensive maintenance. Through the different capacitor technology types, the EDLC presents the highest energy density. Dielectric and electrolytic capacitors, as well as ceramic capacitors show very high power densities but very low energy densities. Compared to batteries, capacitors reveal much longer lifetimes and cyclabilities. In terms of power and energy density the supercapacitor fills up the gap between the batteries and the classical capacitors, allowing new applications. The properties of the different energy storage devices are presented in Table .



	Capacitors	EDLC	Batteries
Energy density [Wh/kg]	0.1	3	100
Power density [W/kg]	10^7	3'000	100
Time of charge [s]	10^{-3}-10^{-6}	0.3-30	>1'000
Time of discharge [s]	10^{-3}-10^{-6}	0.3-30	1'000-10'000
Cyclability [1]	10^{10}	10^6	1'000
Typical lifetime [years]	30	30	5
Efficiency [%]	>95	85-98	70-85

Table 1: Storage component property comparisons

II. SUPERCAPACITOR

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.

2.1 Supercapacitor Construction

What makes supercapacitors different from other capacitors types are the electrodes used in these capacitors. Supercapacitors are based on a carbon (nano tube) 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.

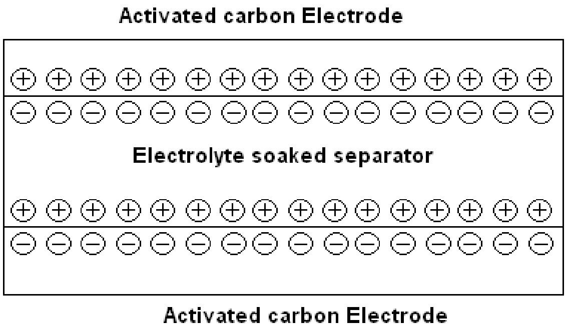


Figure 1: Electrical double layer of Capacitor

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.

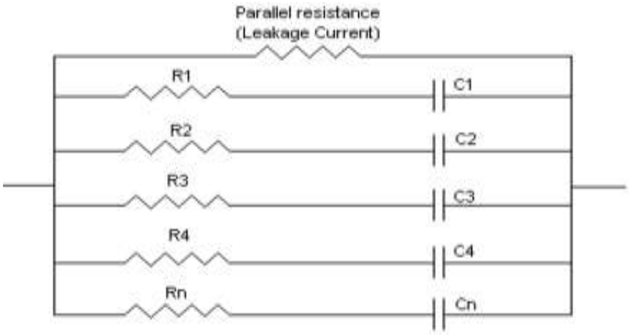


Figure 2: Series of parallel RC circuits

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 C x R values of each RC circuit. Obviously the larger the C x R the longer it will take to charge the capacitor. The amount of current needed to charge the capacitor is determined by the following equation:

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

2.2 Principle of Operation

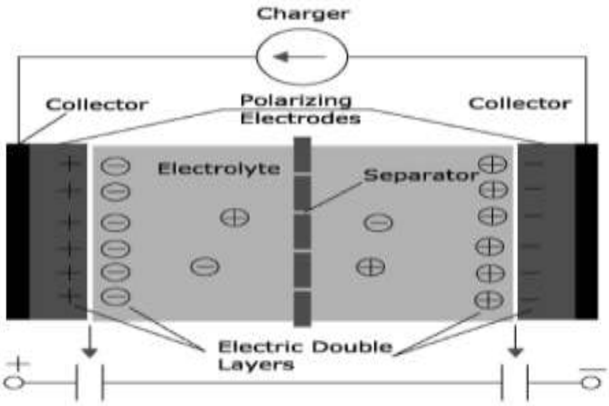
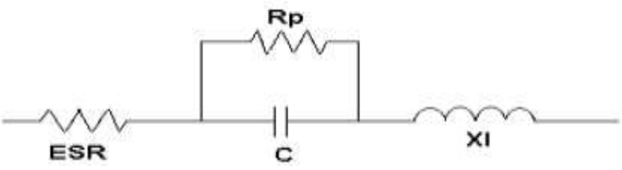


Figure 3: Operation of Supercapacitor

Supercapacitors do not contain a dielectric block. The electrical double layers are formed in the electrolyte surrounding the particles, leading to effective separation of charge on the order of nanometer scale. The area of the electrical double layer depends on the surface area of the particles. High capacitances result from the practical-sized packages. In an electrical double layer, each layer by itself is quite conductive, but the physics at the interface where the layers are effectively in contact means that no significant current can flow between the layers. However, the double layer can withstand only a low voltage. Since the capacitance of these devices is proportional to the active electrode area, increasing the electrode surface area will increase the capacitance, hence increasing the amount of energy that can be stored. The electric double-layer capacitor (EDLC) is ideal for energy storage that undergoes frequent charge and discharge cycles at high current and short duration.

2.3 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.

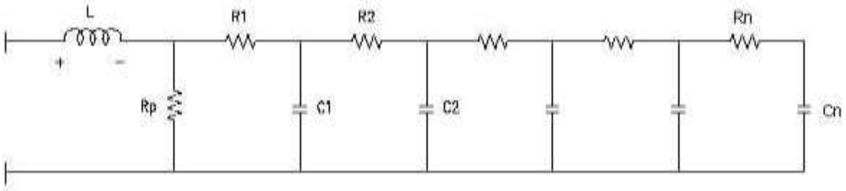


Figure 4: Equivalent Circuit of Supercapacitor

III. PERFORMANCE FOR SELECTION

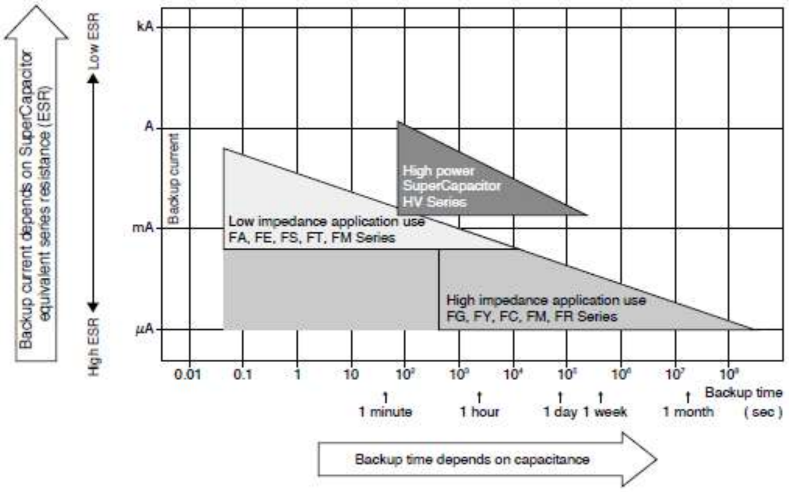


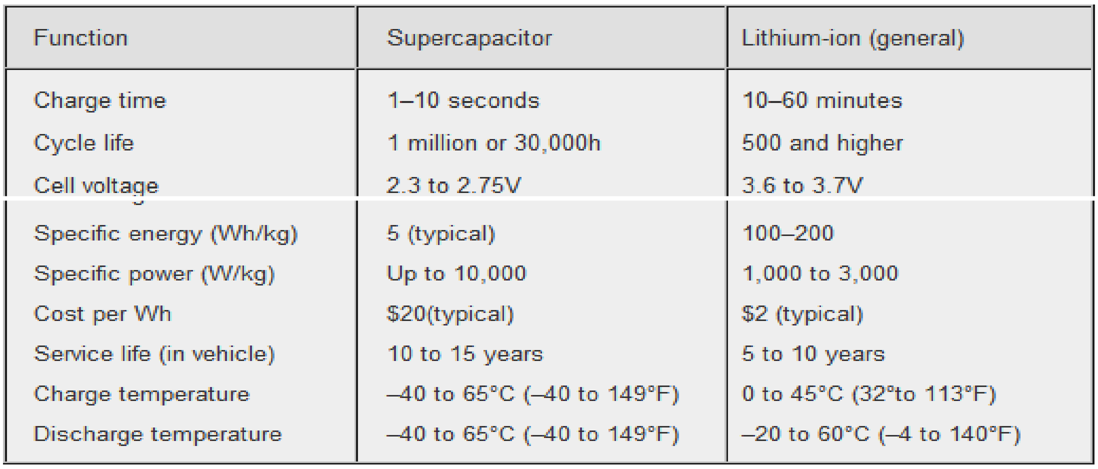
Figure 5: Performance Characteristic of Supercapacitor

IV. COST CONSIDERATIONS

Energy storage system costs for a transmission application are driven by the operational requirements. The costs of the system can be broken down into three main components: the energy storage system, the supporting systems (refrigeration for SMES is a big item), and the power conversion system. The cost of the energy storage system is primarily determined by the amount of energy to be stored. The configuration and the size of the power conversion system may become a dominant component for the high-power low energy storage applications.. The reason for the wide variation in the cost of the power conversion system is its dependence on the configuration of the system. For example, if an SMES is connected to an ac system, a DC–DC chopper and a voltage source converter or a current source inverter is needed, but if the SMES is connected to an existing FACTS device with a dc bus, only the DC–DC chopper is required. Therefore, the percentage of relative cost of each subsystem with regard to the total system cost is dependent on the application. In order to establish a realistic cost estimate, the following steps are suggested:

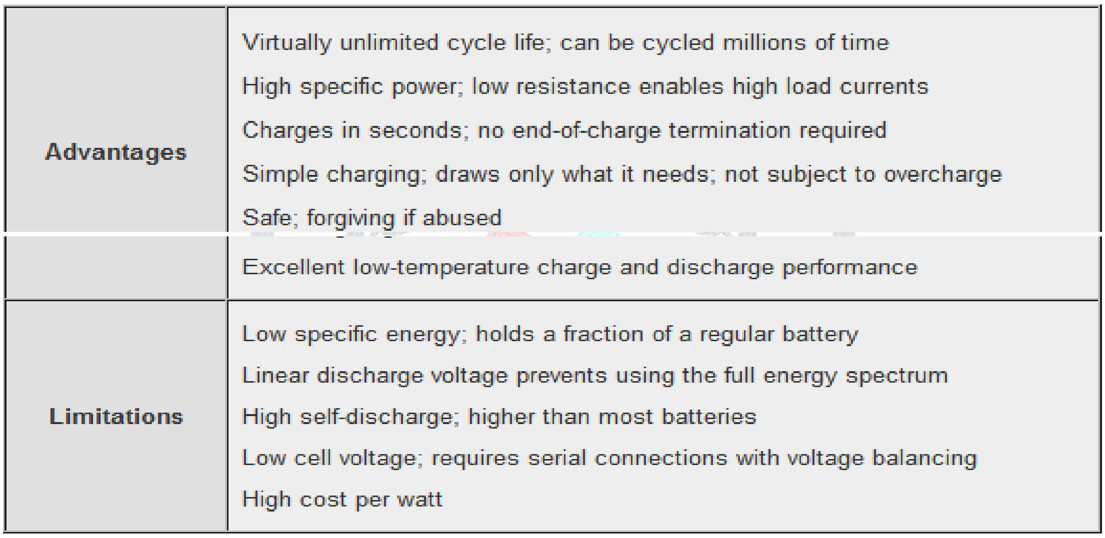
- Identify the system issue(s) to be addressed.
- Select preliminary system characteristics.
- Define basic energy storage, power, voltage and current requirements.
- Model system performance in response to system demands to establish effectiveness of the device.
- Optimize system specification and determine system cost.
- Determine utility financial benefits from operation.
- Compare system’s cost and utility financial benefits to determine adequacy of utility’s return on investment.
- Compare different energy storage systems performance and costs.

V. PERFORMANCE COMPARISON BETWEEN SUPERCAPACITOR AND Li-ion BATTERY



Function	Supercapacitor	Lithium-ion (general)
Charge time	1–10 seconds	10–60 minutes
Cycle life	1 million or 30,000h	500 and higher
Cell voltage	2.3 to 2.75V	3.6 to 3.7V
Specific energy (Wh/kg)	5 (typical)	100–200
Specific power (W/kg)	Up to 10,000	1,000 to 3,000
Cost per Wh	$20(typical)	$2 (typical)
Service life (in vehicle)	10 to 15 years	5 to 10 years
Charge temperature	–40 to 65°C (–40 to 149°F)	0 to 45°C (32°to 113°F)
Discharge temperature	–40 to 65°C (–40 to 149°F)	–20 to 60°C (–4 to 140°F)

VI. ADVANTAGES AND LIMITATION



Advantages	Virtually unlimited cycle life; can be cycled millions of time High specific power; low resistance enables high load currents Charges in seconds; no end-of-charge termination required Simple charging; draws only what it needs; not subject to overcharge Safe; forgiving if abused
	Excellent low-temperature charge and discharge performance
Limitations	Low specific energy; holds a fraction of a regular battery Linear discharge voltage prevents using the full energy spectrum High self-discharge; higher than most batteries Low cell voltage; requires serial connections with voltage balancing High cost per watt

VII. APPLICATIONS FOR SUPERCAPACITOR

- Transportation: HEV, EV, hybrid buses, electric rail, cranes, performance cars.
- Industrial: DVR, UPS, DC power systems, wind turbines, emergency lighting.
- Consumer Electronics: Digital cameras, mobile phones, toys, wireless remote control, PDAs.
- Regenerative braking.
- Releasing the power in acceleration.
- Starting power in start-stop systems.
- Regulate voltage to the energy grid.
- Capture power when lowering loads and assisting when loads are lifted.
- Back-up power in any application where quick discharge (or charge) is required.

VIII. 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. 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. Thus, supercapacitors may emerge as the solution for many application-specific power systems. Especially, there has been great interest in developing supercapacitors for electric vehicle hybrid power systems, pulse power applications, as well as back-up and emergency power supplies. This paper shows that energy storage devices can be integrated to power electronics converters to provide power system stability, enhanced transmission capability, and improved power quality. Adding energy storage to power electronics compensators not only enhances the performance of the device, but can also provide the possibility of reducing the MVA ratings requirements of the front-end power electronics conversion system. This is an important cost/benefit consideration when considering adding energy storage systems.

IX. REFERANCES

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