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High power battery systems for hybrid vehicles☆

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Abstract

Pure electric and hybrid vehicles have differing demands on the battery system of a vehicle. This results in correspondingly different demands on the battery management of a hybrid vehicle. Examples show the differing usage patterns. The consequences for the battery cells and the battery management are discussed. The importance of good thermal management is underlined. © 2002 Published by Elsevier Science B.V.

Keywords: Battery; Hybrid vehicles; Power sources

1. Hybrid vehicles

Hybrid vehicles are vehicles with more than one power source. Most hybrids use gasoline or diesel and an electrochemical battery as their energy sources. An internal combustion engine (ICE) and an electric motor provide the motive force. During braking the electric motor can recuperate energy to be stored in the battery. The battery can be charged during driving, when the ICE can produce more power than necessary for the vehicle propulsion. There are many different types of hybrid vehicles, but in general the consequences for the battery are the same for all of them.

In the early 1990s the Swatch Group started to exploit its broad experience in micro technologies for the development of alternative propulsion systems. Since then Traction Engineering, a company of the newly formed Swatch Group automotive division SMH-Automobile, has worked on the conception, layout, production and testing of hybrid systems and vehicles.

In the past, hybrid vehicles were often modified electric vehicles, with the combustion engine added to increase the daily range and as a last resort power source to be sure to arrive home. These vehicles, also known as range extender hybrids, have large capacity batteries with the resulting low internal resistance and high power.

Because of the high prices of traction batteries efforts have been made to reduce the size of the vehicle battery pack. This has led to the so-called low storage requirement (LSR) hybrid. This reduction in battery size has large consequences for the battery and its utilization. The batteries with their small capacity must fulfill the same requirements for low internal resistance and high power as the large electric vehicle batteries [1].

2. Comparison of pure electric and hybrid electric vehicles

The Figs. 1 and 2 show typical battery usage of pure electric and LSR hybrid vehicles. The data is taken from actual street driving with a LSR series hybrid. The upper portion of each diagram shows the vehicle velocity and the electrical power applied to the wheels. The lower portion shows the power drawn from the battery and the power supplied by the power generating unit (PGU) of the vehicle. For the pure electric vehicle the power from the PGU is, of course, zero. Negative power is regenerated during braking.

Common to the two diagrams are the peaks during acceleration (positive) and braking (negative). The difference, however, is that for the hybrid vehicle, after the initial acceleration peak, the PGU takes over the power supply and the battery power is near zero. A further difference is that the battery is called on to absorb excess power from the PGU when the PGU reaction time is too slow. This can be seen near 3712 s on Fig. 2. The traction suddenly needs no power, but the PGU is supplying approximately 28 kW. To achieve the best fuel economy the battery must be able to absorb this excess power.

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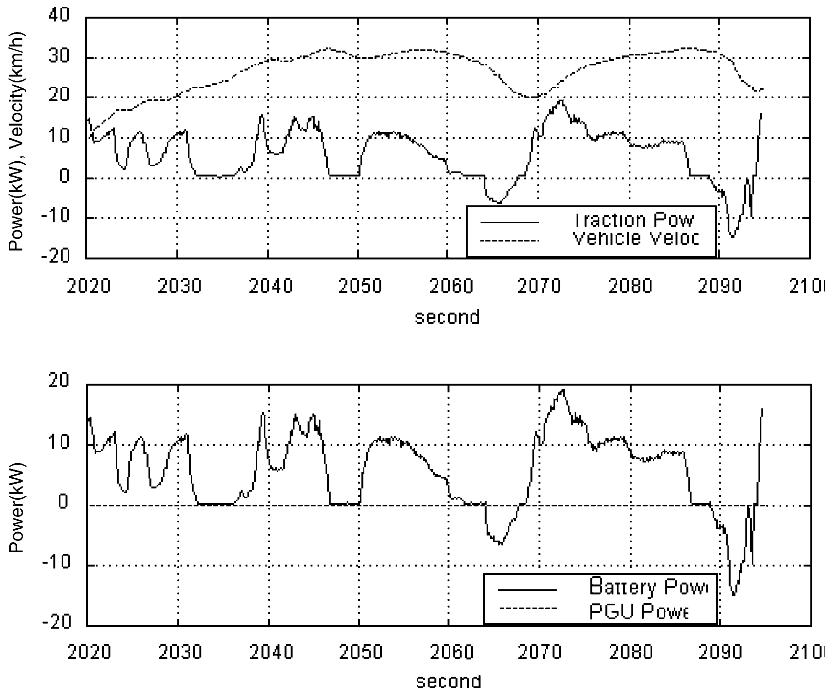

Fig. 1. Pure electric vehicle battery usage.

A difference between the pure electric vehicle and a hybrid that is not seen in the graphs above is the typical charge/discharge pattern. The battery of a pure electric vehicle is fully charged before each use in order to have the maximum vehicle range. It is also regularly discharged to a large extent. The battery of a hybrid vehicle, on the other hand, is rarely fully charged. In normal driving, the battery state of charge (SOC) is kept between 50 and 70% in order to be able to absorb the maximum amount of energy possible during braking.

The fully autonomous strategy followed by most car makers for their hybrids also rules out charging. All the energy used is supplied by liquid fuel. The Toyota Prius, for example, has no provision for user charging. The battery

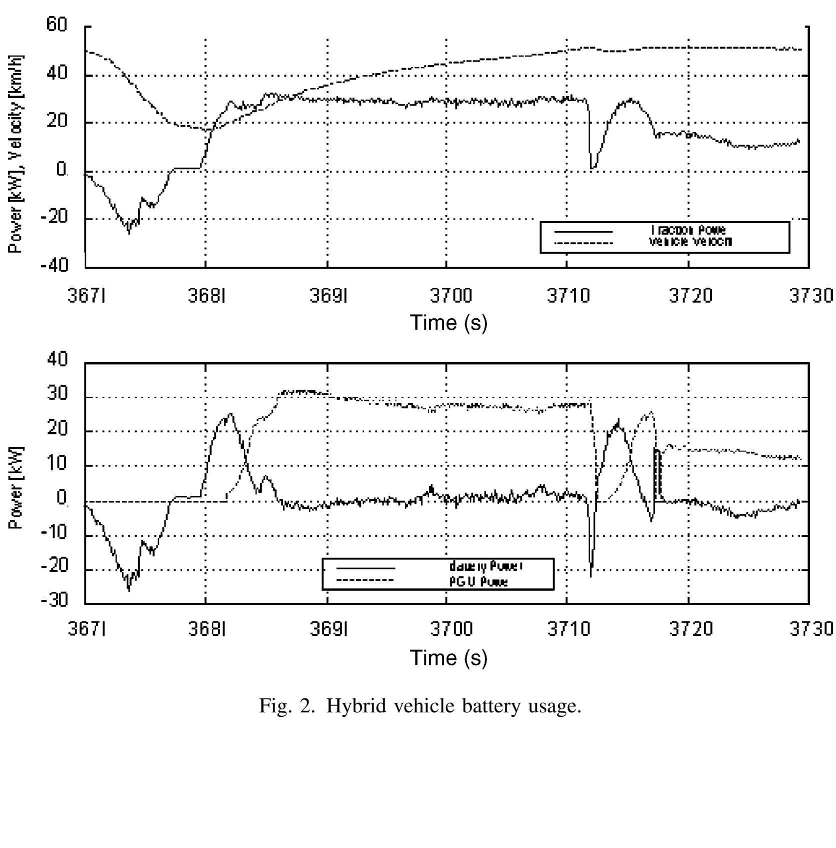

Fig. 2. Hybrid vehicle battery usage.

is only fully charged when it is serviced, at the same interval as the internal combustion engine. This is in contrast to the range extender philosophy where the battery is charged with mains current daily and is the main power source.

3. What are the consequences for the battery cells ?

1. Batteries with memory effects are deadly for hybrid vehicles as they are being used over only a small portion of their SOC range and neither completely charged nor completely discharged.
2. Batteries for hybrid vehicles need similar peak power for charging and discharging. Thus, the internal resistance of the batteries for hybrid vehicles must be similar for charge and discharge to achieve the best fuel consumption.
3. High power levels in a small capacity battery lead to very large relative currents. While in a pure electric vehicle (PEV), the peak currents are rarely over 2 C, in a hybrid electric vehicle (HEV) peak currents of over 10 C are not uncommon (for example, according to the Honda InSight data sheet a 0.8 kWh, 144 V nominal battery supplies up to 10 kW to the electric motor > approximately 15 C).

4. What are the consequences for the battery management?

4.1. Electrical management

To determine the SOC simple ampere hour counting may work for PEVs, but is totally inadequate for HEVs. However small the error of the amperage measurement, it is always existent and over the long period of time between two battery maintenance procedures will lead to large inaccuracies in the SOC. This can easily lead to catastrophic situations for the battery, overcharge or overdischarge, and poor vehicle performance. For example, it will not be possible to store the recuperation energy from braking when the ‘‘real’’ SOC is much higher than the calculated SOC [2].

Procedures for using the battery voltage to correct the SOC measurement depend directly on the cell characteristics. Extensive practical testing of the cells is necessary to know their behavior in all situations. This accounts for a major portion of the know-how of a battery pack manufacturer [3].

In a large battery pack, such as a traction battery, cell equalization is an important parameter. Fig. 3 shows the discharge curves of the battery modules in a complete battery pack. As can be seen, one module is much weaker than the others. This is a typical case of a poorly equalized battery. Today, cell equalization is most often obtained by overcharging the complete battery until even the weakest

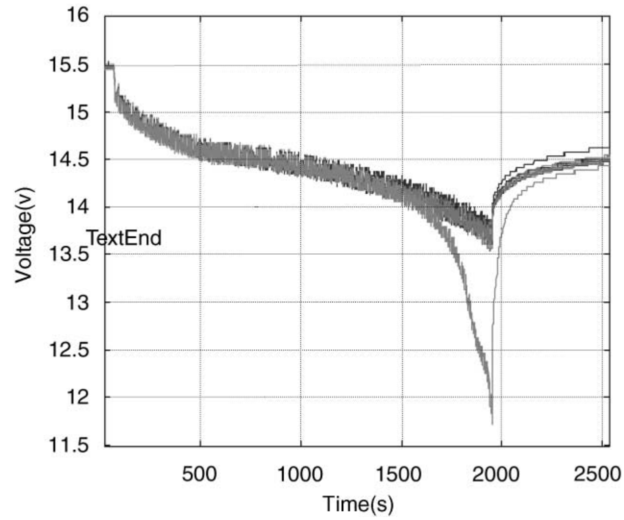

Fig. 3. Battery discharge curves.

cell is fully charged and is actually a side effect of charging. In a hybrid vehicle this is only possible at certain service intervals, for example every 15,000 km when the ICE is serviced. During normal functioning the cells must retain their equality without active measures. To this end, the cell tolerances must be very small and the temperature difference between cells must be held within very tight limits.

The electrical management of the battery must ensure that the SOC is known, the maximum and minimum voltages are respected and the charge routine correctly run and terminated for all of the cells in the battery. For certain cell technologies it must include bypass circuitry to prevent maximum voltages from being exceeded.

4.2. Thermal management

The thermal management within a battery is a much overlooked, but very important, subject for hybrid vehicles. Cell equalization problems are often due to poor temperature management. The temperature is a major influence on the internal resistance and thus, the losses of the cells. The temperature difference between the warmest and coldest cell in the battery pack is a parameter that must be closely controlled.

5. Conclusions

A high power battery system does not end at the energy storage elements themselves. To be able to use the stored energy to its fullest the battery system must include suitable battery management.

Because of the different premises of battery usage between pure electric (high energy) and hybrid vehicles (high power) the battery management of a hybrid vehicle is much more demanding.

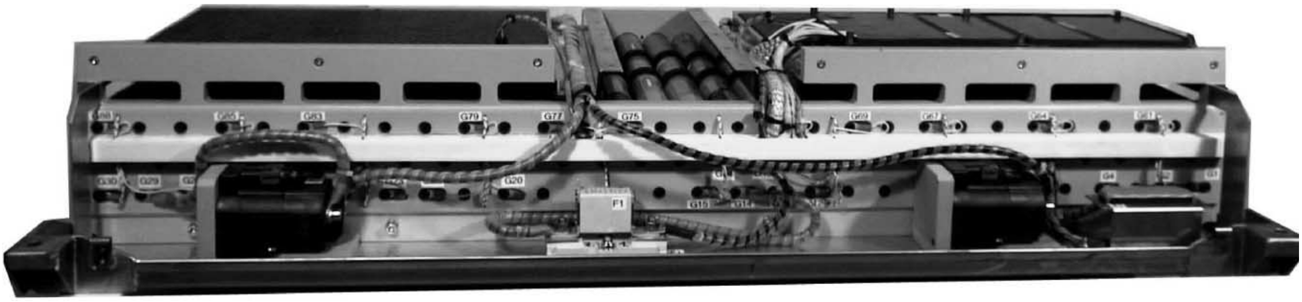

Fig. 4. A 4.1 kWh NiMH battery pack for a hybrid vehicle.

Good thermal management is necessary not only to keep the cells within their working temperature range, but also to prolong the period between equalizations.

Fig. 4 shows an implementation of a complete battery system for a hybrid vehicle by SMH-Automobile, Traction Engineering. This system features a NiMH battery, 316 V, 4.1 kWh, 40 kW including electrical battery management and optimized air cooling using Panasonic cylindrical cells and fulfilling the requirements mentioned above.

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