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EXPERIMENTAL CHARACTERIZATION OF LITHIUM-ION CAPACITORS FOR APPLICATIONS ON ROAD HYBRID VEHICLES

Clemente Capasso*, Ottorino Veneri

Istituto Motori – National Research Council of Italy, via G. Marconi 4, 80125 Napoli, (Italy)

*(Corresponding Author)

ABSTRACT

This paper describes experimental activities for the characterization of Lithium-ion Capacitors (LiC), with particular focus on their application in road hybrid thermal-electric vehicles. These activities represent a valid methodology to perfor\m experimental characterization of storage systems based on lithium technology. With this aim, electrical and thermal characterizations of LiC storage cells and modules, carried out through experimental tests on advanced laboratory facilities, are described in this paper.

The obtained results represent a useful knowledge base to evaluate optimal design and energy management strategies of the on board storage systems for their real application on the vehicle.

Keywords: Energy Storage Systems, Road Hybrid Vehicles, Lithium-Ion Capacitors, Equivalent Circuit Models.

1. INTRODUCTION

Climate change and air pollution represent relevant challenges to be faced during the next years. Since 1990 different sectors, supported by technology developments, have been characterized by a constant decrease in the related greenhouse gas emissions. On the contrary, transport sector has shown an opposite behavior and is now responsible of almost a quarter of greenhouse gas emissions for Europe. In this regard, more than 70% of these emissions are related to road transport systems [1]. In fact, as well known, the great part of road vehicles is equipped with traditional internal combustion engines, based on the use of fossil fuels. Although fossil fuels are currently the most economically available source of power, the related issues in terms of their availability and environmental impacts cannot be considered sustainable in a long term future [2].

A feasible solution for the above issues is represented by the large scale adoption of full electric and hybrid vehicles, which are characterized by high values of well-to-wheel conversion efficiency and by a sensible reduction in vehicle exhaust emissions. In the past decades, despite the above advantages, the diffusion of electric and hybrid vehicles in the automotive market has been limited by the low performance of old battery technologies.

Nowadays, lithium based batteries and power electronic technologies have allowed relevant improvements in the average electric vehicles' driving range and charging times [3]. As a consequence, the market share of full electric and hybrid vehicles is in constant growth and a sensible increase in their diffusion is expected in the short term future [4].Unfortunately, at the present state of technology, as well known from the energy storage Ragone Plot [5], high energy density storage technologies (i.e. batteries) are generally characterized by low performance in terms of power density, with the related consequences on charging/discharging times. At the same time, super-capacitors present high values of power density combined with a huge durability, in terms of charging discharging cycles. In this regard, the use of hybrid energy storage systems, is considered as an interesting choice able to optimize the battery lifespan through the controlled intervention of super-capacitors [7]-[9]. On the other hand, this configuration generally involves the use of a DC/DC converter, interposed between the two

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storage units, with a consequent increase in costs and vehicle weight.

In recent years, starting from the above considerations, scientific and engineering community efforts have been mainly focused on the development of new storage devices able to combine the advantage of batteries and super-capacitors in a single storage cell. Among those, Lithium-ion Capacitors (LiCs) are considered worthy of investigation for their application in the automotive field, because of their promising performance in terms of durability, power and energy density. In this regard, this paper is focused on the experimental set-up and tests for modelling Lithium-ion capacitors, with specific attention to their application in the automotive sector.

2. EXPERIMENTAL SET-UP

As already mentioned in the Introduction section, Lithium-ion capacitors can be considered as a hybrid energy storage technology, which combines the advantages of both super-capacitors and lithium ion batteries. In particular, similarly to classical super-capacitors, their positive electrode is based on activated carbon material, able to store energy by means of capacitive mechanisms. On the other hand, similarly to lithium-ion batteries, a lithium intercalation/insertion carbon material is used as negative electrode in order to store energy through faradaic reactions [10]. In comparison with classical super-capacitor technology, the introduction of this lithium ion negative electrode involves a higher operative voltage values, which results in an increase in energy density between 40 and 70 % [11].

The experimental tests reported in this paper have been carried out with reference to a ULTIMO 2300F LiC cell, characterized by a prismatic shape and is distributed in Europe by JSR Micro NV. The main characteristics of the 2300 F LiC cell are reported in Table I.

In this case, unlike super-capacitor technologies, the presence of lithium based negative electrodes does not allow zero-voltage operative conditions. As a consequence, the minimum voltage of 2.8 V should be respected in order to avoid undesired electrical and thermal behaviours of the cell. An important aspect to be considered about the LiC technology, in comparison with classical electrical double layered capacitors, is represented by the strong impact of the operative temperature on their electrical performance [12]. Therefore, the experimental set-up reported in this paper is focused on a complete characterization of LiCs both from electrical and from thermal point of view.

Table I: Main characteristics of ULTIMO 2300F LiC cell

Range of Operating Temperatures (°C)	-30~70
Maximum Voltage (V)	3.8
Minimum Voltage (V)	2.2
Capacitance (F)	2300
ESR (mΩ)	0.6
DC-IR (mΩ)	0.7
Weight E-density (Wh/kg)	8
Volume E-density (Wh/L)	14
-20°C Capacitance ratio(vs 25 °C)	85 %
70°C Capacitance ratio(vs 25 °C)	100 %
Cell size (mm)	150.0x93.0x15.5
Cell weight (kg)	0.365
Range of Operating Temperatures (°C)	-30~70

From the electric point of view, experimental tests have been carried out by means of a storage system laboratory test bench, specifically design to run steady state and dynamic charging/discharging cycles on storage unit under test. In particular, those cycles can be programmed by the user by means of a software interface, which is realized in Labview environment. The software interface controls the operations of 120 *A* – 80 *V* DC power supplier and a 240 *A* – *120 V* DC electronic load. Both the above device can be set to work in a restricted voltage range, in order to obtained more detailed evaluations at single cell voltage level.

The functional scheme of the storage system laboratory test bench is reported in Fig 1.

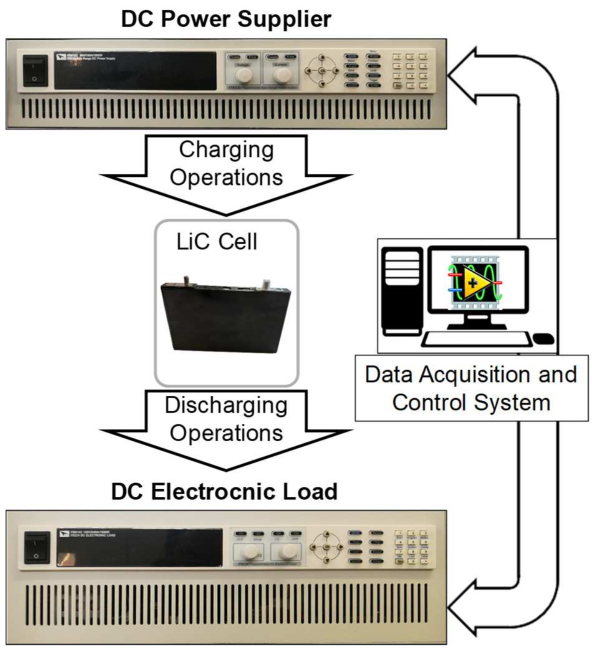

Fig 1 Storage system laboratory test bench

The DC power supplier and the DC electronic load are produced by ITECH ELECTRONIC CO. and are respectively identified by the codes IT6512C and IT8814C.

Thermal characterization of the LiC cell has been performed by means of a climate chamber, with and internal volume of 340 l, able to perform temperature and humidity control during the tests. The thermal chamber is also equipped with a nitrogen inlet, in order to reduce the amount of oxygen within the chamber and avoid risk of fire. A picture of the climate chamber is shown in Fig 2.

Fig 2 Picture of the climate chamber

The chamber can be controlled by means of an on board software interface, which can be accessed either through the front touch panel or through a remote web connection from an external PC/smart device.

The main characteristics of the climatic chamber are reported in Table II.

Table II: Main characteristics of the climatic chamber

Volume (l)	337
Internal Dimensions (mm)	601x810x694
External Dimensions (mm)	875x1786x2015
Rated Power (kW)	7
Temperature Control (°C)	-35~+180
Relative Humidity Control (%)	10~98
Average Variation Speed (°C/min)	4
Volume E-density (Wh/L)	14
-20°C Capacitance ratio(vs 25 °C)	85 %
70°C Capacitance ratio(vs 25 °C)	100 %
Number of P100 Probe	4
Communication Modes	wi-fi, Ethernet cable, RS232
On-board Acquisition and Control Software	MyKratos^{TM}

The chamber is also equipped with thermally insulated lateral ports in order to allow the connection of electric cables, from external devices to the cell under test inside the chamber.

3. RESULTS AND DISCUSSION

Preliminary tests on the Lithium-ion capacitor cell have been performed, in order to evaluate its steady state performance at constant temperature.

With this aim, the climate chamber has been set at a constant temperature of 25°C with no humidity control. In this conditions charging/discharging tests have been carried out with current values of 20 A, 40 A, 60 A, 80 A and 100 A.

The main results of these experimental tests are shown in Fig3.

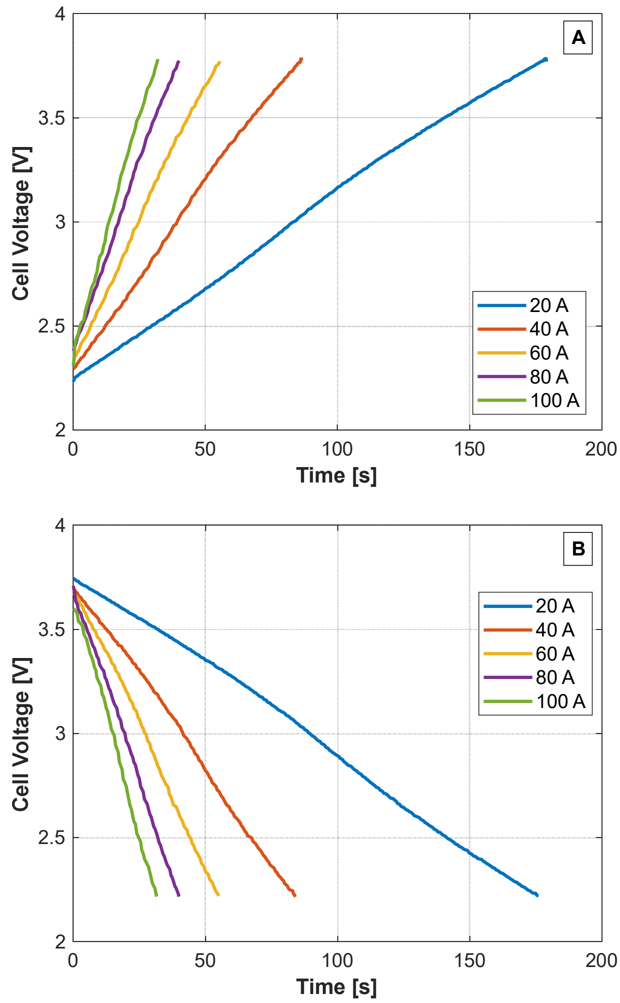

Fig 3 Experimental results of charging (A) and discharging (B) tests on the LiC 2300 F cell at 25°C

In particular, in all the steady state tests at 25°C, the LiC cell has shown the expected behavior with an evaluated capacitance value of about 2300 F and a resulting charging/discharging energy of about 2.8 Wh. For these tests, no relevant increases in the temperature cell have been evaluated.

On the other hand, the charging/discharging tests evaluated in this paper are related to steady state conditions, with no high dynamic transient phases, with a maximum duration of about 180 seconds. As already mentioned in the previous section, the performance of LiC can be affected by environmental temperature and by the specific operative cycle. For this reason, further experimental investigations are required with longer steady state and dynamic operative cycles at different temperatures.

4. CONCLUSION

In this paper the use of Lithium-ion Capacitor (LiC) is proposed as a feasible solution to supply road hybrid vehicles.

The specific application requires an experimental investigation to characterize these devices in operative conditions representative of their use on-board.

With this aim, the authors have realized and described an experimental set-up, able to perform a complete characterization of Lithium-ion Capacitor cells, in both steady state and dynamic conditions, for different values of the operative temperature.

The experimental results reported in this paper have highlighted the good performance, in terms of voltage, temperature and capacitance, of Lithium-ion Capacitors in steady state operative conditions, with the climate chamber temperature fixed at 25 °C.

Further investigations are planned in future work to analyze the behavior of lithium-ion capacitors, in both dynamic and steady state conditions, for different operative temperature.

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