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# Dynamic behaviour of Li batteries in hydrogen fuel cell power trains

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ABSTRACT

A Li ion polymer battery pack for road vehicles (48 V, 20 Ah) was tested by charging/discharging tests at different current values, in order to evaluate its performance in comparison with a conventional Pb acid battery pack. The comparative analysis was also performed integrating the two storage systems in a hydrogen fuel cell power train for moped applications. The propulsion system comprised a fuel cell generator based on a 2.5 kW polymeric electrolyte membrane (PEM) stack, fuelled with compressed hydrogen, an electric drive of 1.8 kW as nominal power, of the same typology of that installed on commercial electric scooters (brushless electric machine and controlled bidirectional inverter). The power train was characterized making use of a test bench able to simulate the vehicle behaviour and road characteristics on driving cycles with different acceleration/deceleration rates and lengths. The power flows between fuel cell system, electric energy storage system and electric drive during the different cycles were analyzed, evidencing the effect of high battery currents on the vehicle driving range. The use of Li batteries in the fuel cell power train, adopting a range extender configuration, determined a hydrogen consumption lower than the correspondent Pb battery/fuel cell hybrid vehicle, with a major flexibility in the power management.



## 1. Introduction

Current means of transportation are strongly dependent on oil-derived fuels, therefore the possible troubles associated with oil price fluctuations and supply scarcity need to be faced. In addition, their contribution to global anthropogenic emissions of $CO_2$ is widely recognized. These issues justify the strong interest of research towards new fuels and innovative propulsion systems, in particular different typologies of hybrid electric vehicles present huge potentialities in terms of efficiency and emission control [1]. In this context the hybrid vehicles which adopt an internal combustion engine in addition to an electric drive have already demonstrated their potentiality in having a significant impact on the light duty vehicle market. Furthermore, the hydrogen fuel cell technology has been gaining much attention in recent years as it offers the great advantage to assure the high efficiency and local zero emissions typical of battery powered electric vehicles, improving at the same time their driving range.

In a fuel cell propulsion system the electrochemical generator can be used as the unique power source on board, but the most reliable solutions include the support of electric energy storage systems, such as batteries and/or supercapacitors. Even if the driving range of a fuel cell vehicle depends on the quantity of hydrogen stored on board, the possibility of adopting high performance batteries, such as lithium based systems, is of great interest for range extender hybrid solutions [1,2].

Lithium metal is attractive as battery anode material mainly due to its lightness and high voltage, in spite of some concerns of safety hazard, due to the metal high reactivity. For this reason, in the so-called lithium-ion batteries, both positive and negative electrodes employ lithium “host” compounds, where an intercalation process occurs. In these systems the lithium ion conducting electrolyte is based on a solution of a lithium salt in organic solvents [3], which is not the best solution in terms of safety. Therefore for automotive applications the so-called lithium polymer batteries seem more suitable, since they adopt a solid polymeric electrolyte to transfer lithium ions between the electrodes [4]. The absence of liquid phases facilitates the construction of leak-proof and lightweight containers, which represents an additional advantage for automotive applications.

The most recent developments in this field have been focused on the possibility of reaching very high energy and power densities by using new types of anode, in particular, it has been found that a Si–Li alloy presents a theoretical specific capacity of 4200 mAh $g^{-1}$, to be compared with 371 mAh $g^{-1}$ of graphite [5,6]. Electrode pulverization phenomena associated with the alloy formation, and the consequent limitation of cycling capability, have led to the research of different solutions, mainly based on reduction of metal particle size down to nanoscale [7,8], utilization of composite materials (in which an inactive component added to the active metal acts as

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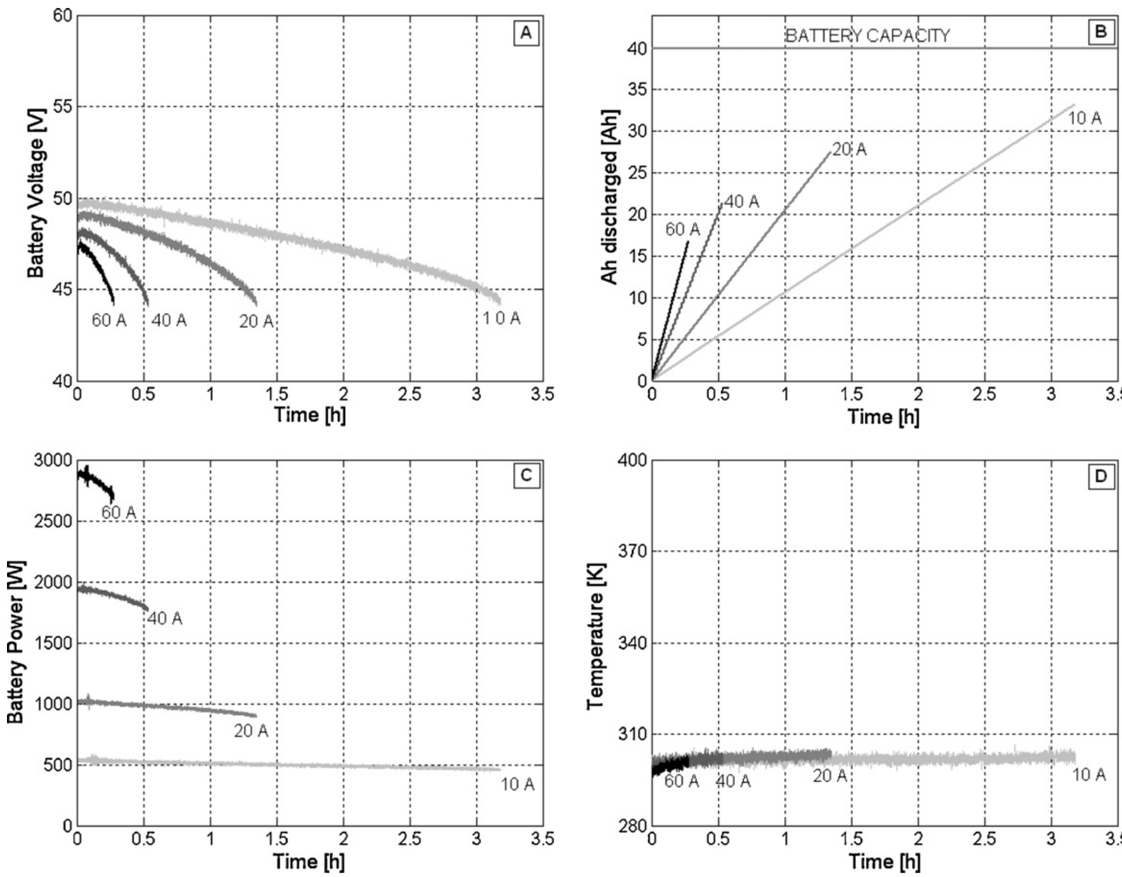


**Fig. 1.** Discharging test on Pb acid battery pack (48 V, 40 Ah) at different current values. (A) Voltage, (B) Ah discharged, (C) power supplied and (D) battery temperature as function of test length.

a buffer for volume variations) [9,10] or metal hydrides as anode [11]. The researches about the cathode are intensively oriented on high voltage spinels and high capacity layered lithium metal oxides [12–15].

Even with reference to the current technology the lithium polymer batteries represent the state of the art in the field of electric energy storage systems, since they are characterized by very interesting values of the basic electrochemical parameters [5]. Nevertheless storage capabilities able to assure a satisfactory driving range to battery electric vehicles have not yet been reached [16].

The aim of this paper was to compare the behaviour of Li ion polymer with Pb acid battery packs when they supply a hybrid fuel cell power train, working in dynamic conditions representative of actual road load requirements. Both battery packs were characterized in charging/discharging test cycles at different constant current values. The same types of batteries were integrated in a fuel cell power train for moped application, which was installed on a laboratory dynamic test bench. Experimental tests were performed on different load cycles varying acceleration/deceleration rates and duration, in order to obtain indications about fuel economy and dynamic behaviour issues associated with the utilization of those types of batteries in hydrogen fuel cell vehicles.

## 2. Experimental

The lithium based storage system used in the present work was a lithium ion polymer battery composed by a graphite based anode, a $Li(NiCoMn)O_2$ based cathode and a $Li^+$ cconducting polymer electrolyte as separator. The battery pack was provided by EiG Battery and its main characteristics and recommended operative conditions are reported in Table 1 in comparison with those of a Pb acid battery pack, provided by Exide Technologies. The lithium and lead battery packs were tested in charging/discharging cycles respecting the recommended values of maximum voltage in charging (54 V for both Li and Pb) and minimum voltage in discharging (39 V for both Li and Pb), in order to avoid battery damages. For these tests the current values for charging and discharging phases were set in the range 4–60 A, compatible with the dynamic conditions required by automotive applications.

The experimental tests with the fuel cell power train were performed using the propulsion system already described in Ref. [17], whose main characteristics are reported in Table 2. It was constituted by fuel cell system (FCS), DC–DC converter, electrical energy storage system, electric drive, and data acquisition systems. The FCS was based on a 2.5 kW PEM stack fuelled with compressed pure hydrogen. The electric drive was based on a LAFERT brushless engine of 1.8 kW nominal power, equipped with a controlled

**Table 1**
Main characteristics of Pb and Li battery packs.

| | Lead battery pack | Lithium battery pack |
|---|---|---|
| Nominal voltage | $4 \times 12$ | 46.8 |
| Nominal cell voltage | 2.0 | 3.6 |
| Number of cells | 6 | 13 |
| Capacity | 40 Ah | 20 Ah |
| Energy | 1920 Wh | 936 Wh |
| Specific energy | 33 Wh kg$^{-1}$ | 105 Wh kg$^{-1}$ |
| Energy density | 99.25 Wh l$^{-1}$ | 130 Wh l$^{-1}$ |
| Operating temperature | −20 +50 °C | −30 +50 °C |
| Weight | 57.6 kg | 8.9 kg |
| Cycle life | 500 cycles | 1000 cycles |
| Accessories | – | Auxiliary cooling fan |