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# Power electronic and battery analysis of Vectrix Scooter

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## Abstract

In 2010, a presentation was done in PCIM [1] about the performance improvements of a small electric car with the replacement of the initial NiCd battery by an iron phosphate Lithium ion battery (LiFePO4). The small car is an AX, an old French electric vehicle from Citroën with a separate excitation DC electric motor. This car has been chosen to illustrate a light electric car around 850 kg with the good level of security provided by LiFePO4 and with a 20 minutes fast charge.
The other demonstrator vehicle in the laboratory is a Vectrix scooter, which is an illustration of good power electronic and electric motorization state of art in a modern vehicle.
The goal of this presentation is to detailed the scooter power electronic and motor, to compare NimH battery specifications and test results, to present some reliability aspects after one year of use, and the interest of iron phosphate batteries in replacement of NimH ones in this application

## 1. Vectrix Scooter presentation

### 1.1. Vectrix Scooter presentation

The Vectrix scooter is a high speed electric one (100 km/h) with good acceleration (specified 0 to 80 km/h in 6.8 s). The electrical motor has a specified nominal power of 10 kW to be used with a car driving license, and a maximum power of 20 kW. The brakes are mechanical ones. Regenerative breaking is controlled by reverse rotation of the throttle.

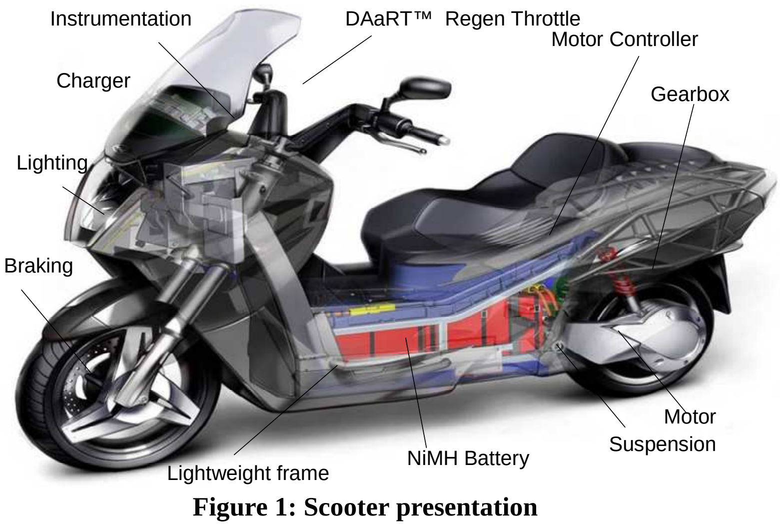


**Figure 1: Scooter presentation**

The magnet electrical motor and the reduction gears are integrated within the rear wheel in a compact design.

The battery is a 30 Ah 125 Volts NimH one. The specified stored energy is 3.7 kWh.

**Figure 2: battery pack**

**Figure 3: the two modules, the back one without cover**

The battery is designed with two modules in series. The front module has a weight of 42.5 kg and the rear one has a 47.5 kg one. The global weight of 90kg is an important part of the total weight of the scooter (230kg).

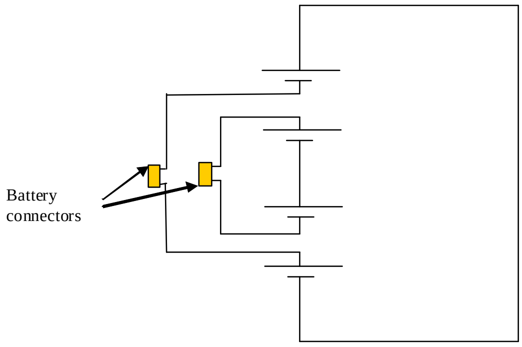


**Figure 4: modules and connector**

The connector between the two modules provides the disconnection of the battery at ¼ and ¾ of the voltage.

The battery is specified for 1700 cycles with 80% DOD (deep of discharge). The lifetime is specified to 80 000 km.

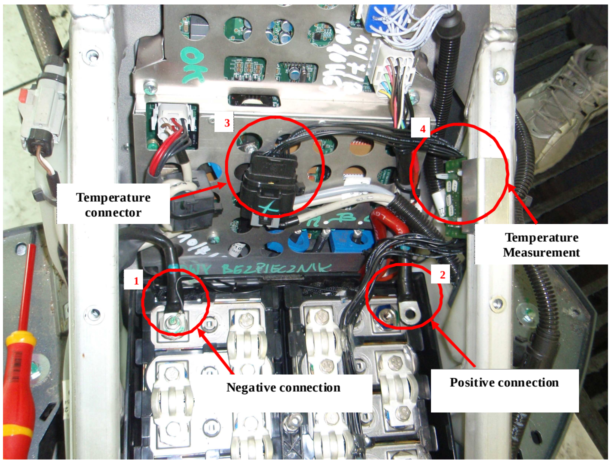

**Figure 5: motor inverter**

The inverter is under the sea at the back of the scooter. It is an air cooling system. The heatsink is under the scooter enclosure.

## 1.2. Kilometric ranges

The supplier specifies the kilometric ranges for different speeds.

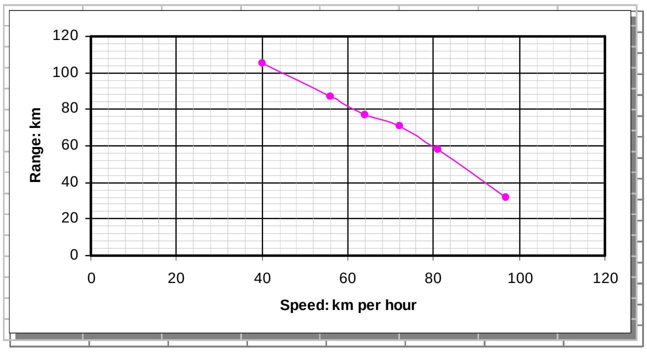

**Figure 6: kilometric range versus speed**

The specified range varies from 30 km (at maximum speed) to 100 km (for 40 km per hour).

The charger has a maximum power of 1.5 kW. The battery charge time is around three hours in standard mode, and 5 hours if additional charge balancing is necessary.

## 1.3. Monitoring

We installed a monitoring system in our Vectrix scooter.

For example, the battery current evolution versus the scooter speed is presented below.

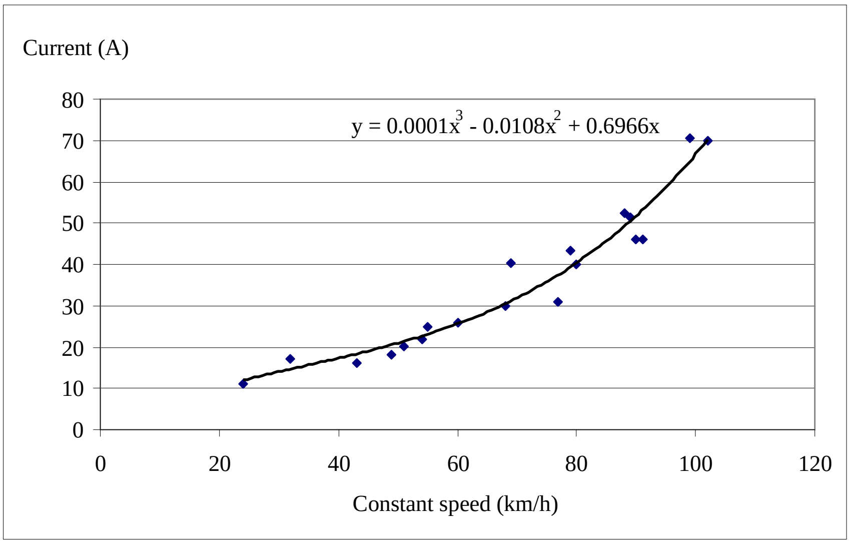


**Figure 7: battery current versus scooter speed**

The wheel resistance is a constant so the corresponding power and the battery current are linear functions of the speed. The wheel resistance would correspond to a constant range.

The aerodynamic force is a function of the square of the speed, so the corresponding power and the battery current are cubic functions of the speed. Because of aerodynamic force, the range decreases rapidly with speed.

# 2. Power electronic

## 2.1. Motor

The motor is a magnet synchron one, with a reduction integrated at the wheel level.

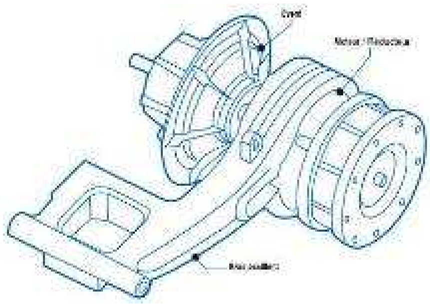

**Figure 8: electric motor and reduction**

**Figure 9: electric motor and reduction integration**

The inverter is connected directly to the 125 volts battery. There is no contactor to open the circuit. The voltage is low, but IGBT are used, and not MOSFETs.

There are no high voltage contactors. Battery is connected continuously.

After been disconnected of the battery for maintenance, an external precharge tool is necessary to reconnect the battery.

There is no 12V battery for accessories. It has a cost and space interest, but a security impact.

In case of converter failure or fuse disconnection, there is no power for lights or warning indicators. It is dangerous mainly at night.

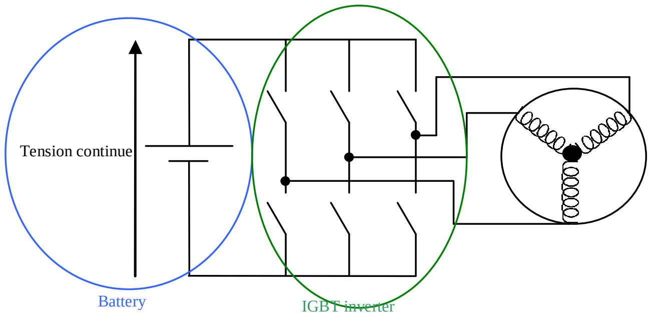


**Figure 10: inverter connection**

The inverter is very compact. To provide this low volume, there is no electrolytic or film power capacitors, but MURATA ceramic capacitors. This technology of ceramic capacitor is used for KERS (kinetic energy recovery systems) in Formula 1.

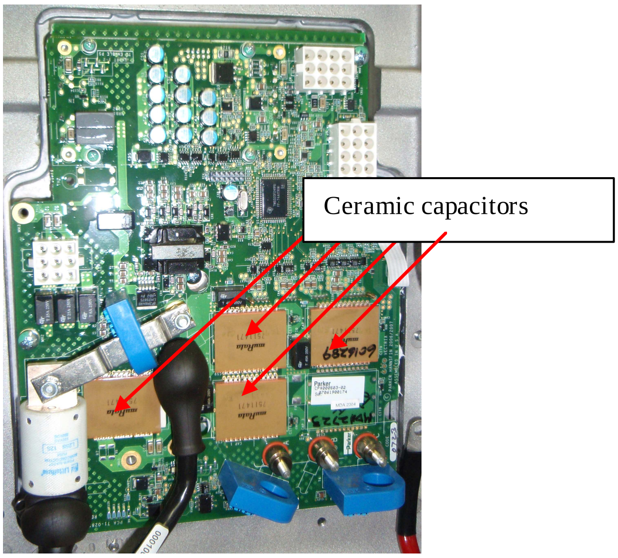


**Figure 11: ceramic decoupling capacitors of the inverter**

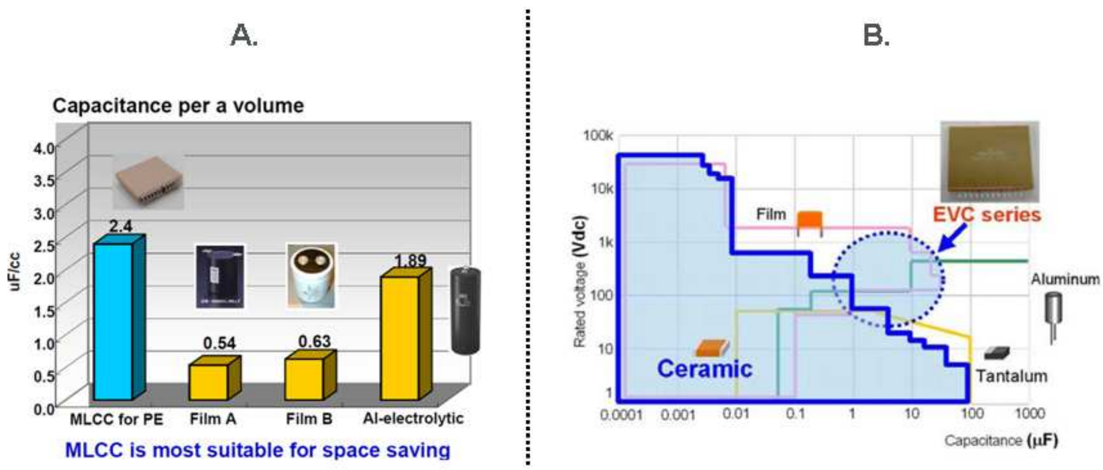


**Figure 12: comparison between chemical, polypropylene and ceramic capacitors**

Ceramic capacitors provide space and weight saving compared to chemical and polypropylene ones.

The main drawbacks are cost and the possibility of failure mechanism of the ceramic.

In Vectrix scooter, a fuse is associated in series with each capacitor to disconnect the capacitors in case of short circuit failure because of ceramic breakdown.

## 2.2. Reliability results

After one year of use, two of three scooters have failed.

Initially, the scooter fuse is undersized for the application. It's a 125 Amps one for 200A maximum current. Failure appears after one year on two scooters. Because there is no 12V battery or specific fuse for 12V auxiliaries' converter, the fuse opening may be dangerous. All the electricity and lights are lost.

Now Vectrix use 200 Amps fuses.

After one year, one of the batteries has lost half of its capacity. There is no problem on others batteries.

# 3. Battery performances

## 3.1. Battery discharge

For fast discharge, the real battery capacitance is lower than the specification for electrochemical reason, and the voltage is lower because of the internal resistance of the battery.

For example, a 30 Ah battery provides only 24 Ah for 90 Amps discharge.

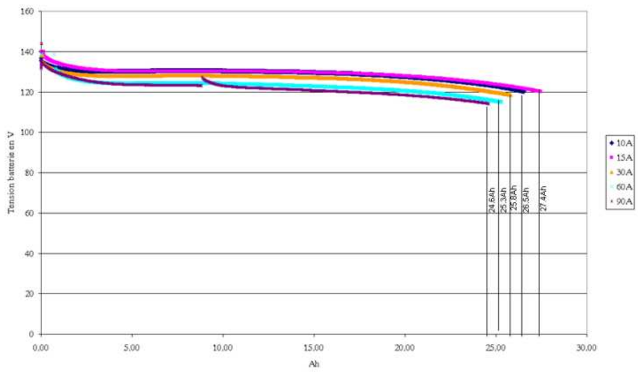


**Figure 13: Battery discharge curves**

The energy versus current is presented below:

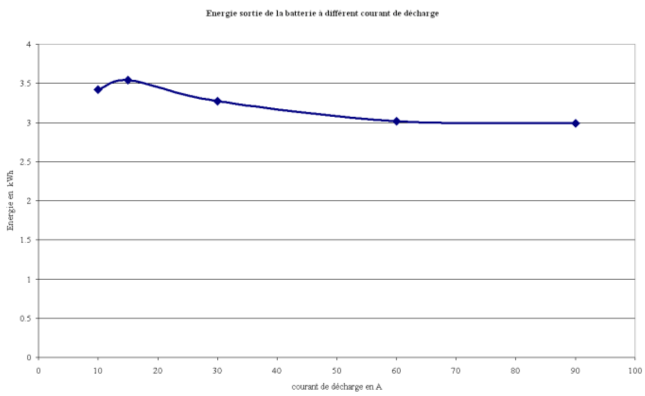


**Figure 14: Energy versus discharge current**

The battery is specified 3.7 kWh, in real use the energy is around 3 kWh because of the high rate discharge in accelerations.

# 4. Conclusion

Vectrix scooter is a very interesting electric vehicle at the state of the art of the technology:

- magnet synchronous motor integrated in the rear wheel with reduction,
- high power very compact IGBT inverter with ceramic capacitors and DSP driver,
- powerful fast charger,
- good integration of all the power electronic.

Vectrix scooter is a pure electric vehicle with an optimized mechanical design around the battery. It is not the electrification of a thermal vehicle.

The cost including the battery (7500€) is very correct compared to electric cars and is an example of order of magnitude to estimate cost for micro cars (15k€) and for light cars (800-900kg and 20k€). If the weight of the car is around 1.6 tons as the electrification of standard thermal vehicles produced now, the cost is twice.

Magnet synchronous motors are the best solution for the urban vehicles because of the high number of acceleration and deceleration with a high level of torque. Others motors need additional losses to create internal magnetic field with excitation or induction current. These losses have little impact at high power and/or low torque, but the efficiency decrease at low power at high torque.

For train, there is little efficiency difference between induction asynchronous motors and magnet ones because the train uses mainly the motor at full power. For electric cars or scooters, which are urban vehicles, magnet motors have a great advantage for efficiency and to increase vehicle range.

Vectrix scooter and the AX car have the same nominal power (10 kW) and maximum power (20 kW), with the same voltage 120-130 V. But because of difference between the sizes of the batteries the solicitations are very different. The maximum discharge current of 200 A corresponds to 2C for AX battery and 6.5C for Vectrix battery.

The NimH batteries are a first solution for scooter battery but with high weight, and the obligation to design the scooter for this high weight. We have some doubt about reliability of the battery because of the failure of the battery of one scooter between three ones after one year. The reason of this failure may be important part of high speed or climbing driving with high battery current.

For NimH battery the end of charge estimation and state of charge gauge is difficult. The classic criteria, negative dV/dt and temperature rise depend on temperature. If the battery is hot there is no negative dV/dt information. The only end of charge information is temperature rise. For NimH battery, the end of charge is an overcharge to balance the cells in series with total energy dissipation in the charged cells and cells temperature rise. Fast charge in one hour or two is necessary to have a sufficient temperature rise for detection.

On the scooter, the gauge is mainly coulombmetric, with current integration at charge and discharge. The main charge strategy is to recharge to compensate the discharge in accordance with the gauge information with a 5% constant overcharge.

At storage, NimH battery has an internal discharge. The gauge estimates this discharge.

The replacement of NimH battery by LiFePO4 provides:

- less weight, around half the weight for the same energy, or higher energy in the same volume,
- no internal discharge,
- no overcharge for cells balancing (interesting for efficiency and reliability),
- a more precise coulombmetric gauge for rang estimation,
- full range after storage.

In storage, NimH battery loses energy and the gauge losses estimation is difficult. It's a weak point for electric tools application or for scooter application. With Lithium, after storage the electric tool or the vehicle can drive immediately, without charging. It's a very interesting point to be able to use the tool or to drive after storage without charging loss of time and gauge dysfunction risk.

# 5. Literature

[1] Chatroux D., Béranger B., Fiette S., Perrin M., Fernandez E., Fiette S.: Performance improvement of a small car with LiFePO4 batteries PCIM2010 Nurnberg