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Lithium-Ion/Supercapacitors storage system powered microcar: development and testing

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Abstract

The use of SuperCapacitors together with the lead-acid battery storage on electric vehicles have the advantage of improving the vehicle range and life-cycle of the lead-acid batteries.
An urban City car, was tested on cycle ECE15, (the urban part of the type approval procedure of vehicles, the NEDC) and an automatic tool and procedure to run it on the dynamometer chassis has been developed.
The results of the experimentation show the advantages in adoption of hybrid storage (Li-Ion + UC) systems in terms of range are lower (+5%) than those obtained with lead-acid + UC (+50%).

Peer-review under responsibility of the Scientific Committee of ATI 2014

Keywords:

1. Introduction

When the first hybrid vehicles were commercialized in the early '90, traction lead-acid batteries were used as on board storage system, and their limits in this application were soon complained from users and recognized by manufacturers. In those years, ENEA acted as independent testing institute and tested a number of high power lead-acid batteries of various technologies (flat plate electrodes and spiral wound) for EV and HEV applications. Among these, two high power lead-acid batteries, of the same type and manufacturer but differing in size, were tested in

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ENEA laboratories, one for ALTRA-IRIBUS, an Italian bus manufacturer, the other for EUCAR,(European Council for Automotive Research, a collaborative partnership of most European car manufacturers). The test configuration was defined to represent a significant model of the potential real application, where the operative result could be extended to a full-scale system. The obtained results showed clearly that reducing the allowable peak power is a way to extend the life of a battery, and this can be done by using a hybrid storage system, composed by battery + supercapacitors. At present, fast charge with reduced size of electric storage systems aggravates module-to-module unbalance problems and revives the use of supercapacitors for load levelling the batteries.
Previous works on the adoption of SuperCapacitors [1, 2] on vehicles showed big increase on vehicle range and battery life-cycle. The lead-acid batteries show by improvements in hybrid storage systems: the Urbe vehicle, a microcar developed in ENEA Research Centre, when running on the dynamometer chassis the ECE15 driving cycle passed from 37 km of range to 54 km with the adoption of lead-acid batteries and SuperCapacitors. Also the cycle-life of the batteries has been improved: the two voltage-current profiles (with and without Supercapacitors) have been tested to two battery packs on a cycler and the number of charge cycles with the hybrid storage system is more than double.

The purpose of this work is to test the Supercapacitors together with Li-Ion batteries and to check if the above benefits can be extended also to last generation batteries. The vehicle tested and the driving cycle are the same used to test the lead-acid batteries, the Urbe. The difference is only the battery pack, that in the present work are 4 modules of Valence U U24-12XP2V with 12.8V and 100 Ah.

The other difference is that in the present work, an automatic procedure has been developed in order to run the driving cycles without the driver; a microcontroller called Arduino has been used and a PID has been developed to follow the path time-speed of the ECE15 driving cycle.

2. The Urbe

The vehicle used in this experimentation is the URB-e microcar (Figure 1), a prototype designed and realized in the ENEA Research Centre, used to test different powertrains, The Urb-e was when built an hybrid series microcar with Supercapacitors [3,4], then an electric vehicle with lead-acid batteries with SuperCapacitors [1] and now is electric with Li-Ion batteries plus SuperCapacitors.

A summary of the specifications of the actual powertrain can be found below in Table 1 and in Figure 1.

Table 1- Specifications of the URB-e microcar.

Weight	530 kg
Electrical Motor	Synchronous with permanent magnets
	55V-16kW peak @ 4600rpm, liquid cooled
Battery	Valence U24-12XP2V, 12.8 V, 100 Ah, 4 in series
BMS	Valence UCharge XP LV 10-15v0
Supercapacitors	MAXWELL BMOD0500 E016, 500F, 16.2 V, 4 in series
Link Voltage	82V

The vehicle, with a weight of 530 kg has been equipped with a syncronous electrical motor with permanet magnets with 55V and 16 kW of peak power. The battery system is composed by 4 modules of Valence U24-12XP, with 12.8 V (51.2V total)and 100 Ah and a BMS from Valence to control them.the toal energy of the storage system is 5120 Wh The previous battery system, the lead-acid one, was composed by 5 modules from HAZE, the HAZE HZY-EV12-65 60Ah; the total energy is 3600 Wh.

Figure 1- The Urb-e microcar and the battery storage

The SuperCapacitors, in parallel with batteries, are 4 BMOD0500 E016 modules in series with 125 F and 64.8 V. The original architecture has been maintained in which the batteries + UC, and the traction motor have connected to a bus with 83V [4].

2.1. CAN communication system

The information communication among components and control unit is implemented by a local network that utilizes 2.0A CAN protocol at a speed of 1Mbit/s.

Control system of the entire propulsion system is designed as a distributed logic system with a supervision program.

It consists of three main subsystems that communicate through CAN network. Subsystems are: the Battery +UC group, the TM group, the Arduino group.

The figure below illustrates the connections between groups.

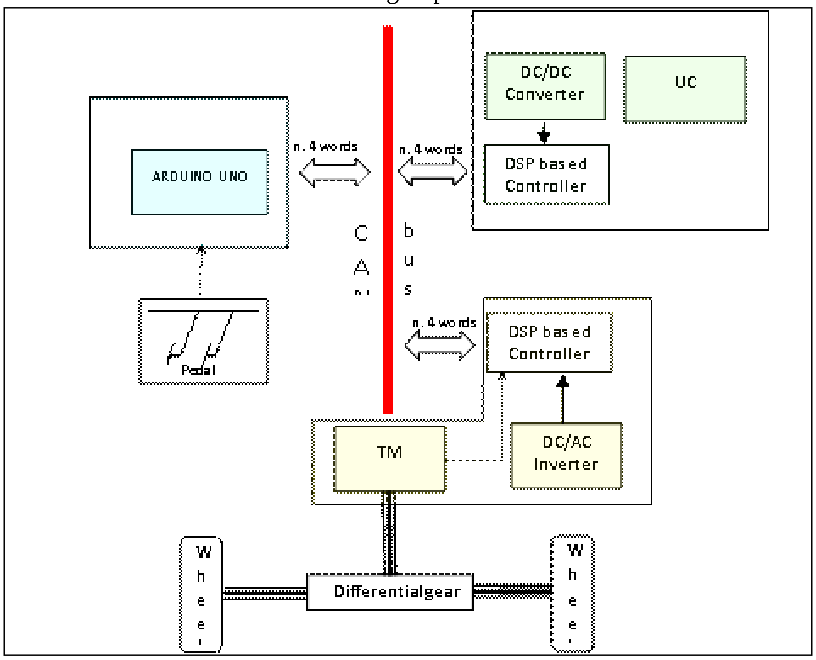

Figure 2 – Scheme of on-board CAN communication

The three information words that each logical group makes available to CAN are:

From battery + Supercapacitors group: link voltage, link current, various messages (ok, protection, errors).
From TM group: rotational speed, throttle position, brake position, reverse drive, protection and errors.
From ARDUINO UNO: set point TM current, various messages of enabling and errors from DSP.

2.2. The ARDUINO Tool

To test the performances of the storage system, the vehicle has been tested on a dynamometer chassis, executing a fixed driving cycle, the ECE15 driving cycle.

The test has been made developing a tool that run automatically the cycles until the storage system reach the minimum battery voltage.

This tool, made using a simple microcontroller called ARDUINO UNO, equipped with a CAN-BUS adapter; to follow the speed track of the driving cycle, a simple PID controller has been developed and it is explained below.

For each reference speed of the driving cycle, the wheel Force that the electrical motor has to supply is calculated as sum of the reference losses Forces (as sum of friction, aerodynamic and slope terms) and the PID term:

$$F_{Wheel} = F_{losses} + m_{vehicle} \cdot a_{PID};$$

The acceleration value is calculated as below:

$$a_{PID} = K_p \cdot e + K_I \cdot \int_0^t e \cdot dt + K_D \cdot \frac{de}{dt};$$

where:

$e = v_{ref} - v_{real}$ is the error between the reference speed value and the real vehicle speed:

$K_p \cdot, K_I, K_D$ are the proportional, integrative and derivative coefficients of the PID. These values are set (Ziegler-Nichols):

$$K_p = 0.6 \cdot K_u;$$

$$K_I = 0;$$

$$K_D = \frac{K_p \cdot T_u}{8},$$

with $T_u = 0.4$ seconds and $K_u = \frac{1}{T_u}$.

The integral part of the PID has been neglected to avoid the Windup, while the coefficients K_u and the engine torque is then:

$$T_{Engine} = \frac{F_{Wheel} \cdot r_{wheel}}{\tau \cdot \eta}$$

Where

τ : gear ratio;

η : transmission efficiency.

The motor inverter need a motor current value through the CAN-BUS to be controlled so, for this kind of engine, there is a proportionality between engine torque and current:

$$T_{Engine} = K_e \cdot I_{Engine}.$$

The results of the ECE15 driving cycles made on the dynamometer chassis using the present tool are reported in Figure .

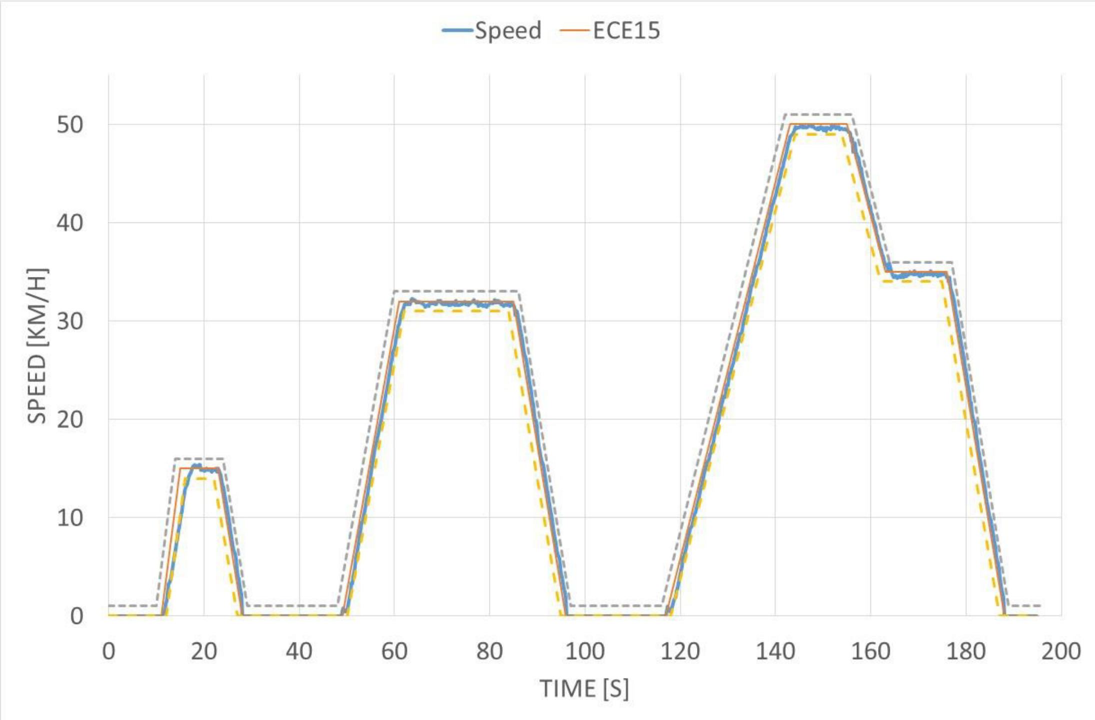

Figure 3 Comparison between the reference speed of the ECE15 driving cycle and the real speed of the vehicle on the dynamometer chassis.

The vehicle speed covers almost everywhere the reference speed with the exception of the first 15 km/h module where the engine maximum power is lower than reference power. The repeatability of the driving cycle is

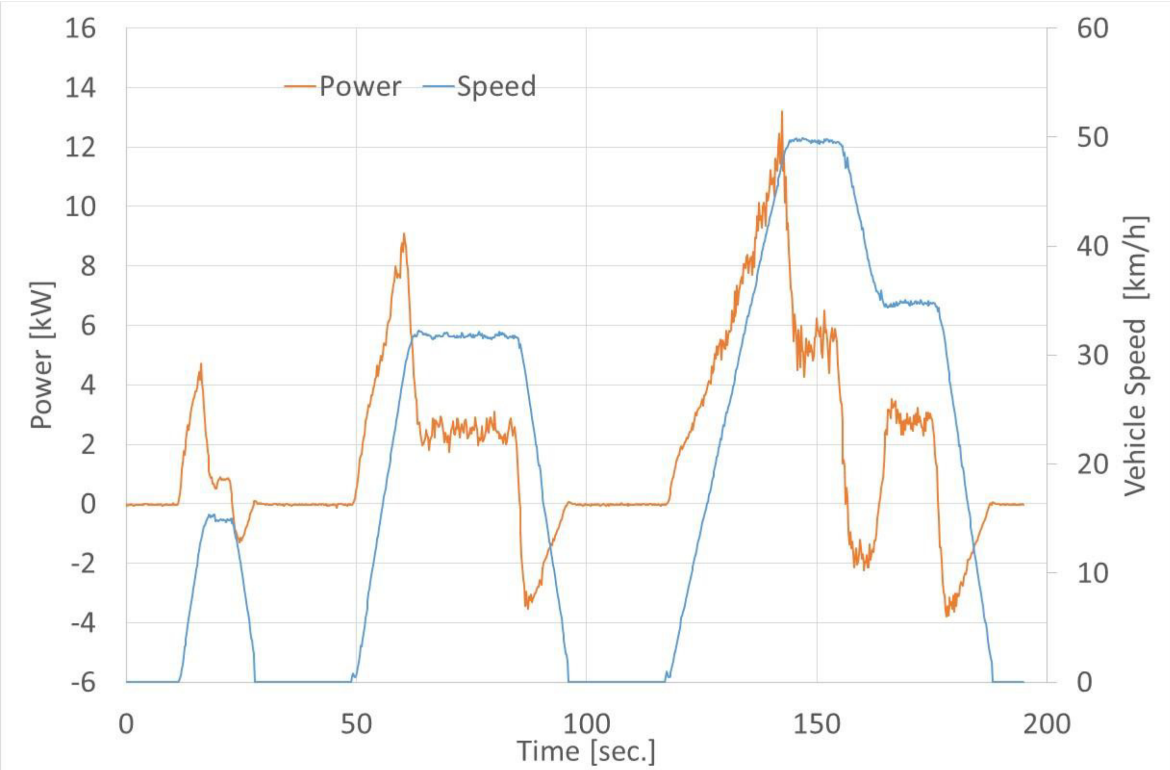

Figure 4 Speed and power from batteries during the ECE15 driving cycle

Figure show the values of power supplied from the batteries during the driving cycle, it is possible to show how the vehicle supply power during the acceleration phases and recover all the energy during the decelerations. All the cycle has been made without using the brakes.

3. Results and discussion

Two tests have been performed on the dynamometer chassis for both the battery storage and the Battery plus Supercapacitors. The vehicle has performed the ECE15 driving cycles automatically without driver. The length of the ECE15 cycle is about 1 km so to measure the range the cycle has been performed many times until the battery voltage reached its minimum allowable value and the BMS open the contactor. The results are reported in Table 2

Table 2 results of the ECE15 driving cycles for the two storage systems

Storage System	Range km	Kwh from batteries	Energy kWh/km	Range Difference
Li-Ion	57.6	4.94	0.0858	
Li-Ion +UC	60.8	5.0685	0.08336	+5.55%

The difference in terms of range is about 5.5%. It is lower than that obtained from lead-acid batteries: 37 km versus 54 with supercapacitors.

The reason is that the voltage curve of the lithium cells in function of the state of charge is quite constant from 90% to 10% SOC and then decrease rapidly so the advantages of the SuperCapacitors cannot extend the range of the vehicle.

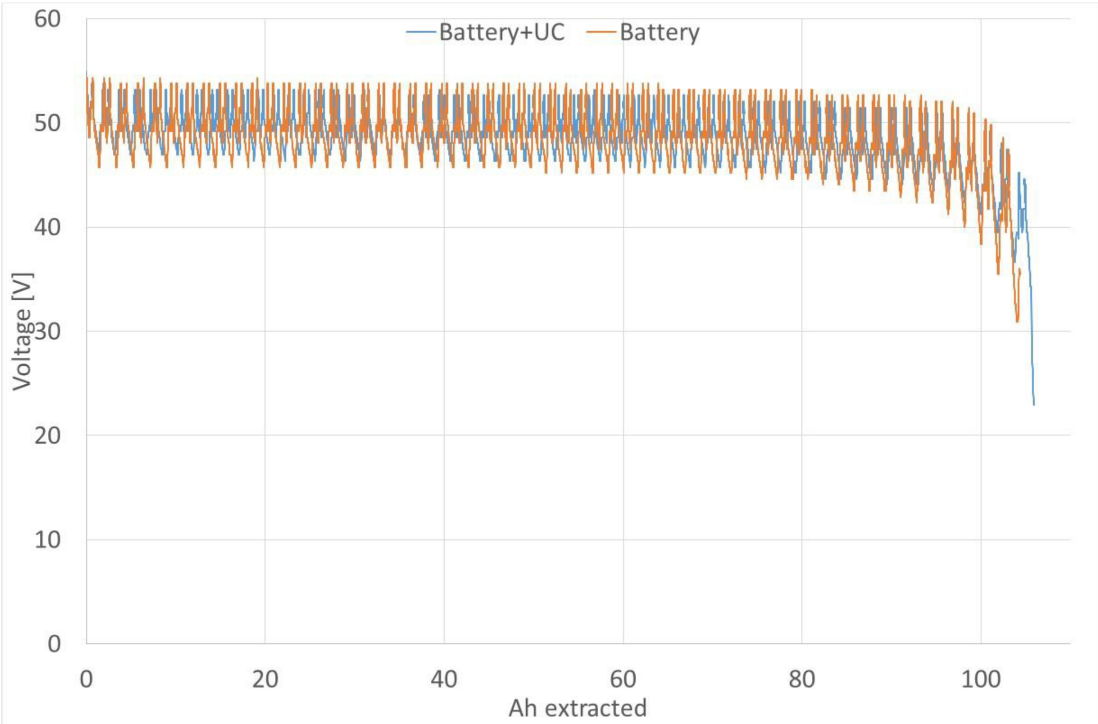

Figure 5 Comparison of the battery voltages along the tests with battery storage and battery + UC

In Figure the battery voltages are reported and in the constant value of voltage from 0 to more than 90 Ah of the charge extracted from the battery can be appreciated. Only the last part of the picture the influence of the Supercapacitors can be useful, where of the Open Circuit voltage of the cells fall down rapidly.

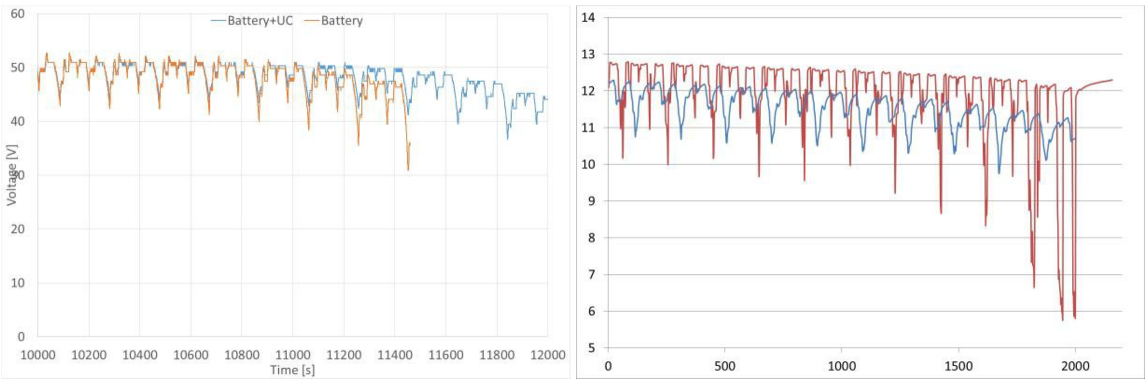

Figure 6. Last 2000 second of acquisition for Li-Ion and Li-Ion+ SuperCapacitors (left) and Lead-acid and lead-acid+ SuperCapacitors (right).

To comprehend better what happen to the last 2000 seconds of the test in Figure are reported the Li-Ion and Li-Ion+ SuperCapacitors on the left and Lead-acid with Lead-acid + SuperCapacitors on the right. Lower internal resistance of the Li-Ion batteries cause lower Voltage drop during the acceleration phases and then the benefits of Supercapacitors are not showed so much. A different behavior can be observed in the right picture of Figure ; higher values of internal resistances of lead-acid batteries lead to higher voltage drop during accelerations. These are much smoothed with SuperCapacitors and also in the last seconds of acquisition these are not lower peaks of Voltage.

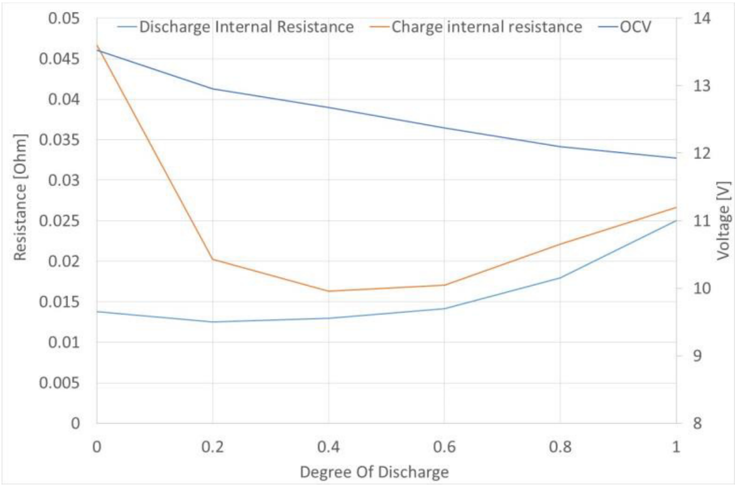

Figure 7. Open Circuit Voltage and internal resistances of the HAZE HZY-EV12-65 60Ah

The strong influence is due to lower values of currents: in Figure the open circuit voltage and the internal resistances of the HAZE HZY EV12-65 with 60 Ah of capacity. The resistances increase decreasing the degree of discharge so when the lead-acid batteries are discharged the phenomenon increases. Furthermore the open circuit voltage has a linear behavior, while the voltage of Li-Ion batteries are almost constant for a large part of the curve.

4. Conclusions

The use of supercapacitors together with the lead acid battery of electric vehicles have the advantage of improving the behavior of the lead-acid batteries.

In the present work such comparison have been made with Li-Ion batteries (Valence 100Ah) and supercapacitors (163 F).

A simple tool that allows to run an automatic mode the ECE15 driving cycle has been developed and the vehicle speed was always within the type approval procedure limits.

The results show that there is not a big increase of the range of the vehicle (+5.5%) due to the different voltage curve with degree of discharge for Li-Ion batteries and lead-acid. The first, having a constant voltage for degree of discharge from 10 to 90% can have benefits only in the last 10%, while the lead-acid have a linear decrease with degree of discharge and with Supercapacitors, that limit the current are able to extract more energy from batteries.

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