Hybrid power source with batteries and supercapacitor for vehicle applications

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Abstract : This paper presents a hybrid power source with batteries and supercapacitors realization. Supercapacitors are used in series with a power battery to provide power requirement in transient state. An energy battery is placed in parallel, this battery gives the power in steady state.

1. Introduction

The increase of comfort in vehicles (air-conditioning, ESP, heating seat, de-icing rear-view mirror, electric pane....) results in a significant rise of the power and of the current requested from the battery. This higher demand of current results an important heating of the battery, this heating will generate several consequences, firstly a reduction of lifespan of the battery and secondly a significant loss of capacity. More problematic, at starting of internal combustion engine; the current required by the starter/alternator group is very important compared to the rated current of the battery, which results again in a heating in the aim of reducing the lifespan of the battery and its capacity. Finally, the last problem of batteries is the recuperation of braking energy. For charging correctly the battery and preserves the capacity at maximum, it is necessary to respect some conditions, a battery voltage lower than the maximum voltage supported, in general, this voltage is about 2.35 V per cell, but also a low current of refill compared to its rated current. However in mobile application and more precisely in electrical vehicle field, such conditions are never met.

These problems have delayed the technological advance of the electrical vehicle. To limit these problems, the cheapest and simplest solution consists in increasing the voltage of the battery to 42 V. This solution will make possible to decrease by the current required by the battery at equal power, but also the joule losses by nine, those being proportional to the square of the current, and to finish a reduction of the section of electric cables, which involves a reduction of the total weight of vehicle, that is particularly interesting in term of efficiency, performance and cost. However, if this idea delete the problem of overload, it results an another problem, the complete change of electronics in the vehicle, which will not be able to function to 42 V, it will result an additional cost.

Power batteries developed by the manufacturers are able to provide the power necessary to the vehicle, for some batteries (lithium-ion, Nickel-Cadmium, Nickel- Metal hydride) the price will be a brake. For the batteries lead-acid, it acts rather of a physical limit, its lifespan being limited according to the number of cycles and especially the depth of discharge. Stop&Go technology in order to reduce the consumption, will be present on the hybrid vehicle, this technology will involve many starting (approximately 100 000 in urban environments), power batteries to lead-acid will not be able to support this number of cycles if the depth of discharge is high.

It is necessary to use a component of power able to provide a strong power to starting and to assist the vehicle accelerate, the lifecycle of this energy storage device must be in adequacy with stop&go technology.

The introduction of the supercapacitors into the applications of power is an industrial reality. Developed at the origin for the markets of memory safeguard in public electronics, the adaptation of the supercapacitor technology to the power range encountered a long time against the absence of industrial process economically viable and insufficient performances. Thus new concepts of applications and products are under development:

- In the car to reduce consumption and to reach the network 42 V and 400V in hybrid vehicle.

- In public transport to recover energy with the braking of the trains and subways.

- To develop trams without overhead line.

- In industry, to start the power generating units

- To provide the demands of instantaneous power

- To replace the batteries of the inverters and to reduce the costs of maintenance of the park of batteries.

The environmental stakes are important; the supercapacitor will take an important part for the optimization of the dimensioning of electrical grids, in the improvement of the energetic efficiency of the embarked systems and in the reduction of batteries replacement. Indeed the supercapacitors will not be used as source of pure energy, because of their weak energy mass, but rather of complement to the battery, providing the strong demands of power. The supercapacitor solution as source of power is clearly interesting; however the cost of the kilowatt per hour remains higher than for the batteries lead-acid (approximately 30 times more) but with a weight and volume weaker.

2. Structure of supercapacitor

The elementary structure of a supercapacitor consists on aluminum current collectors, electrodes generally out of activated carbon impregnated in an organic or aqueous electrolyte. A separator is inserted between the two electrodes to insulate them (figure 1). The assembly of the unit is carried out as for the traditional capacitors [1-5].

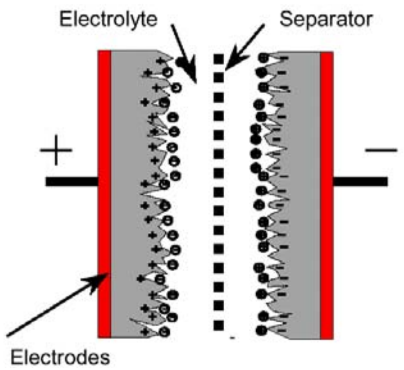

Figure 1: Structure of a supercapacitor

The principle of operation of a supercapacitor is based on the storage of energy by distribution of the ions coming from the electrolyte in the vicinity of the surface of the two electrodes. Indeed, when one applies a terminal voltage of supercapacitors, one creates a zone of space charge to the two interfaces electrode-electrolyte. It is what one calls the double electric layer. The storage of energy is thus electrostatic and not faradic as in the case of the batteries, since there is no electrochemical reaction.

A supercapacitor has a structure anode-cathode containing activated carbon, allowing to have a surface activates considerably high compared to the traditional capacitors, and thus to obtain very high values of capacities (1 to 5000 F). This made of the supercapacitors of the potential elements of storage auxiliary, ideally complementary to the batteries or the fuel cell. The use of parallel-series structures of several cells of supercapacitors makes it possible to reach a voltage and a high current output.

Figure 2 presents the equivalent capacitance and equivalent series resistance of Maxwell MC2600F according to the frequency. These results are obtained by using electrochemical impedance spectroscopy. These curves show that the capacitance is higher at low frequency (f<100 mHz),. For f< 100mHz the supercapacitance equivalent capacitance decreases with frequency. For example at f = 1 Hz, the capacitance is in order of 1400F. In dynamic mode, it's necessaru to take into account of this variation according to the frequency. On the other hand, the resistance series variation according to the frequency can be neglected.

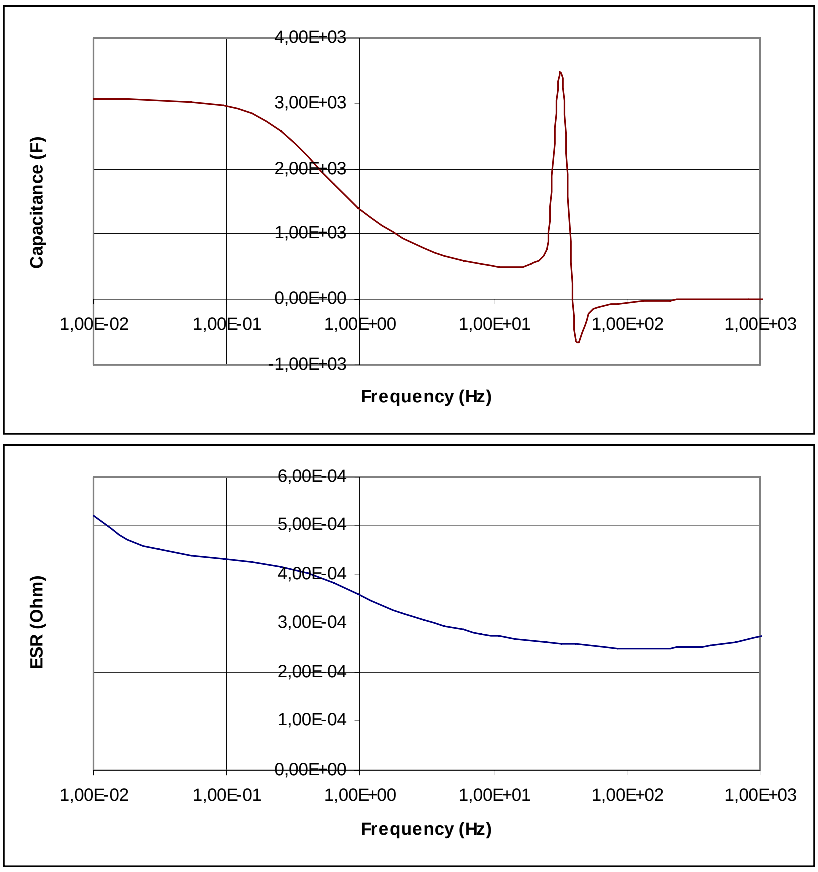

Figure 2: Maxwell MC2600F capacitance and equivalent series resistance as a function of frequency (V= 2.7V)

3. Experimental result

The objective of this project consists to associate an energy battery (with high capacity) in parallel of a supercapacitor module associated with a power battery (with low capacity) in series. The goal of this association is to reduce the starting current and the current when the vehicle accelerates into the energy battery (with high capacity), in order to guarantee the best lifecycle for the energy battery (with high capacity).

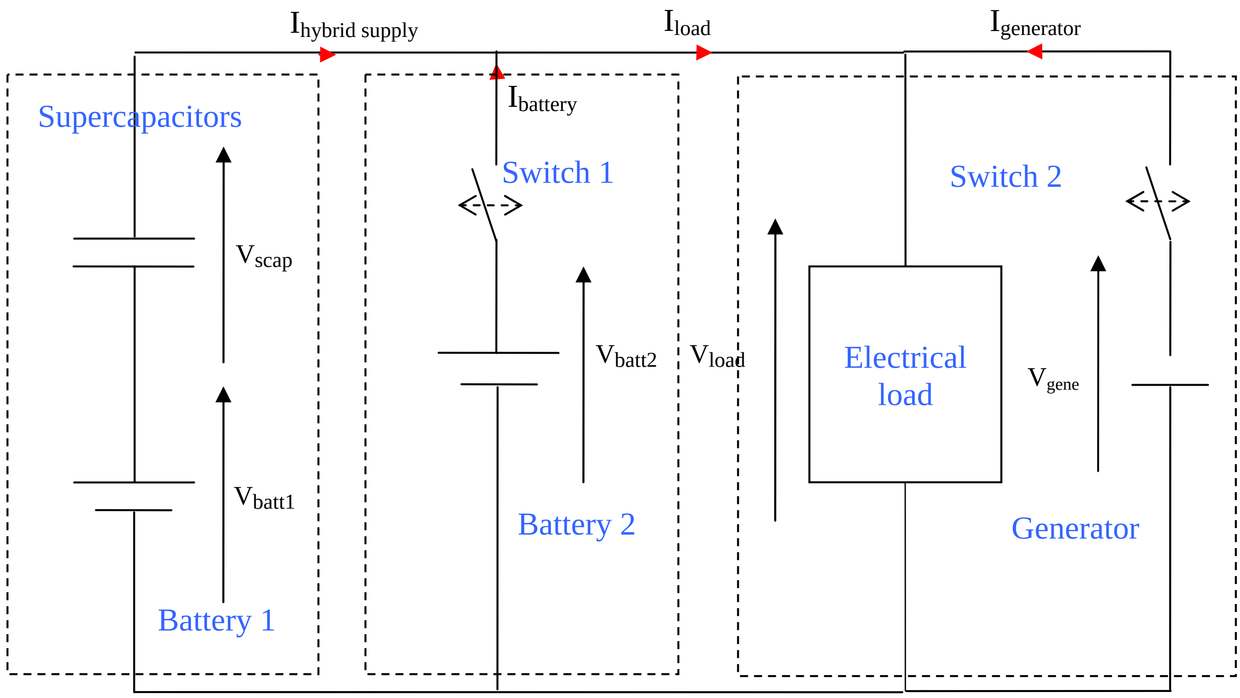

Fig. 3: Experimental setup principle

Battery 1 will be selected with a capacity lower than that of battery 2 and the same than that of the supercapacitor module, this in order to guarantee better held in temperature (in particular in cold weather) and the best held with the variations of capacity according to ageing.

Battery 2 will be an energy battery with a strong capacity dimensioned either to provide the points of power, but dimensioned to supply the electric installation (headlight, air-conditioning, motor in steady operation). This new dimensioning will make possible to reduce the capacity of the battery, and so the price like the volume. However this battery must have a resistance higher than the resistance of the hybrid supply.

The supercapacitor module will be dimensioned to provide the high demand of power. Moreover supercapacitors will be able to limit the depth of discharge of the battery, and to inform us of his state of charge more or less precisely, according to the battery used (depend on the self-discharge, internal resistance, ageing). The supercapacitors will ensure the part of energy buffer at the time of braking phases, energy stored may be retransmitted quickly to the electrical load, or slowly to battery 2 if this one is not entirely charged. Finally the supercapacitors will be able to ensure the part of energy source, if the energy battery is failing.

The first results presented in figure 4 are obtained with the following configuration: Supercapacitor module (12V) is connected in series with a 12V battery. The used load is a moto-ventilator group for vehicle application. These results show that when the electrical motor starts supercapacitor module provides the requirement power in transient state. Hence, the battery current peak is very low compared with that of supercapacitors. In steady state, the battery current rises and the supercapacitors current decreases. So, battery voltage and supercapacitors voltage are the same in the beginning. The battery current depends on the supercapcitors state of charge. It's clear that this association allows to reduce the battery peak power in transient regime. Consequently, this makes it possible to increase the lifetime of the battery and to improve the energy performances of the system.

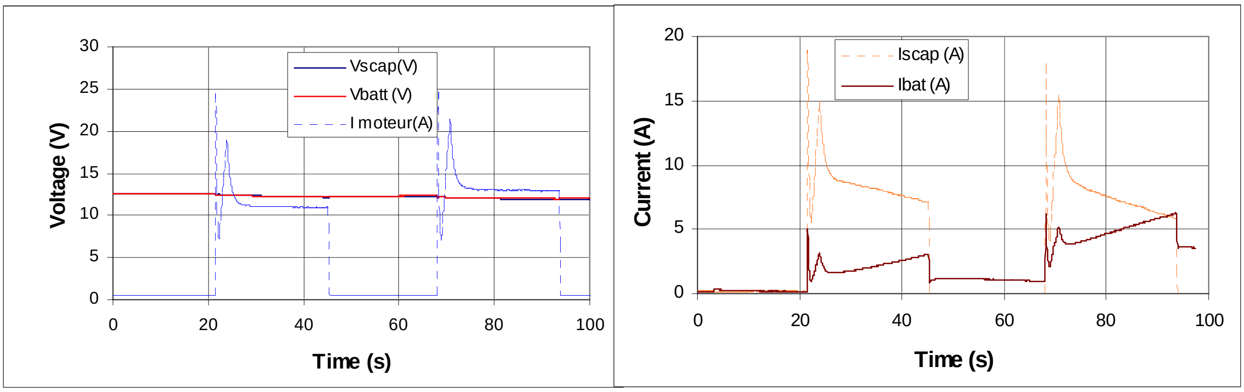

Figure 4 : Supercapacitor and battery voltage and current variations as a function of time, the used load is a motor ventilator

Conclusion : The hybrid power source with batteries and supercapacitor for vehicle applications presented in this paper can be used to start the internal combustion engine, for stop&go application and for micro hybrid vehicle.

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