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Enhancement of the Electric Storage Battery Using the Super Capacitance

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Abstract

In case PV systems characterized by high peak power requests, the battery system is usually the most expensive part within the system, oversized in order to provide the needed peak discharge currents. The integration of super capacitors with battery cells optimizes power supply for loads equipment requiring very high power for short times (such as satellites, mechanisms, and transmitters,), i.e. it can increase battery lifetime and involve a significant mass reduction of the energy storage system. Such mass saving is a function of peak power/average power ratio .Super capacitors is electrochemical devices able to store energy through a physical process. The absence of chemical reactions grants higher power densities and higher charge/discharge currents, but lower energy densities with reference to common battery cells. Such characteristics make super capacitors particularly suitable for the integration in hybrid energy storage systems, e.g. to support Li-ion battery cells in case of peak power requests. It is worth noting that the integration of electrochemical capacitors with battery cells requests an accurate evaluation of the problem areas related to the use of such technology in the space environment and of the impacts on both Electrical Power Subsystem and Spacecraft System, and so on

Keywords: Electric storage, Capacitance, Electrochemical, Capacitors, Supercapacitor.

Introduction

Answering to a growing demand of lower cost, re- usable and flexible space architectures, Carlo Gavazzi Space (CGS) has been developing modular components for space applications including a Li-ion battery. The first battery system configuration designed by integrates n cell modules (based on Li-ion technology) and a single balancing electronics module. Such modular battery can satisfy a large number of power requirements for different satellite configurations by simply adding or removing cell modules, i.e. it does not need to be re-designed and re-qualified for each mission, minimizing development times and costs. In this times, answering to the spacecraft need of lower cost long-lived battery systems able to provide bursts of high power, such initial modular battery design has been improved. The design of a hybrid battery system has required an evaluation of potential benefits provided by super capacitors integration and a survey of related problem area whose detailed characterization will be the aim of further future work [1].

The purpose of this paper is to analyze the potentialities and critical aspects of the CGS integrated Li-ion cells/super capacitors modular battery system design.

The work has been carried out according to the following structure

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Supercapacitor technology overview

A super capacitor is an electrochemical device composed of two electrodes (immersed in an electrolyte) and an ion-permeable separator. Electrodes are made by nonporous materials providing an enhanced internal surface area (up to 1000 m^2/g).

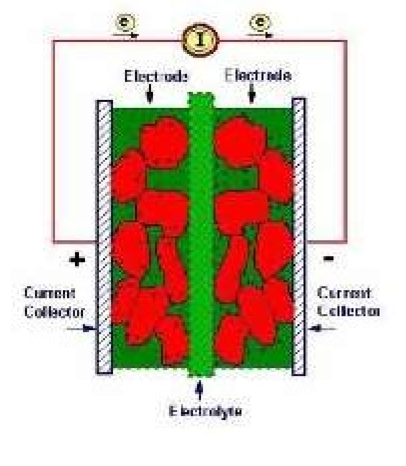

Figure 1. Super capacitor.

The following figure shows a super capacitor equivalent electrical scheme, where C1 and C2 represent the capacitance at each electrolyte/electrode interface, while R1, R2 and RE represent the electronic resistance of the electrodes material and the electrolyte/ separator ionic resistance [2].

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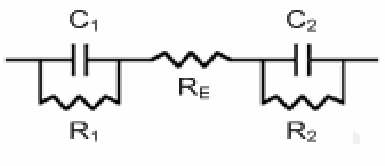

Figure 2: Super capacitor Electrical sympole.

With reference to traditional capacitors, whose capacitance is usually measured in microfarads, the envision the same material for both electrodes, such as activated carbon. Symmetrically designed supercapacitors can be completely discharged to zero volts like a conventional capacitor. Asymmetrical cell designs use a different material for the two electrodes, such as ruthenium oxide and activated carbon. The key advantage of the asymmetrical design is that it is characterized by a higher energy density even if it shows a lower cycling life. The operating voltage of a supercapacitor depends on its electrolyte stability. It can vary from about 1.2V for aqueous electrolytes up to near 3V for organic electrolytes. In spite of their higher operating voltage, because of their larger solvate ions, organic electrolytes present the disadvantage of a higher ionic resistance and lower power density [3].

As an alternative to liquid electrolytes, an interesting option is represented by solid polymer electrolytes. Polymer electrolytes super capacitors can provide further advantages, such as a more flexible structure, a more compact geometry, and an easier packaging. In addition, this solution is safer from the management point of view as it is free from accidental leakages of corrosive and dangerous liquids. As solid electrolytes are composed of semi- aqueous polymers, drawbacks of this design solution are related to the low operating voltage, i.e. near 1.2V. The following table provides a super capacitors classification based on the type of electrolyte and summarizes the main advantages/disadvantages Table 1.

Electrotype	**Advantages**	**Disadvantage**
Aqueous	High power	Low operating
		voltage
	Density	
Organic	High operating	Low power
	voltage	density
Solid	Easy packaging	Low operating
	No accidental	voltage
	leakage	

Table 1: Comparison of SC types.

Consequently, supercapacitor energy density is up to twenty times lower than an energy-optimized-Li- ion- battery. Moreover, due to reactants mass transport and reaction kinetics, battery charge/discharge currents are significantly lower. Super capacitors power density is up to ten times greater than a power-optimized-Li-ion-battery. Furthermore, as their components do not stand any phase change, super capacitors energy storage process is highly reversible. Consequently their number of cycles is up to one hundred times greater with respect to batteries, their response time is lower, and their lifetime is significantly higher. Another advantage with reference to batteries is that super capacitors temperature range is wider, while a non-negligible disadvantage is that the higher electrode surface area involves a greater internal resistance, i.e. higher leakage currentsand self-discharge. The previously described main differences between batteries and super capacitors (summarized in the following table) highlight their potentialities in a complementary use for a hybrid energy storage system characterized by the best of the two technologies and compensating their disadvantages [4].

Sizing of cgs hybrid modular battery system for a leo mini satellite

While a large number of hybrid energy storage systems including super capacitors has been realized for many Earth applications the use of integrated super capacitors/battery Li-ion cells systems for space applications has been under evaluation for some time.

The present section carries out the sizing of a hybrid system for a LEO mini satellite, assessing the mass saving with reference to a battery system not including super capacitors. Battery sizing has been carried out taking into account the standard battery cells module shown in the following figure and characterized by the parameters listed in the following table 2.

8S1P CGS Battery Cells Module	
Module voltage range	21.6 V – 32.8 V
Module energy (@ 29.2 V)	169 Wh
Module capacity	5.8 Ah

Number of cells in series	8
Type of cells	Saft Li-ion prismatic MPS176065
Module mass	1.5 kg

Table 2: battery cells module parameters.

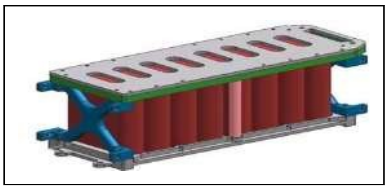

Figure 3: battery cells module overview.

The hybrid battery system shall supply power for a sun synchronous LEO SAR satellite mission. Satellite key parameters are described in the following Table 3.

Satellite Total Mass	300 Kg
Orbit	Sun Synchronous
Altitude	600 Km
LTDN	10:30
Average power consumption	111 W
Peak power consumption (SAR)	1600 W
Acquisition Time	10 s

Table 3: LEO SAR mini-satellite parameters.

SAR acquisition time is fixed to 10 s, corresponding, for a LEO satellite, to a swath on ground of hundreds of kilometres. Supposing to limit the discharge current of the single Li-ion cell to 17.4 A (3C), the optimum battery configuration (not including supercapacitors) able to supply the requested power (1600 W) is composed of 4 cells modules. CGS modular battery is also equipped with a further module called “balancing electronics box” providing a balancing of series- connected cells voltage. Such box includes eight “items” (one for each cell of the cell module) and is able to carry out the balancing function for 1 to 8 integrated cells modules. In this configuration, the battery system total mass (including 4 cells modules and one balancing box) is equal to 6.75 Kg.

Let us supposed to integrate a supercapacitor module and connect it in parallel to the Li-ion cells modular battery. Supercapacitors shall supply SAR payload during peak power requests (1600 W for about 10 s). With reference to the previously described configuration, energy demand to the Li- ion cells has not changed, as they have to gradually recharge supercapacitors after power bursts. On the contrary, power claim has significantly decreased. On the base of mission profile, of Li-ion cells discharge efficiency value (about 0.95) and of recommended average DOD (about 20%), cell modules number can be chosen according to an average energy request of about 338 Wh. The part of the integrated battery system including Li-ion cells is composed of two cells modules and one balancing box (mass: 3.75 Kg).

Supercapacitors to be integrated in the hybrid system have been selected among COTS products. On the base of the peak power requirements, the supercapacitor providing the optimum characteristics for this specific application is Maxfarad MES2245. MES2245 is included into Maxfarad High Energy series shown in the following image.

Figure 4: Maxfarad High Energy Series.

Maxfarad MES2245 characteristics are: On average, mass saving increases with peak power/average power ratio and tends to a horizontal. peak duration it is possible to define a minimum peak power/average power ratio for which the hybrid system is advantageous with reference to the non-hybrid battery. The non-monotonic behaviour of the displayed function can be interpreted as follows.

The function decreases when the peak power/average power ratio rise:

Reaches a threshold requiring a further supercapacitors string in the hybrid system has not yet reached a threshold requiring a further Li-ion cell module in the non-hybrid system.

The function increases when the peak power/average power ratio rise: reaches a threshold requiring a further Li-ion cell module in the non-hybridsystem has not yet reached a threshold requiring a further supercapacitors string in the hybrid system.

The previously carried out hybrid system sizing is based on a peak power/average power ratio equal to 14.4. An increase equal to 150 % of the peak power duration decreases the mass saving percentage down to 1.1%.

Hybrid battery system space application critical areas overview

Positive impacts of a hybrid battery on the satellite Electrical Power Subsystem are mass saving (widely analyzed in the previous sections) and lifetime increase. Anyway, accurate investigations are needed (mainly in the reliability and FMECA fields) to grant that the functional benefits are not jeopardised by additional circuitry required to cope with specific super capacitors characteristics. Thus, a careful study of hybrid system electrical implications shall be carried out.

Adopting improved solutions as a consequence of the optimization process of a satellite equipment (e.g. battery) can also generate some impact on the spacecraft system level design and other subsystems (thermal control subsystem, configuration, structure, data handling etc.) level design. In fact, the optimization, while it increases the performances of the optimized subsystem, can jeopardize the benefit in terms of system total mass. The variation of volume, complexity, and reliability of EPS subsystem requires to carefully evaluate the impact on spacecraft system and subsystems in order to verify that the subsequent design modification do not nullify the “local” benefits. Thermal behavior. Super capacitor thermal behavior has been widely studied but only for terrestrial applications. An analysis of super capacitor thermal behavior in case of vacuum and low pressure shall be carried out in order to design proper cooling systems [5].

Conclusion

The present work has carried out an analysis of the potentialities and critical areas related to use of Li-ion cells/super capacitors integrated battery systems for a satellite mission. Such analysis has been performed through: O a description of super capacitor technology state-of-the-art o the assessment of battery system mass saving due the selection of a hybrid configuration for a SAR minisatellite mission. Such evaluation has highlighted the dependence of mass saving from peak power/average power ratio and bursts duration. an overview of criticalities to be investigated in order to evaluate the impacts of the hybrid technology at satellite subsystem/ system level and the interaction of super capacitor technology with the space environment. Radiations. Radiation environment could impact on the supercapacitor double layer, modifying the way charges and ions are accumulated at the electrode/electrolyte interface. Moreover, the electrolyte ionic content could be modified influencing the ionic conductivity, and more generally the component’s life-time due to non- reversible phenomenon.

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