An innovative balancing solution used to supply the 12V auxiliary network of an electric vehicle

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Abstract

In a Lithium Ion battery pack, it is necessary to balance the pack in order to guarantee that at the end of the charge, all cells are fully charged. This step is necessary, otherwise the available energy stored will decrease continuously charge after charge. There are traditional ways to achieve it: an active balancing dissipative method, or a non-dissipative balancing method (energy converters) with higher level of energy saving. Both ways work to compensate the dispersion of farad efficiency (balancing) but a non-dissipative solution can also compensate dispersion of capacity of the accumulators in series.

There are other solutions, which could be named "smart balancing with direct energy use" solutions, because the energy involved in balancing is used instead of being transferred between accumulators.

The goal of this presentation is to describe this innovative solution, to explain its main advantages and to show how it works.
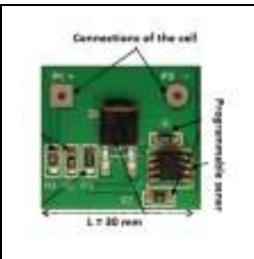
1. Introduction

In LIGE laboratory of CEA, we design and manufacture Li-Ion battery pack for different kinds of transport applications. We always integrate a BMS (Battery Management System) in those battery packs. BMS's main functions could be organized in the following priority order:

- ensure the safety of the pack and the user,
- calculate the state of charge (or others like State of Energy, State of Health)
- balance the pack and communicate information to an external part
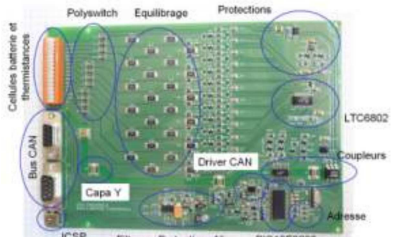- and sometimes manage the temperature of the pack.

After a brief summarize of the different known balancing solutions, we will focus this paper on the presentation of a new and innovative balancing solution (6 patents have been registred on the subject), which can be used in different electric or hybrid vehicle.
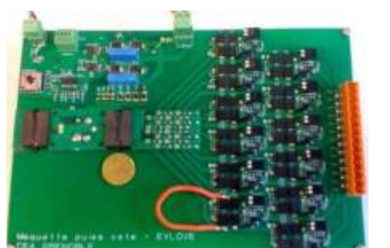
2. Balancing system – different known solutions

21. First solution - zener or programmable zener

Active/passive	Passive (no intelligence)	
Dissipative or not?	Yes	
Electronic used	zener or programmable zener	
Balancing time	End of charge	
Efficiency of balancing	0 % (no energy recovery from balancing	
Main Advantage	Simple	
Main Disadvantage	no cell's voltage measurement	

22. Second solution – programmable resistances

Active/passive	Active	
Dissipative or not?	Yes	
Electronic used	component like LT6802	
Balancing time	End of charge	
Efficiency of balancing	0 %	
Main Advantage	Simple, robust	
Main Disadvantage	Can't compensate dispersion of capacities	

23. Third solution - converters

Active/passive	Active	
Dissipative or not?	No : Energy is transferred to other cells	
Electronic used	Isolated DCDC converters	
Balancing time	during charge or discharge	
Efficiency of balancing	estimated at about 80%	
Main Advantage	efficiency, capable to compensate	
Main Disadvantage	cost, complexity	

3. New and innovative solutions
31. Fourth solution – smart balancing with direct energy use

The main and original idea of a new solution is to use more energy **on the cells** with the highest state of charge to supply the auxiliaries' network. For example, a higher state of charge could be a consequence of dispersion of capacity, appearing after manufacturing or after ageing, or a dispersion of faradic efficiency, or a consequence of the replacement of an old module with a new one, presenting higher capacity.

In standard solutions, balancing energy is dissipated or transferred from cell to cell. Here, we transfer the power from the selected cells directly to the auxiliaries' network (typically 12Vdc bus), like on figure 1.
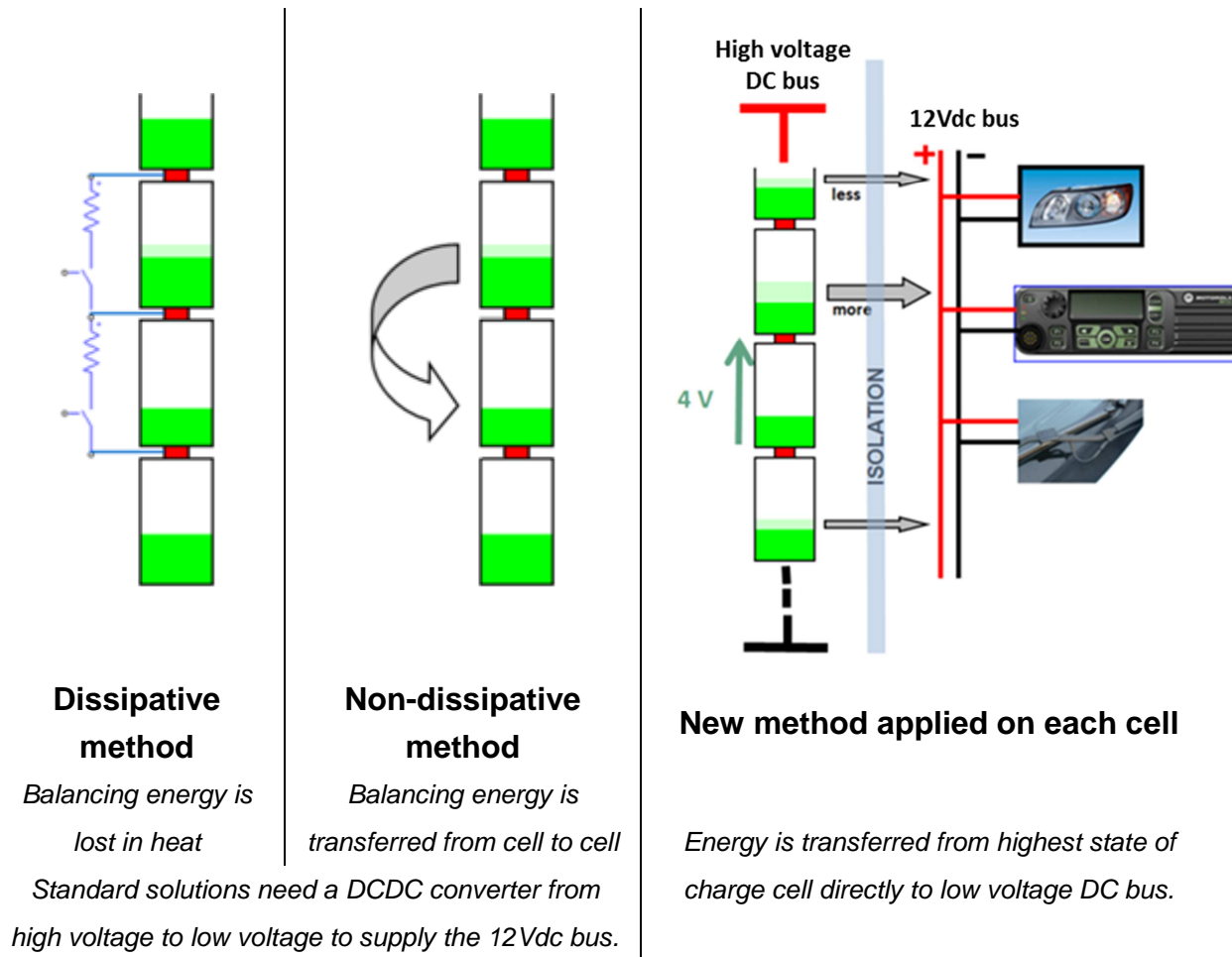
Dissipative method

Balancing energy is lost in heat

Standard solutions need a DCDC converter from high voltage to low voltage to supply the 12Vdc bus.

Non-dissipative method

Balancing energy is transferred from cell to cell

New method applied on each cell

Energy is transferred from highest state of charge cell directly to low voltage DC bus.

Figure 1 – smart balancing with direct energy use

The main difficulty with the "smart balancing with direct energy use" method is the need of a specific isolated converter, on each level of the battery pack. Let see the example, of an electric vehicle supplied with 160Vdc high voltage battery pack (48 cells in series), which needs 12Vdc-1kW low voltage bus network for auxiliaries. To apply our solution, we have to use 48 converters of about 20W each, with an input voltage of 3,2V and an output voltage of 12V. Due to the low input voltage of the converter, the efficiency will be only around 80% or less. To implement this solution, we would need a high number of converters, with protections against short circuit on each one, and a difficult thermal management system has to be designed.

If we compare this solution with the others on same criteria, we obtain:

Active/passive	Active
Dissipative or not?	No : balancing energy is 100 % used
Electronic used	DCDC converters
Balancing time	during charge or discharge
Efficiency of balancing	about 100%
Main Advantage	efficiency of balancing, capable to compensate dispersion of capacities
Main Disadvantage	number of converters, costs, difficulties of control

32. Fifth solution – application of this solution to module

To avoid a high number of converters and a low efficiency, the solution can be applied to each module, which are already an association of cells in series and parallels (see Figure 2).
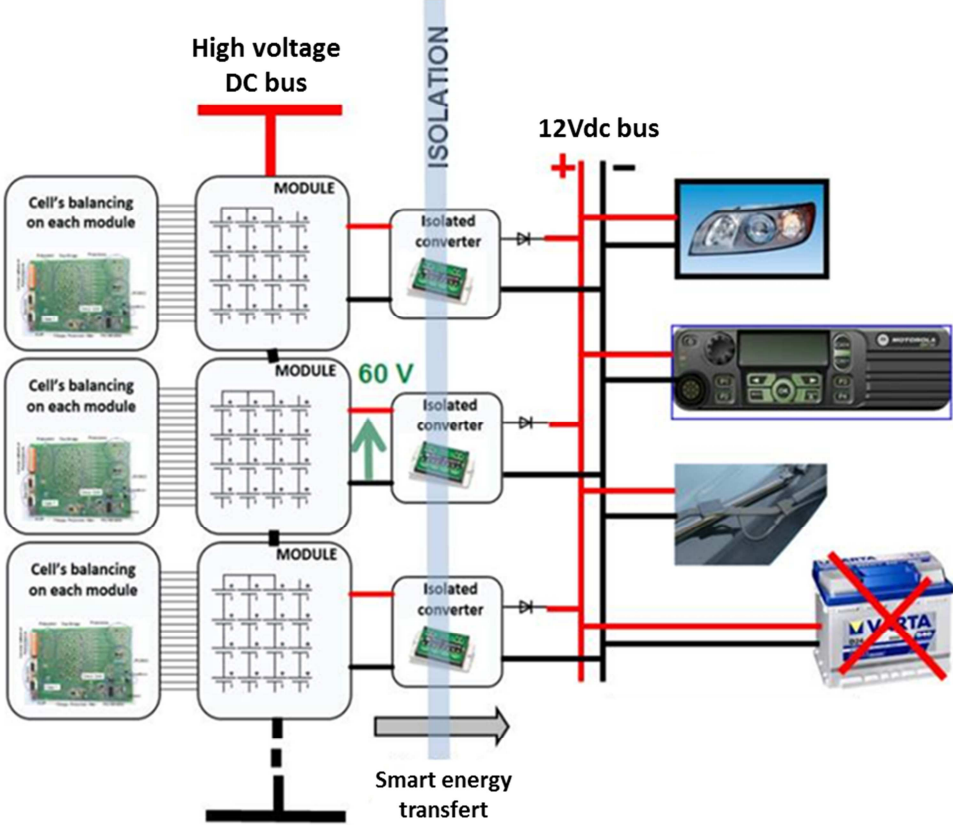

Figure 2 - smart balancing with direct energy use - method applied to each module

The Figure 2 presents a powerful solution, able to offset the dispersion of capacities between modules: 12Vdc bus can be fed mainly, by the module with the highest state of charge. Inside each module, we usually use accumulators with low dispersion of capacities. That is why a low cost active dissipative balancing circuit is usually sufficient. The dispersion of the capacities between modules are more important because the temperature, the age, between modules can be different.

If we compare this solution with the others on same criteria, we obtain:

Active/passive	Active
Dissipative or not?	No : balancing energy of module is 100 % used
Electronic used	DCDC converters
Balancing time	during charge or discharge
Efficiency of balancing	about 100%
Main Advantage	powerful module balancing, efficiency of balancing, capable to compensate dispersion of capacities between modules
Main Disadvantage	A standard balancing solution is always needed on each level of the battery pack (dissipative or non-dissipative)

The three main advantages of this last solution

The "smart balancing with direct energy use applied to each module" is not only useful to balance a pack and offset the dispersion of capacities. It presents also other advantages:

- **First advantage:** no energy losses in balancing process and maximum energy use of each module (increase the range of the car).

The DC/DC converter (Vin = 160V, Vout = 12V, 1kW) is replaced by four small converters (Vin = 40V, Vout = 12V, 250W) placed on each battery module. The efficiency at maximum power is nearly the same. With an intelligent management of theses converters, we can supply the 12V DC bus (**and** so offset the dispersion of capacities) when maximum energy comes from the highest state of charge module..

Compared to standard solutions, there are no additional losses to provide the balancing process in this new electrical architecture. That is the reason why we can say we can perform a "module balancing efficiency of 100%".

Consequently, in case of dispersion of capacities between modules, we can use the maximum energy from each module, and thus **increase the range of the car.**

- **Second advantage:** possibility of removing the low voltage battery (or decrease the size).

At the output of each converter, we have added an "ORing Diode" (see Figure 2). In case of fault on one converter, we can always continue to supply the 12Vdc bus thanks to the redundancy. If we choose DC/DC converters with higher power on each module, we can **remove the low voltage battery** without derating. If we accept a small derating, we can continue to supply the auxiliary network, even if one converter is in fault.

- **Third advantage:** DCDC converters used in high efficiency area.

In an electrical vehicle, the mean power needed on the 12Vdc bus is usually low in comparison with the peak power of few consumers like power steering system, vehicle's headlight, …

Consequently, the efficiency of the main converter isn't very good because most of the time, it is working with low load (maximum efficiency of a DCDC converter is performed between 50% and 100% load).

The difference increases with the number of modules: a comparison of efficiency between a single converter solution and a 8 small converters solution is presented on Figure 3.

With paralleled converters, in order to optimize the consumption of energy, the power supplied can be adapted to the needs of the 12Vdc bus. Consequently, **we can improve the whole efficiency of the system**.
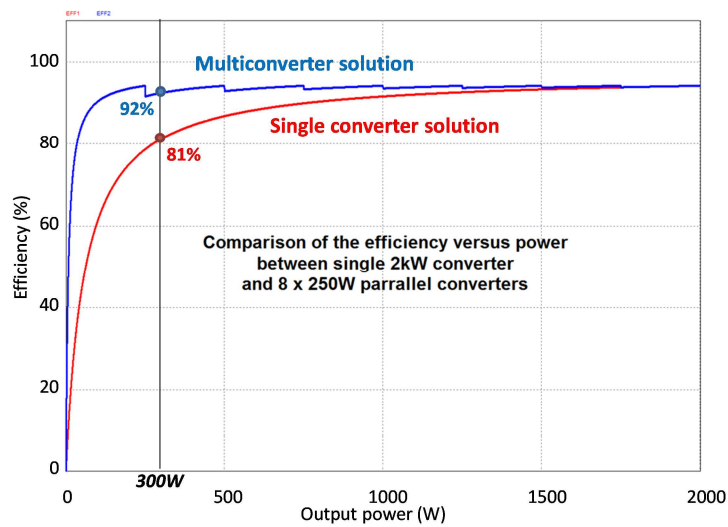
Figure 3 – DC/DC converter efficiency comparison of the 2 solutions

4. Strategy used to control some converters in parallel

The main difficulties to design and implement the last presented solution are, first evaluate separately the state of charge of each module, and second choose and turn ON the right modules during discharge.

An algorithm (triggered every second or more for example) consists in:

- calculate the maximum load current absorbed by the auxiliary bus
- calculate the state of charge of each module
- classify the modules from the highest to the lowest SOC in order to turn ON, firstly modules with highest SOC
- turn ON the right number of modules in order to optimize the system efficiency

This algorithm improves system efficiency and allows to balance modules with different SOC.

Practically, the different modules are not always turn ON or OFF whenever the load current changes: an analog regulation allows provides current from modules with the highest SOC. Each module converter is voltage regulated with a current limitation, but the level of regulation voltage is a little bit different for each converter. Like it is presented on figure 5, we can see that the current is drawing from the module with the highest level of voltage regulation. This kind of regulation is possible because the auxiliary network of a vehicle allows a wide bus voltage range, usually from 12V to 16V.

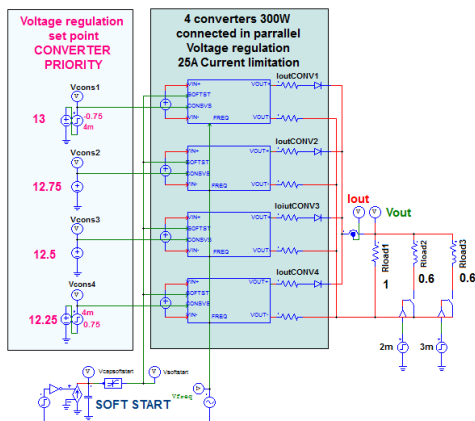Figure 4 - Simulation of 4 parallel converters

Figure 4 presents the high level schematics of the simulation with 4 converters in parallel. We apply different voltage set points and analyze on figure 5 which module provides the current at different load current levels.

We can see that the output voltage decreases when the current increases, not only because of the serial resistance, but mainly because the current limitation of 25A is reached on the first two modules (module 1 and 2)

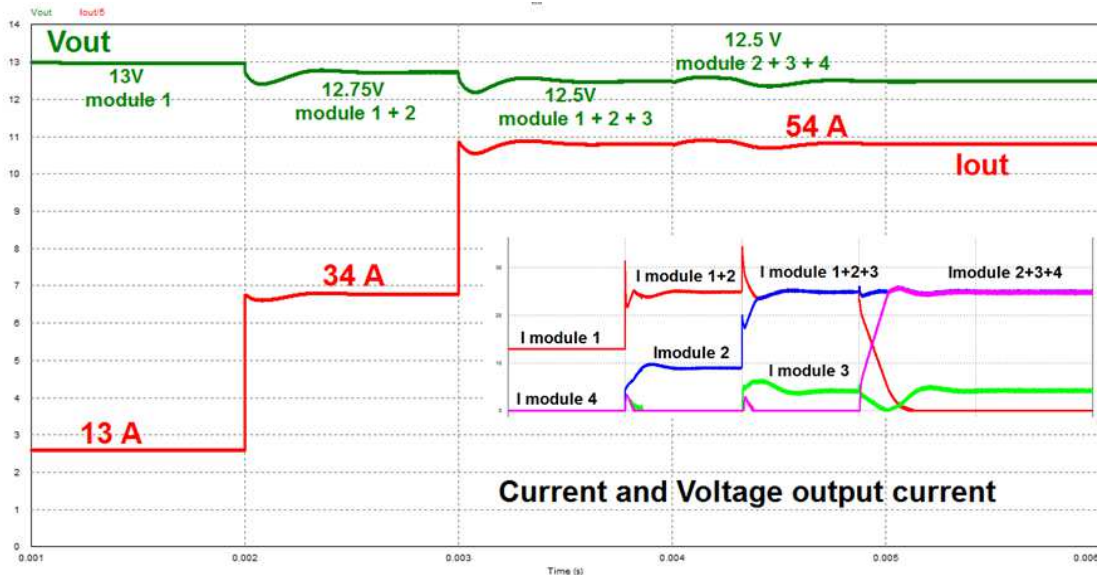We can also see that it is possible to change the priority between two modules (1 and 4).

Figure 5 - Current and voltage waveforms

5. Tests performed on an electric vehicle

The last solution presented was tested in real configuration on an electric vehicle. We worked with 160V-40Ah battery pack composed by four 40V modules with about 5% of difference of capacity. We removed the 12Vdc battery.

During tests, we follow 2 objectives:

- The first one was to ensure that the 12Vdc bus was correctly supplied even with the 12V battery removed.
- The second one was to confirm the simulation's results and evaluate the gain of energy we could obtain with a battery pack built with different module capacities.

On the Figure 6 below, is represented with dark blue color the voltage on the bus (12V here), with pink color the total load current, with yellow color the current of the highest state of charge module (module #1) and in light blue color the current in the module #2. The electric load is made up of steering system, headlights, electric windows, windscreen wipers, and warning lights which have been successively started and stopped.

As we can see, the 12V voltage is quite stable and balancing management works great: the module with the highest capacity (module #1) produces its maximum current.

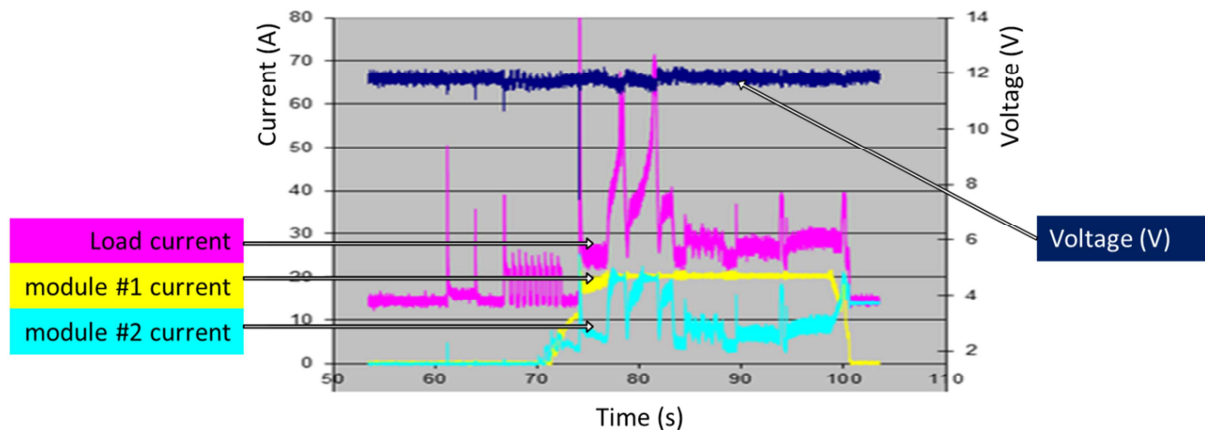It's better to use the module #1 in priority, because it has the highest energy.

Figure 6 - Current and voltage on auxiliary network

In order to show the advantage of the new architecture, in term of vehicle range, we performed two comparative complete discharges with the same configuration (5570W on power bus and 300W on auxiliary bus), like it is presented in Figure   :

- First discharge with module balancing OFF (blue curve)
- Second discharge with module balancing ON (red curve)

The end of discharge was activated when one cell of the battery pack was under 3 V. We can verify that the smart strategy allows to recover some Wh (exactly 5570W*(3120s-3020s) = 154Wh), **which represent about 3% of the available energy of the whole pack.**
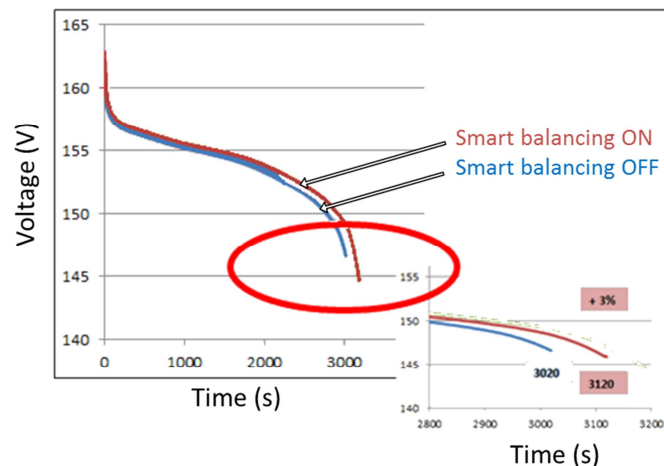

Figure 7 - End of discharge with (red) or without (blue) cell's module balancing activated

6. Conclusion

In this paper we have presented an innovative balancing solution also used to supply the 12V auxiliary network of an electric vehicle.

During the design of the vehicle's architecture:
- o   we can remove the 12V battery
- o   we replace the main DC/DC converter by several small converters (one per module).

This allows us to:
- o   Perform a module balancing with a 100% of efficiency when other solutions have 0% up to 80%.
- o   Increase the efficiency of DC/DC conversion, using several small converters instead of a big one.
- o   Offset the dispersion of capacities between modules (best use of the energy of each module), thus increase range of the vehicle, especially with a battery pack presenting dispersion of capacities between modules, for example after maintenance.
- o   And remove the low voltage battery

and these advantages with a low impact on the cost, thanks to the 12V battery removing

7. Litterature

[1] Davide Andrea nBattery Management Systems for large lithium-ion battery packs", Publisher, Artech House, 2010