VRLA BATTERIES COMBINED WITH ULTRACAPACITORS

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ABSTRACT

With the introduction of the ultracapacitor, a new possible storage system of electrical energy was introduced. Given the differences in behavior between batteries and ultracaps, investigations had to be performed in order to capture possible advantages when both are directly combined into one common energy storage system.

This paper will present the results of investigations executed on a variety of applications with VRLA cells and batteries. Tests, consisting of several charge and discharges cycles, were executed with energy storage systems varying from a few volts (cells) towards several volts (batteries). Test results were not only obtained from test benches but also from several applications, varying from portable power packs and electric scooters towards full hybrid buses.

Besides investigations on thermal and electrical aspects, interactions between the different storages systems were recorded, which could lead to new approaches for optimal energy management and possible enhancements towards durability and lifetime.

INTRODUCTION

The objective of the enrolled project, called "Study of VRLA Batteries with UltraCapacitors" (SLABUC), financially supported by the Institute for the Promotion of Innovation by Science and Technology in Flanders (IWT-Flanders - www.iwt.be), was to investigate if, on the market available, Ultracaps are possible alternatives to improve performance, durability, and lifetime of VRLA (Valve Regulated Lead Acid) batteries. More specifically, VRLA cells and batteries (capacity > 5 Ah) were directly combined with Ultracaps (capacity > 2000 Farad). 'Direct' means that no additional power electronics (e.g., DC/DC converters) were applied, allowing both storage systems (electrochemical and electrostatic) to fully, dynamically exchange the electrical energy.

Furthermore, with this project, possible advantages with this combination were collected. More specifically, the behavior with transients (fast sequences of charges and discharges) and, on longer term, possible effects towards durability were recorded.

The project was divided into the following three phases:

- Phase 1: Knowledge platform Ultracaps
- Phase 2: Combinations VRLA/Ultracaps
- Phase 3: Integrations aspects

Some results from phase 2 are described in this paper.

CELL WITH ULTRACAP

The objective of this testing was to determine the impact of an ultracap (UC – Maxwell 2.5V 2600F) added in parallel with a VRLA cell (Enersys – Cyclon 2V 8Ah) submitted with a given test cycle programmed on a Digatron BTS600.

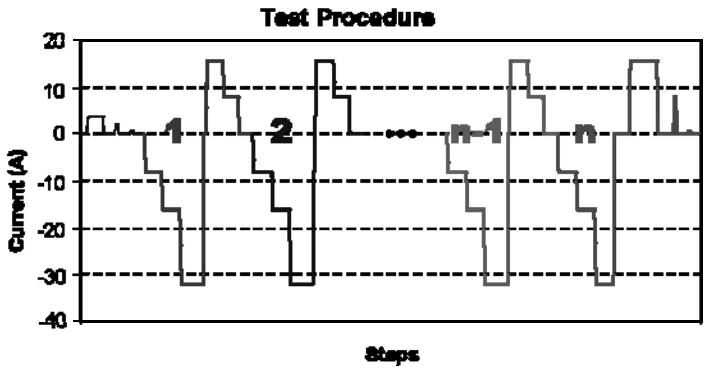

Figure 1: Test procedure applied on 2V cell with UC in parallel

The following steps were executed:

- Initial charging: Three steps charging (constant current) until full charge (2,67V).
- Cycling: Three steps discharge followed by two steps charge, repeated until cell voltage reaches a predefined threshold (1,67V).
- End charging: Three step charging (constant current) until full charge (2,67V).

The results are given below.

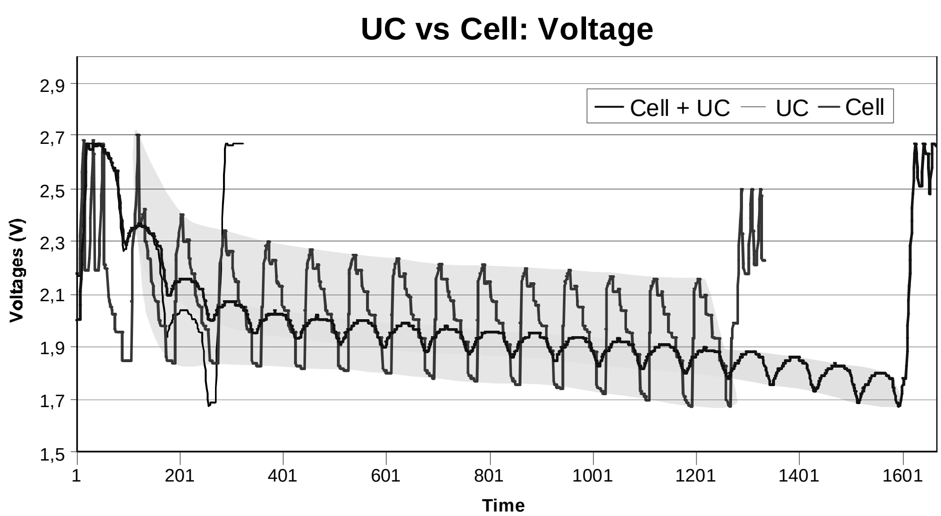

Figure 2: Voltage behavior, 2V cell with UC

The following observations were noticed:

- As expected, the cell possesses more cycles then the UC (14 versus 3), while extra cycles were obtained when combined.
- Strong reduction in voltage fluctuation with introduction of UC.
- More efficient charging with UC (shorter charging time).
- No longer a presence of ‘overshoots’ at initial cycles (no longer ‘overvoltage’ cell).

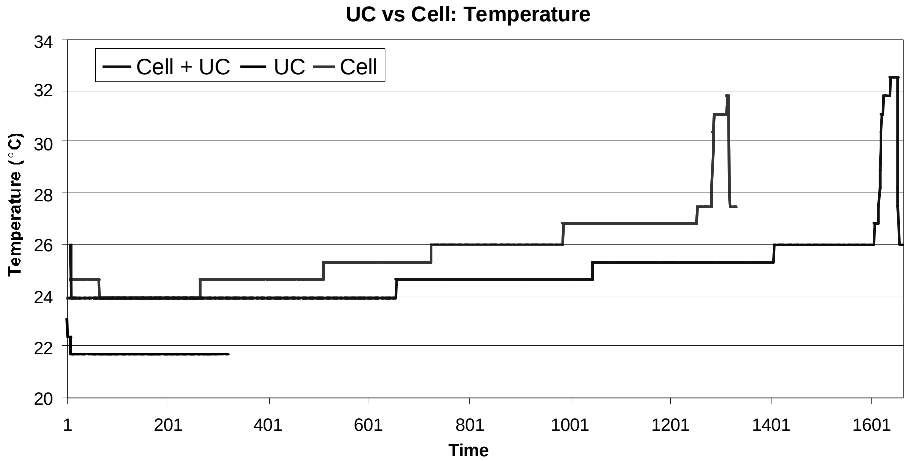

Figure 3: Temperature behavior 2V cell with UC

The temperatures of the different components were measured:

- No significant increase for the UC.
- Similar behavior for the cell with or without UC, except during the charging steps.

BATTERY WITH ULTRACAPS

The objective of this testing was to determine the impact of UC's (Maxwell 2.5V 2600F) added in parallel with a VRLA battery (Enersys – Odyssey 12V 70Ah) submitted towards a given programmed test cycle. To obtain the right operating voltage, several UC's were put in series (string). In addition, more UC's were put in series, to allow investigation of the relationship in capacity (Ah of battery versus F of UC).

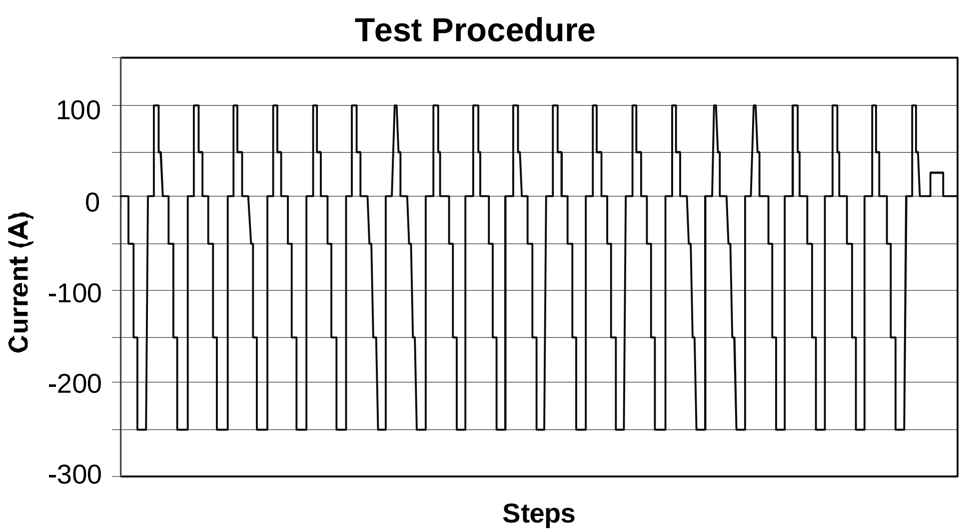

Figure 4: Test procedure applied on the 12V cell with UC's in parallel

The following steps were executed:

- Initial fully charged battery (SOC 100%).
- Cycling: Three steps discharge followed by two steps charge, repeated until battery voltage reaches predefined threshold (10.5V)
- End charging: Three steps charging (constant current) until full charge (14.7V).

The results are given below.

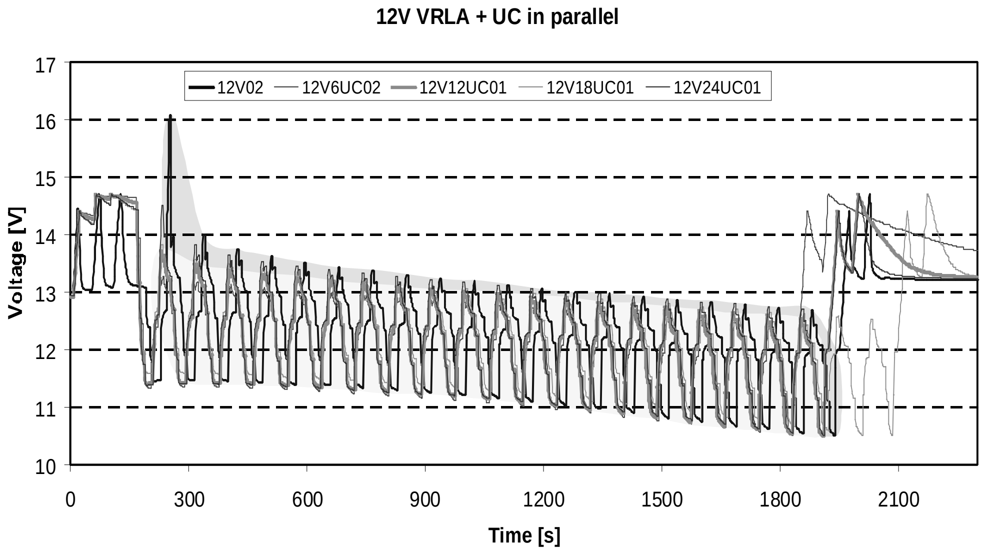

Figure 5: Voltage behavior, 12V battery with UC's

The following observations were noticed:

- Combinations resulted in better performance.
- Reduction in voltage fluctuation with introduction of UC's.
- More efficient charging with UC's (shorter charging time).

Notice that there is a tendency for an optimal capacity ratio between the battery (Ah) and the UC (F). See Figure 6. Since all UC's were put in series, doubling the number results in reduction of total capacity of the UC's by a factor of 2.

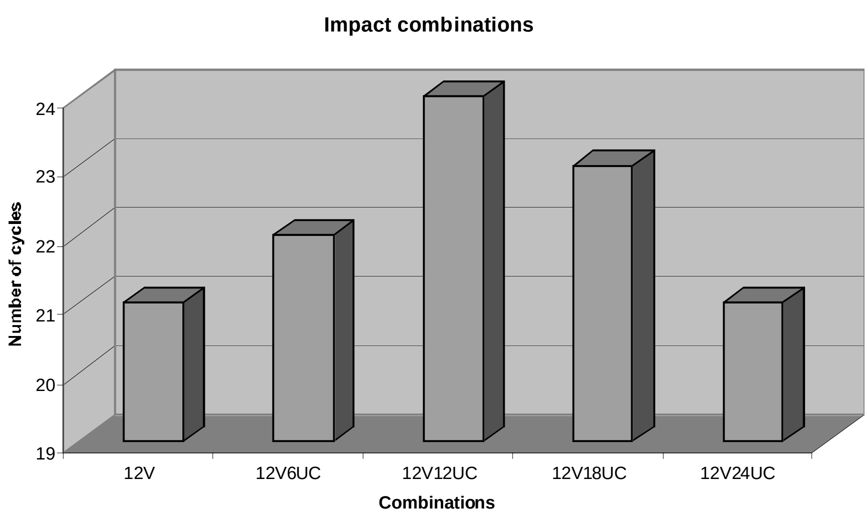

Figure 6: Optimal number of UC's

APPLICATION 1: PORTABLE POWER PACK WITH ULTRACAP

With this testing, the impact of UC's (Maxwell 2.5V 2600F) added in parallel with a VRLA battery (Enersys DataSafe 12V 150W per cell 15 min - 27Ah) was evaluated, applying a given programmed test cycle.

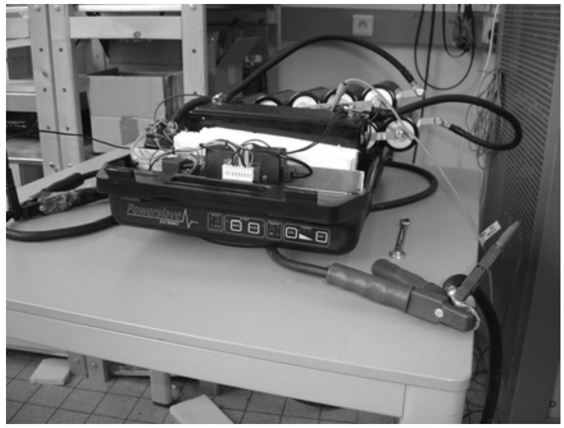

Figure 7: Power pack with UC's

As shown on the figure below, the combined energy system proved to be superior (reduction of fluctuations and an additional cycle).

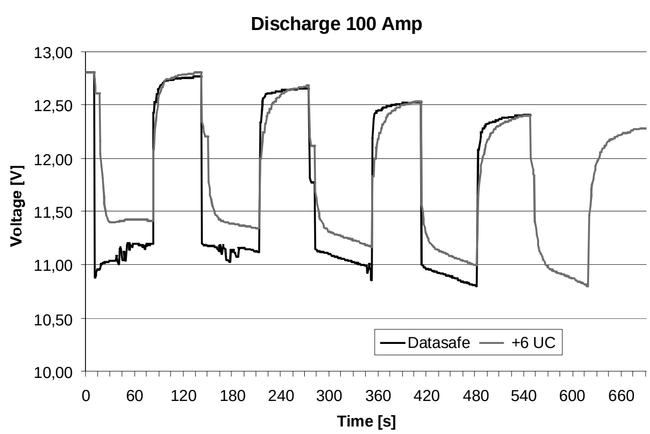

Figure 8: Test results, power pack without and with UC's

APPLICATION 2: ELECTRIC SCOOTER WITH ULTRACAP

An electric scooter (EVT Technologies Type 140-40221) equipped with four batteries in series (Genesis NP 12V 38 Ah) was tested with and without the UC's (Maxwell 2.5V 2600F) mounted on an additional box. See Figure 9.

Figure 9: Electric scooter with UC's

The following results were obtained by execution of repetitive test cycles (based on ECE-15):

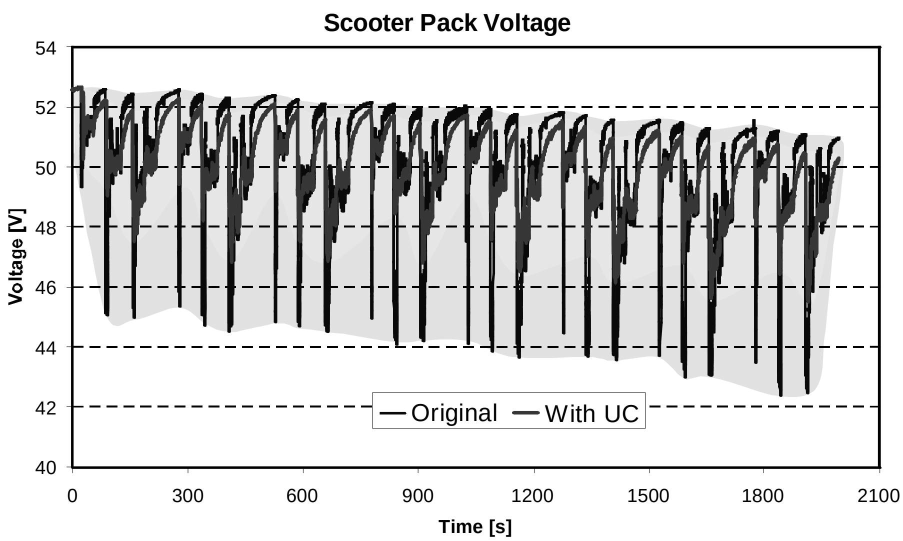

Figure 10: Behavior of pack voltage with and without UC's

Notice that the introduction of UC's resulted in:

- Significant reduction of the voltage spikes.
- Higher average pack voltage.

In addition, the SOC indicator (four LED's) was working more accurately, reacting due to the disappearance of unwanted transitions (no longer increases of SOC). Interesting is that the UC's take over a significant part of the motor current, especially during the initial phase of an excessive increase in power demand, resulting in a less aggressive load for the battery pack. (See Figure 11.)

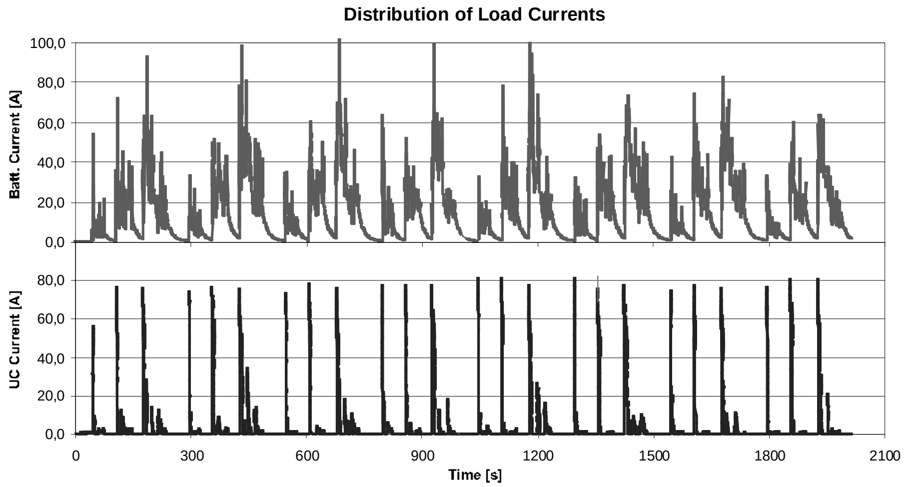

Figure 11: Distribution of current load between battery pack and UC's

APPLICATION 3: HYBRID BUS

With the last application, UC's were integrated into an existing, so-called Serie-Hybrid bus - the propulsion is always electrical - bus. The bus is based on a standard, so-called MidiCityBus, a full, low-floor design, obtained through a special body structure, and the integration of all hybrid related subsystems (propulsion system, battery packs, APU, pumps, DC/DC converters,…) in a cradle at the rear of the bus. The body is made of aluminum filled with wood to obtain low weight. To kneel the bus for even easier access (wheelchair ramps are provided) or to pass a low ground clearance, the suspension can be varied in height.

General specifications of the bus:

- length: 9,50 m
- width: 2,50 m
- height: 3,01 m
- wheelbase: 6,35 m
- max. vehicle weight: 14000 kg
- capacity: 15 seated + 22 standees
- maximum speed: 55 km/h (*)
- peak power: 160 kW (*)
- acceleration (0…30 km/h): 6s at 1,2m/s² (*)
- acceleration (0 .. 50 km/h): 14s at 1,2m/s²(*)
- gradability (hill start): 15 %
- gradability (at 20 km/h): 12 %
- pure electrical range: 35 km
- hybrid electrical range 300 km

(*) electronically limited by calibration

The vehicle is driven by two AC induction motors (105 kW peak) with a common combining gear system. Each motor has its vector-controller IGBT inverter (120 kW peak), which allows regenerative braking. The overall propulsion peak power is 200 kW. The average power demand of the vehicle is 35 kW. While the Auxiliary Power Unit (APU) delivers the average power, batteries can deliver up to peak power demand in electric mode. A central vehicle control unit (Propulsion System Controller – PSC) performs overall control functions of the vehicle, communicating with controllers from the other subsystems and ensuring proper vehicle operation. The bus consists of two battery packs, each of a string of 26 VRLA batteries, which are switched in parallel. Each battery pack has its own Battery Pack Management (BPM) with integrated safety control (Automatic Disconnect Circuit – ADC). The nominal system voltage is 312V with battery energy of 33 kWh. In total, 168 UC's (Maxwell 2.5V 2600F) were integrated into the vehicle, respecting the existing systems configuration, including the required thermal management, diagnostics, and HV related safety aspects.

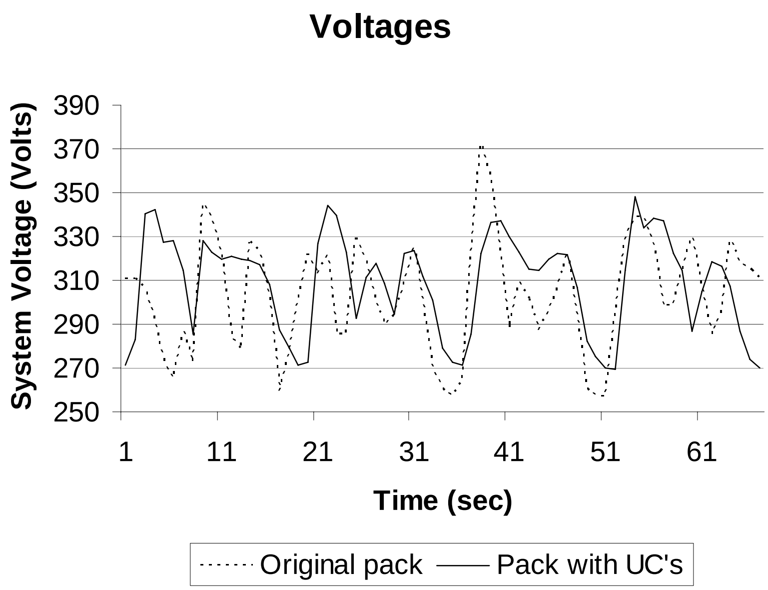

Fig. 12: Behavior of pack voltage with and without UC's

Notice that the introduction of UC's resulted in significant reduction of the 'dynamic' voltage range. With the UC's in parallel with the battery packs, electronic limitation of regenerative braking was no longer present during aggressive braking.

SUMMARY

There is no doubt that, for certain battery applications, a combination of VRLA with UC's will result in enhanced performance, durability, and lifetime.

The challenges will be more situated at the cost side. Introduction of UC's stands for additional initial investments. However, given the continuous price reductions with UC's, a scenario is likely to happen where the original battery is replaced by a combination of a different battery with UC's at the same or even lower initial cost, without any degradation in performances, durability, and lifetime. Even such a combination could, in some cases, be a better solution than applying another battery technology.

Obtained test results for stationary applications (fast charge station for hybrid bus, based on battery banks, energy storage system for photovoltaic systems for domestic energy supply) showed similar results as described within this paper. A new research project that will investigate the long-term influence for different battery technologies with several stationary (UPS, start modules, defibrillators, medical equipment) and non-stationary (start batteries conventional vehicles, battery packs hybrid vehicles, forklifts) applications was recently approved and announced (National Initiative Environment Innovation Platform) and will be executed, together with several industrial partners (batteries suppliers, OEM's), universities, and end users.

Proper energy management will further lead towards more efficient solutions, and more benefits are to be expected from applications with reverse energy flows like regenerative braking.

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