Fuel cell and battery hybridization for automotive application

D. Chatroux

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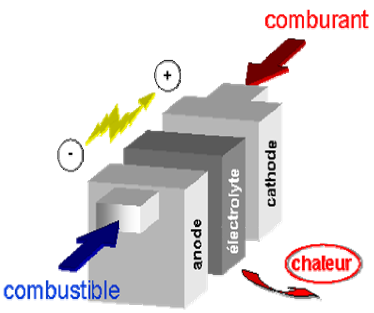
D. Chatroux, CEA 17, rue des Martyrs, 38504 Grenoble Cedex, France
daniel.chatroux@cea.fr

Abstract

In 2006, a fuel cell technology was developed between CEA and PSA in France. The first design is a 80 kW one for a 65 kW automotive power train. Theses specifications are adapted for a fuel cell vehicle without power battery hybridation. Now, in our different applications, the fuel cell system is designed with hybridation with a Lithium ion power battery. A first example is electric vehicle with about 100 km range with the battery electricity and a fuel cell range extender which is designed for mean power and not for maximum power. Another example is the use of a fast charge and discharge high power lithium ion battery with a very good intrinsic security. With this kind of battery, it's possible to use the stored electricity and to recharge very quickly the battery due to the fast charge.

1 GENEPAC project

The fuel cell is an electric generator. With hydrogen and air, electricity is produced. The efficiency is in the 60 to 70 % range for the fuel cell only. A cooling circuit is used for thermal losses.



The fuel cell system includes all the auxiliaries, air compressor, hydrogen pressure regulator, cooling pump and heat exchanger, electric converter.
The system efficiency is lower because of all the additional losses. The main consumption is the air compressor one.

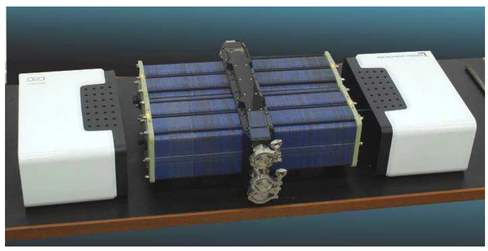
In collaboration between CEA (technical research center) and PSA (automotive) an industrial fuel cell stack technology was developed with metallic bipolar plates. It was unveiled on January, 9th, 2006.
The GENEPAC fuel cell is part of the development of a complete fuel cell system [1] for automotive application
.
The main specifications for the all system are:

- System rated power: 60kW
- System efficiency at rated power: ≥45%
- Fuel cell stack power density: 1.5 kW/L and 1 kW/kg

In order to reach the system rated power, the stack is designed to deliver 80kW.
These specifications are adapted to generate the all power for an electric power train without the additional power of a power battery.

The initial application of such a system is a fuel cell vehicle without power battery hybridation.

The design of the GENEPAC technology is:



The bipolar plate design is very thin. Bipolar plates and EMA (Electrode Membrane Assembly) are stacked.
The power of the stack is tuned by the number of bipolar plates and EMA. For the electric point of view, the cells are in series. The maximum current level is due to the bipolar plates and EMA surface. The voltage is due to the number of cells in series.

For the 80 kW GENEPAC design, the voltage in open circuit is 400V. This voltage is around 200V for the maximum current.

This first realization is designed to move a vehicle with the only fuel cell system, without additional power battery. There are technical and cost limitations for this approach.
The all system is designed for the maximum power. This has a direct impact on the cost of the stack and the main components (fuel cell stack, air compressor and electrical converters).

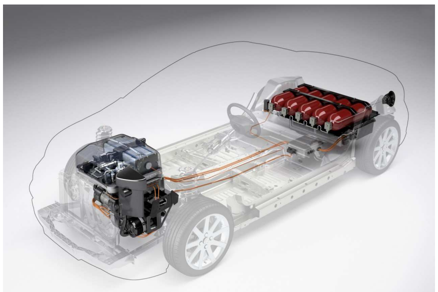
Some technical problems are difficult. To provide acceleration, the fuel cell has to generate a lot of power. In the same time, it's necessary to accelerate strongly the air compressor speed to provide the necessary additional air for the fuel cell. It' clear than an additional electric storage is an advantage for transient behavior.

2 Fuel cells and high energy Lithium ion battery hybridation

The PSA second realization is based on hybridation between the fuel cell system and a Li-ion battery (www.207cc.net/peugeot-207-cc-epure-vt90.html).
In this case, the battery is a high energy one with a good level of power.
A part of the range is provided by the battery. The additional range is provided by the fuel cell system. It's designed as a range extender.

The specifications of the power system are
- Li ion battery
    - o 10 kWh energy battery,
    - o maximum battery power 50 kW
- 20 kW fuel cell system
- electric motor:
    - o Nominal power: 40 kW
    - o Maximum power: 70 kW
- Hydrogen storage:
    - o 3 kg H2 Storage
    - o 700 bars
    - o 5x15

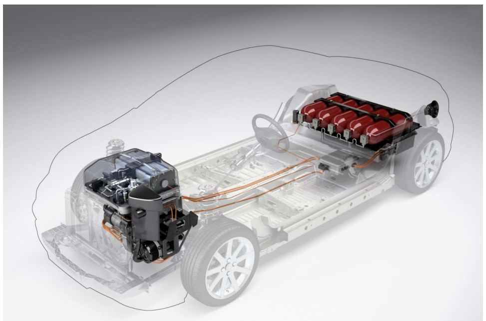
The localization of the different parts is:



The battery and the hydrogen storage are in the back of the vehicle. The fuel cell system is in the front of the vehicle.

The vehicle performances are
- Zero emission vehicle,
- High efficiency power train,
- Good driving performances,
- Range: 500 km,
- Plug-in vehicle,
- Possibility to use H2 or electricity.

The vehicle integration is very good for air and hydrogen circuits. Now the limitation is power electronic.

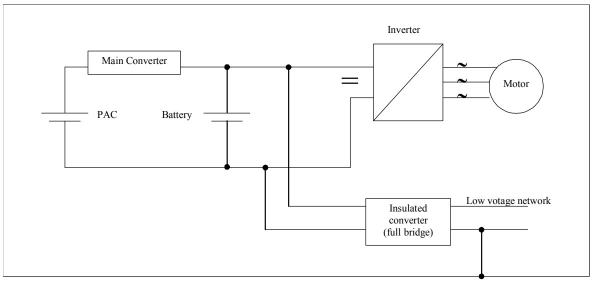


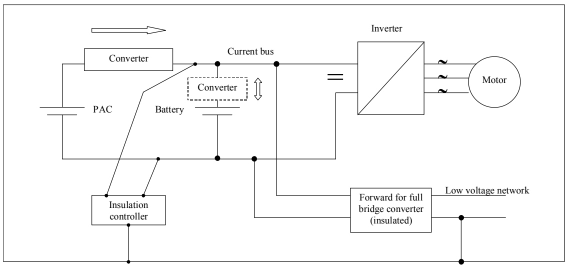
The challenges for power electronic are [2]:
- Volume (Integration)
- Weight
- Efficiency
- Cooling

For integration point of view, it will be very interesting to have only one cooling circuit in the 80 – 90℃ range and high temperature inverters and converters.

3 Very safe high power phosphate battery for fuel cell hybridation

For the different fuel cell systems in our applications, there are generic electrical architectures.





For fuel cell systems of some tens of kilowatts, a boost converter is connected at the output of the fuel cell.
The insulations of all the high voltage components are controlled by an insulation controller.
Depending of the level of voltage of the battery, a converter is used to boost the voltage of the battery, or the battery is connected directly to the high voltage bus. This converter has to be bidirectional. The positive current discharges the battery and a negative current is necessary for charge. This bidirectional converter allows a very good battery charge current control
An insulated converter provides the electrical power for the low voltage network of the application.
For example, the magnet motor is supplied by an inverter.

For an electric car with a high energy battery, the maximum charging current provided by the fuel cell system is low. The charge rate for the battery is limited.
This configuration is adapted with standard Lithium ion batteries which have current charge limitations not to have a negative impact on security.
Standard Lithium ion battery use Cobalt Oxide. This oxide has a low temperature decomposition level. Some safety rules are to be respected not to have fire, and to limit the impact of fire:

- no overcharge voltage on each element,
- no fast charge at negative temperature (metal Lithium can be generate instead of the only lithium ion process),
- mechanical protection,
- fire temperature protection.

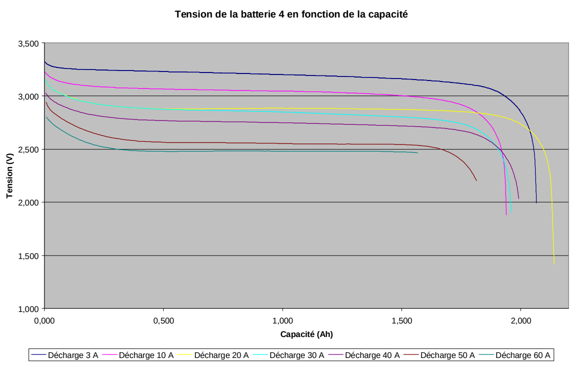
Because of the negative and cost impact of lithium ion fire in portable computers, new lithium ion batteries with a very good intrinsic safety are now available.

One of the key Lithium ion technology is nanostructured phosphate one.

Phosphate Lithium ion battery are used in electroportative tools.
The energy is lower than Cobalt oxide Lithium ion battery, but the allowed level of power can be very high.
CEA is working on phosphate Lithium ion for years. Up to now, the lower level of energy was a disadvantage for the main portable applications.
Now, the high level of power for discharge and for charge is a key advantage for automotive and fuel cells applications.

Because of the high intrinsic security and very low internal resistance, not only fast discharge is allowed, but fast charge too.

The test of a industrial 2,3 Ah phosphate Lithium ion prove very fast discharge with low internal losses.



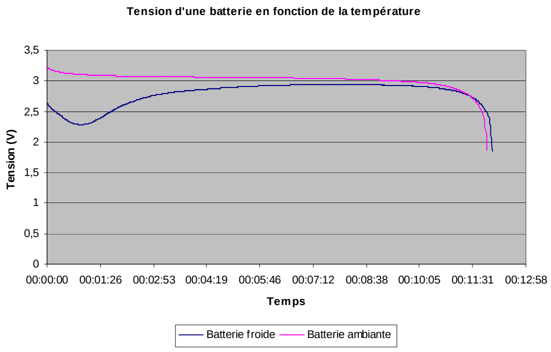
The charge rates are huge for such a standard accumulator. The different curves are for the following discharge rates.

Current (A)	Charging rate / C=2.3 Ah
3	1,3 C
10	4,3 C
20	8,7 C
30	13 C
40	17 C
50	21 C
60	26 C

The specified charging current is 10 Amps (4,3C). We test 10 A charges and 20 A charges at ambient temperature.

These standard nanophosphate Lithium ion accumulators can be charge in some minutes. The internal losses are low, so the temperature rise is totally acceptable.

The comparison of a fast 10 A discharge (4,3C) at low temperature (-18℃ Storage) prove a higher but low internal resistance at low temperature.



Because of the higher internal resistance, losses are more important. There is a temperature rise. At higher temperature, the internal resistance decrease and the voltage drop decrease too.

This nanophosphate Lithium ion technology is well adapted for hybridation with fuel cell systems where a battery with a high energy is not adapted because of cost or weight.
High level of power can be generated with a low volume and weight. Fast recharges allow to be fully recharged between two high power solicitations.

Conclusion

In 2006, a fuel cell technology was developed between CEA and PSA in France.
The first design is a 80 kW one for a 65 kW automotive power train. Theses specifications are adapted for a fuel cell vehicle without power battery hybridation.
Now, in our different applications, the fuel cell system is designed with hybridation with a Lithium ion power battery. A first example is electric vehicle with about 100 km range with the battery electricity and a fuel cell range extender which is designed for mean power and not for maximum power.
Now, for different fuel cell systems the electrical architecture is the same. It's a generic one from some watts to tens of kilowatts.

The use of a fast charge and discharge high power lithium ion battery with a very good intrinsic security is presented. With this kind of battery, the nanostructured phosphate lithium ion battery, it's possible to use the stored electricity and to recharge very quickly the battery with fast charge. This technology provides very high level of performance with high intrinsic security. It's well adapted for hybridation with fuel cell systems.

3 Literature

[1] Chatroux, D.; Poirot-Crouzevier, J.-P.; Roy, F.; Fuel cell Electric Vehicle, GENEPAC Project, realization of a fuel cell stack prototype dedicated to the automotive application, ITCT2006, november 20th-23d 2006 – Ministère de la Recherche Paris.

[2] Chatroux, D.; Milly R.; The challenge of new energies: Power electronic point of view. EHEC 2003, Grenoble, september 2d -5th 2003.