Performance improvement of a small car with LiFePO4 batteries

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Abstract:

In 2009, a presentation was done in PCIM about the experience feedback on electric vehicles of the French car fleet and the cost of battery use in this application. The initial expensive price of NiCd batteries, combined with poor cycles endurance, induce a kilometric cost two to three times higher than the one of traditional gasoline vehicles.

The replacement of the initial NiCd battery of an AX vehicle by an iron phosphate Lithium battery with 1600 small cells was presented in conclusion [1].

This presentation is focalized on the improvements of the vehicle performance due to this power iron phosphate Lithium ion battery.

I. Introduction

Nearly 10.000 electric vehicles have emerged from the French car fleet during these 15 last years. The initial expensive price of the NiCd batteries, combined with poor cycles endurance, induce a kilometric cost two to three times higher than the one of traditional gasoline vehicles.

To be competitive with thermal vehicle the cost of stored/restored energy must be lower than 0.5 €/kWh.

In CEA-LITEN, an AX from Citroën is used for vehicle monitoring and NiCd battery replacement by Lithium ion ones.

This car was chosen because of its low weight. Its one of the lightest car produced. With 280 kg of the battery, the global mass is less than a ton (950 kg).

For electric vehicle, a small weight is one of the key points to minimise the battery size and cost.

The CEA-LITEN has been working for 9 years on Iron Phosphate Lithium battery technology.

The LifePO4 technology provides a lower energy density than others Lithium ion batteries, but a high level of intrinsic safety.

This chemistry has a very good level of intrinsic safety because of phosphate thermal stability compared to regular Lithium battery for laptops. These batteries use Cobalt Oxide Lithium ion battery. This chemistry proves low thermal stability. Sufficient security level has to be provided by additional components and electronics.

Iron phosphate Lithium ion technology has a good security level and its price is going down. The performances are very good for urban electric vehicles due to the low internal resistance and high number of cycles.

The cost of wear (the cost of stored/restored energy) may become as low as 0.3 €/kWh for high volume productions and good cycling performances.

In January 2009, new battery packs are designed and installed in the AX small car. The battery packs used 1600 small power cells from A123Systems. These cells are iron phosphate Lithium ion accumulators designed for electric power tools. This marked provides now first high volume production with good quality.

The cells are installed in the same place as initial NiCd batteries, in the same plastic boxes.

II. LiFePO4 Power battery

The A123Systems accumulators are designed to provide a very high level of power corresponding to power electric tool specifications.

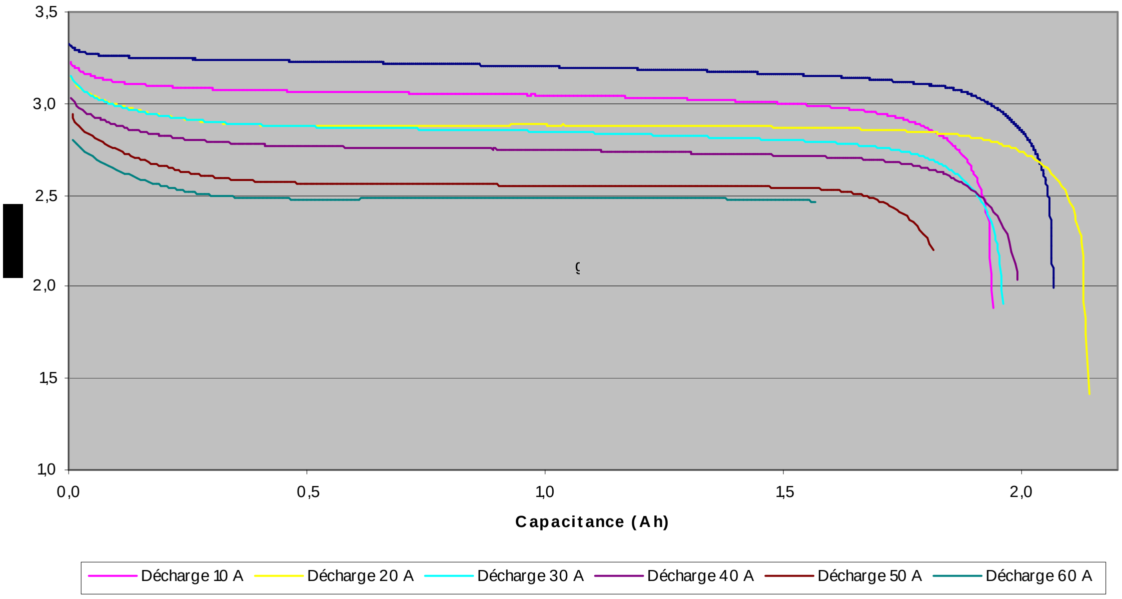


Figure 1

The cells are specified 2.3 Ah. The internal resistance is very low.

Discharge currents are specified up to 120 A for 10s.

The results of some discharge curves from 10A to 60A are presented upper.

With connections, the parasitic resistance is 10 milliohms for the 2.3 Ah cells. This low value provides low losses in charge and discharge.

With this high power LiFePO4 cells the losses are very low, so the battery packs are design without any forced air or water cooling.

LiFePO4 discharge curve is nearly constant around 3.2 Volts for standard discharge. This voltage provides a very important safety margin compared to electrolyte maximum voltage. This is a great difference compared to oxide Cobalt Lithium ion battery where the final charge voltage (4.2 Volts) is near the electrolyte maximum voltage.

III. LiFePO4 batteries

The original vehicle AX includes 3 batteries packs:

- A rear pack with 11 modules (154 kg).
- A lower front pack with 6 modules (84 kg).
- An upper front pack above the electrical motor with 3 modules (42 kg).

The total weight of the initial NiCd batteries ready to use with water cooling and electrolyte is 280 kg.

We replace this three NiCd packs by two LiFePO4 ones.
We delete the lower front pack above the electrical motor.

The water cooling circuit for NiCd batteries is deleted. The whole cooling circuit is now dedicated to power electronic system.

The energy stored is 10.5 kWh in only two packs instead of three:

- A rear pack (72 kg).
- A lower front pack (66 kg).

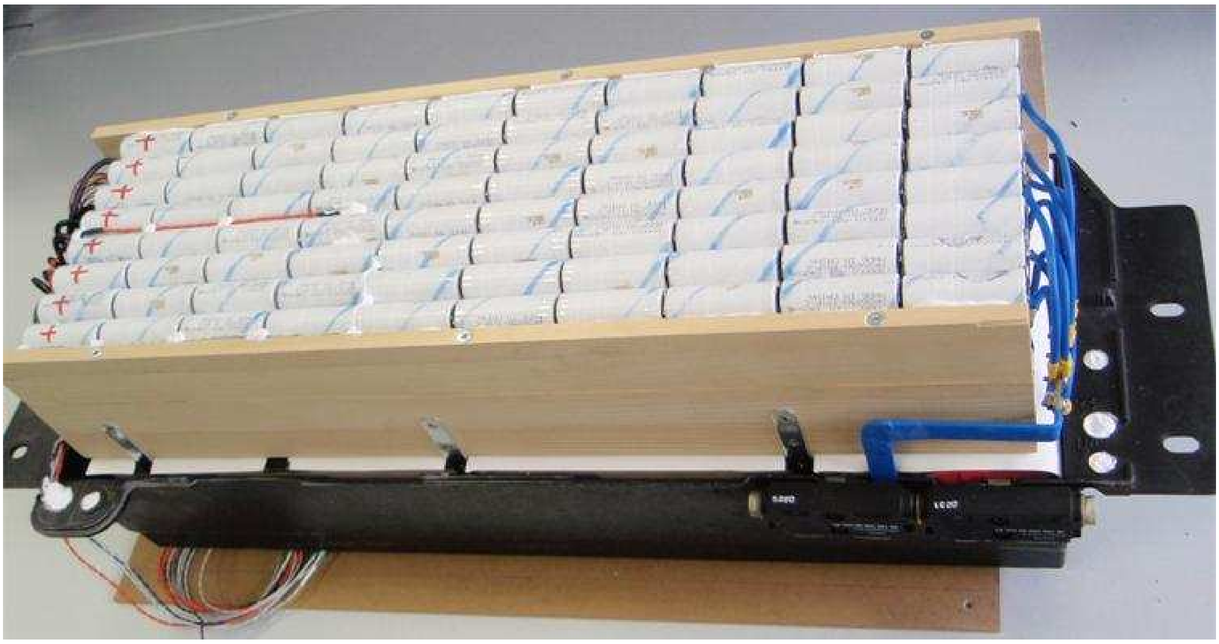


Figure 2: front pack

The new energy density is: 76 Wh/kg, including all the battery system and the packaging.

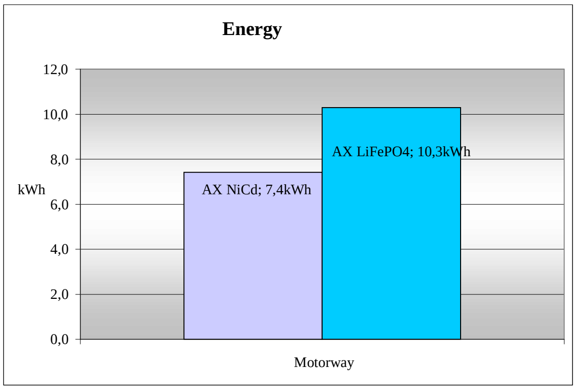
The total weight of the new battery system is less than half of original one (138 kg).

The AX mass is now 810 kg, about the same value as for a thermal engine version.

The car gives now good accelerations.

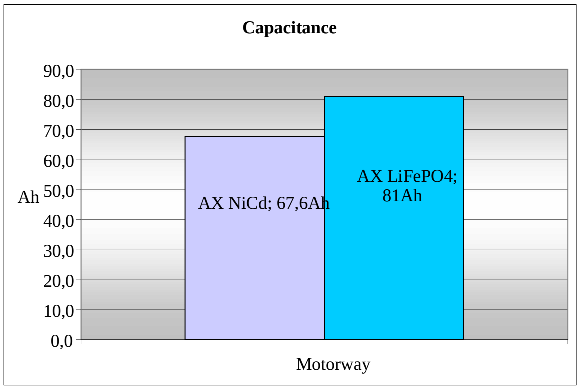
IV. Batteries energy comparison

The specified energy of the initial NiCd battery is 12 kWh, but in use on road or motorway the real energy is only 7.4 kWh for our car. This result is due to the discharge rate of the battery in real use (C) which is more important than the discharge rate of the specification (C/3). The real energy depends on the driving conditions and on the battery (from 7.4 kWh to 9.8 kWh for different vehicles).



For the LiFePO4 battery the real energy is 10.3 kWh.

Because of the very low internal resistance, this energy is constant with a very low dependence on driving conditions.



The specified capacitance of the initial NiCd battery is 100 Ah (at C/3). In real use on road and motorway the measured capacitance is only 67 Ah (at C).

For the LiFePO4 battery, the capacitance is 81 Ah.

Because of the low voltage variation of the LiFePO4 battery, we design a battery for higher voltage than NiCd one to minimise the current losses in wiring and in power electronics.

V. Kilometric ranges and electric consumption

On road or motorway the range improvement is due to the more important energy stored. With the initial NiCd battery, the kilometric range is only 75 km. With the LiFePO4 battery, the kilometric range is 110 km.

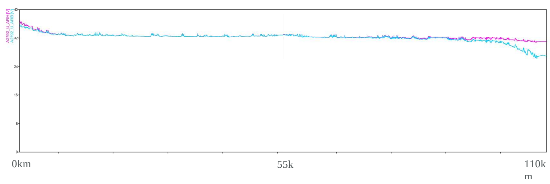
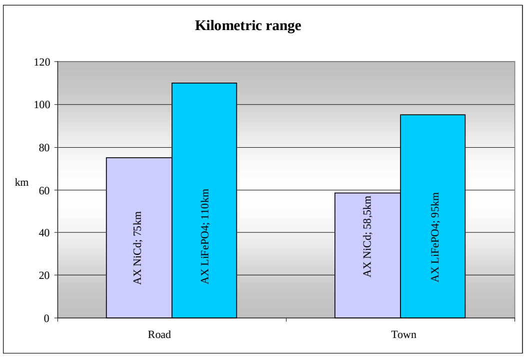
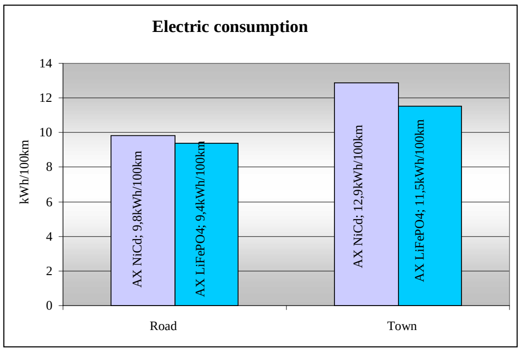


Figure 3: rear pack voltages (on road)

The upper figure present the two mid rear pack voltages for a road driving.



In the city, the improvement is due to the more important energy stored and the light weight of the vehicle. With LiFePO4 battery, the vehicle weight decrease is 140 kg. The kilometric range improvement is 38 km (95 km compared to 57 km).

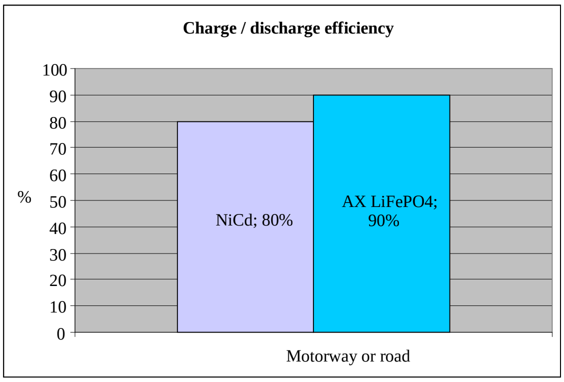


On road or motorway, the electric consumption for the vehicle with LiFePO4 battery is 9.4 kWh/100 km. It's around the same value for NiCd batteries (9.6k Wh/100 km). The weight improvement has a low impact on energy consumption at constant speed.

In the city, with LiFePO4 battery the consumption is 10.9 kWh/100 km compared to 12.6 kWh/100 km. In the city, the impact of the weight improvement is important.

VI. Battery charge / discharge efficiency

The charge / discharge efficiency is 90 % for LiFePO4 battery compared to 80 % for NiCd ones.
Losses are divided by two.



In fact, in real use, the improvement is more important. With NiCd battery there is an important overcharge for charge balancing after the charges. In real use, there is a lot of partial charge of the battery where the charge efficiency is less than 80 % due to overcharge for charge balancing.

VII. Battery cooling

The LiFePO4 battery has a very low internal resistance. The low level of losses, in charge and in discharge, allows having no additional cooling circuit.

Without any cooling circuit, the temperature rise is only 2 ℃ for a motorway drive in 50 min, and 3 ℃ in a city drive for the same time.

VIII. Fast charge

A lot of Lithium ion accumulators are specified as power ones. The gravimetric and volumetric power densities are specified. <u>But these specifications are for discharge only</u>. And the fast charge isn't really specified.

For a lot of Lithium ion technologies, fast charges are forbidden because of security aspects. Compared to maximum voltage the safety margin is not sufficient for fast charging, or the too high internal resistance provides a too high level of losses compared to maximum temperature rise.

With high power LiFePO4 Lithium ion battery fast charging is allowed because of the great voltage safety margin and of the intrinsic security.

A123Systems specified a 10 Amps charge current for 2.3 Ah cells (around 4-5 C).

We do a first fast charge test for the rear AX pack.

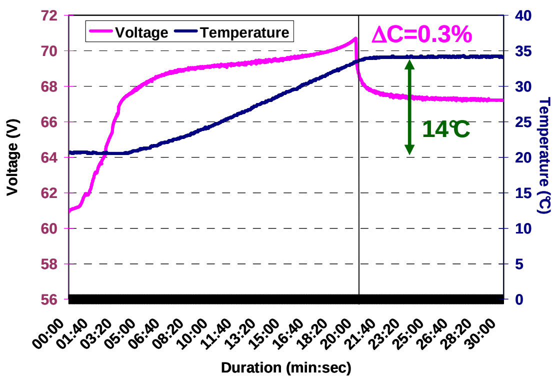


Figure 4: 250 Amps fast charge

A C/2 discharge is done to measure the charge stored in the battery.

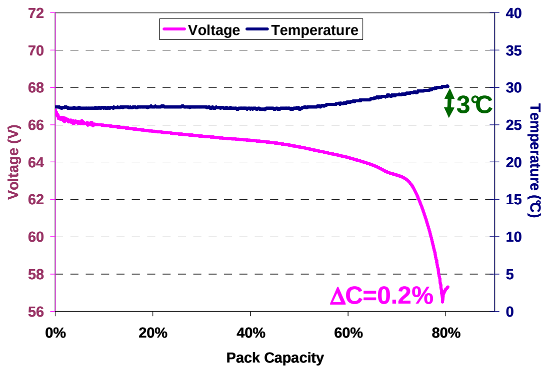


Figure 5: C/2 Discharge after fast charge

An 80% fast charge is done in 20 minutes. The current is 250 Amps.

The temperature rise is only 14℃ because of the low internal parasitic resistance.

In fast charge the thermal behaviour is mainly adiabatic. Thermal losses are stored in the battery thermal capacitance. Thermal losses are dissipated after. The thermal constant is around some tens of hours.

Because of the high production quality, the charge dispersion between the accumulators in series is only 0.3%. This is a very good result. Cells charge balancing circuit losses are very low because of this very low dispersion.

IX. Conclusion

The LifePO4 technology provides a lower energy density than others Lithium ion batteries, but a high level of intrinsic safety.

We design a battery with 1600 high power small cells in two existing packaging of a small light car.

Because of the low internal resistance, the totality of the energy is accessible. Energy recovery during braking and downhill is efficient. The 140 kg weight improvement is important for acceleration performance and city electric consumption.

With the initial NiCd battery, the kilometric range on road is only 75 km. With the LiFePO4 battery, the kilometric range is 110 km.

In the city the kilometric range improvement is 38 km (95 km compared to 57 km).

The standard charge / discharge efficiency is 90 % for LiFePO4 battery compared to 80 % for NiCd one. Losses are divided by two.

The low level of losses, in charge and in discharge, allows having no additional cooling circuit. The temperature rise is only 2 ℃ for a motorway drive in 50 min, and 3 ℃ in a city drive for the same time.

In fast charge, with 250 Amps at 80% charge is done in 20 mn. In this case, the temperature rise is only 14℃.

The initial NiCd battery suffers from memory effect. In case of partial discharge, memory effect limits the effective range. So it's necessary to discharge totally the battery before recharging. This limitation is very difficult to manage for a collective fleet with different drivers. For Lithium ion battery, there isn't memory effect. So it's possible to recharge at the plug after each drive. This is a very important advantage for a collective fleet, and the total range is so available.

For electric vehicle, a small weight is one of the key points to minimise the battery size and cost.

Iron phosphate Lithium is a good candidate to provide a high performance, fast charge, low losses battery with a good level of intrinsic security.

In case of high volume production the cost of stored/restored energy should be lower than 0.5 €/kWh and so be competitive compared to thermal vehicles

X. References

[1] Bruno Béranger, Daniel Chatroux, Eric Fernandez, Sébastien Fiette: Experience feedback on electric vehicles of the French car fleet – battery impact PCIM2009 Nüremberg