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BATTERIES MANAGEMENT SYSTEMS FOR AN HYBRID ELECTRIC VEHICLE TEST BANCH

BY

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Abstract. The purpose of this paper is to present an automated battery monitoring system used to monitor battery parameters in real time on a stand of hybrid electric vehicle. Battery Monitoring system (BMS) has a critical role in optimal functioning of a hybrid vehicle having different tasks like estimating state of charge, monitoring the batteries voltage during operations, estimating instantaneous available power.

Key words: battery; batteries monitoring systems; SOC; hybrid electric vehicle.

1. Introduction

Due to worldwide increased pollution in the recent years, the society is looking for environmental solutions in every area of life. The transport sector has an important contribution to the pollution so the researches increased also in this area. The currently proposed solutions are hybrid vehicles, electric vehicle, plug-in hybrid vehicle, fuel cell vehicles. In all these cases the major problem is represented by the energy storage system. An important issue that directly affects vehicle’s performance and reliability is the battery performance and

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reliability. The battery performance can be improved with a proper designed battery management system which accompanies any source of electrical energy on the vehicle.

Chemical processes that occur in the batteries causing their irreversible aging, cause a gradual reduction of the capacity that can be delivered to a point where the battery can no longer support any load. This aging process can be delayed by monitoring battery parameters and imposes some operational limits (*e.g.* state of charge cannot fall below a certain limit, the battery voltage should not exceed a certain threshold during charging, charging current is required within certain limits, etc.) (Weijun *et al.*, 2010).

The battery management system needs precise information (such as battery voltage, state of charge, charging or discharging current) to ensure optimal operation of the battery. For a more accurate estimation of the energy storage system (battery pack) is needed that each battery from the pack to be monitored. Monitoring the battery voltage and current allows in addition to the state of charge estimation, implementation of a protection function especially for Li-Ion batteries, where an increased voltage above a certain level leads to ignition of cells and for Pb batteries a sulphation process (Huang *et al.*, 2011). In order to measure each cell voltage, different solutions have been proposed (Bei & Xuezhe, 2010), the main problem being the growth of the potential as we approach to the last battery.

2. Batteries Management Systems

Battery management system should provide a range of functions such as measuring the voltage on each cell of the battery pack, the current through the batteries, ambient temperature based on which the state of charge (SOC) and state of health (SOH) of the batteries will be estimated (Plett, 2004). Also another important function is the equalization of the battery pack because each battery start from different initial SOC and reaches 100% SOC at different moments of time. The battery management system should be able to properly estimate the SOC regardless the situation the battery is running. Although there are many applications where the batteries are used the most difficult situation is met on hybrid vehicle where the battery is constrained to work in different situation: cranking, variable current discharge, regenerative breaking and constant current discharge/charge (Coroban *et al.*, 2007).

Battery management system used on a hybrid electric vehicle must ensure the following functions for each battery separately, as shown in Fig. 1 (Plett, 2004):

a) at the ignition moment the self discharge level will be tested; if it’s too big will trigger an alarm;

b) at each sampling time state of charge is estimated based on voltage, current and temperature measurements;

c) based on the state of charge of the batteries the system will estimate the maximum available power so that it does not exceed the maximum acceptable voltage or current;

d) equalization of the cells or batteries in case there are discrepancies between states of charge of the batteries.

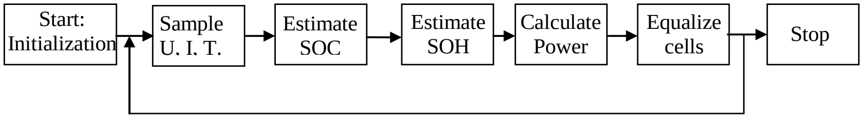

Fig. 1 – Algorithms in a HEV BMS.

The basic circuit used to monitor the batteries voltage is shown in Fig. 2. Each battery is connected in turn to the AD converter through an operational amplifier with the role of translation and adaptation of voltage signals in the range accepted by the microcontroller (0…5 V_{dc}). Connecting the battery to the measurement system is achieved through specialized circuits called photomosfet relay which ensure galvanic separation between the control and power system. Each photomosfet relay is controlled by the microcontroller, in this way is known which battery is measured. Battery management system is powered from a dc/dc power source that provides galvanic separation. Also the serial communication RS232 and CAN communication are passed through circuits which ensure galvanic separation of the monitoring system from communicating systems.

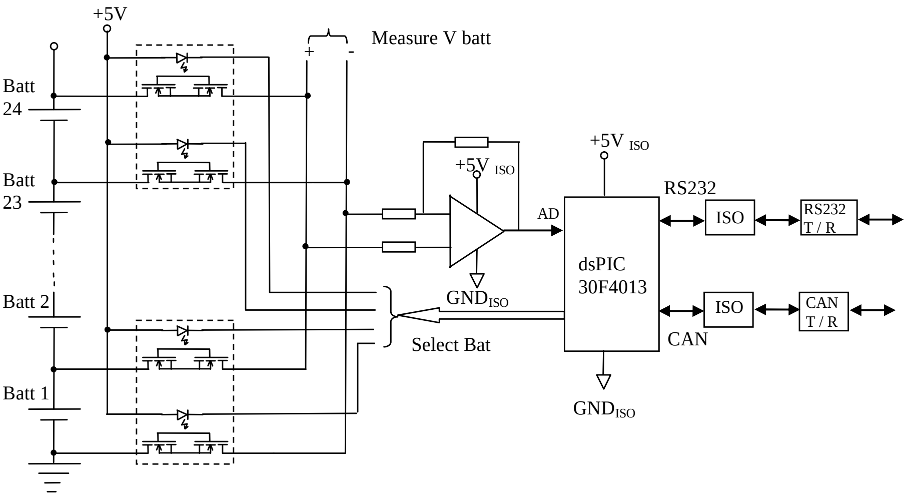

Fig. 2 – Scheme for measuring the batteries voltage.

2.1. Hardware Structure of the Battery Monitoring System

The battery management system (BMS) is designed around a 16-bit microcontroller of Microchip Company which offers the possibility to communicate the important decisions concerning the battery monitoring to the vehicle's electronic control unit (ECU) *via* CAN communication network. Also to view and analyse the data acquired a serial communication is used to communicate with the PC. The data acquired are monitored and saved with the help of LabVIEW interface as it can be seen in Fig. 3. Through the LabVIEW interface developed it can be seen the voltage on each battery and the current dictated by the dc/dc converter. There is a close connection between the battery management system and the dc/dc converter in terms of data flow exchanged between these systems, because the battery pack is connected to the vehicle's dc network *via* dc/dc converter.

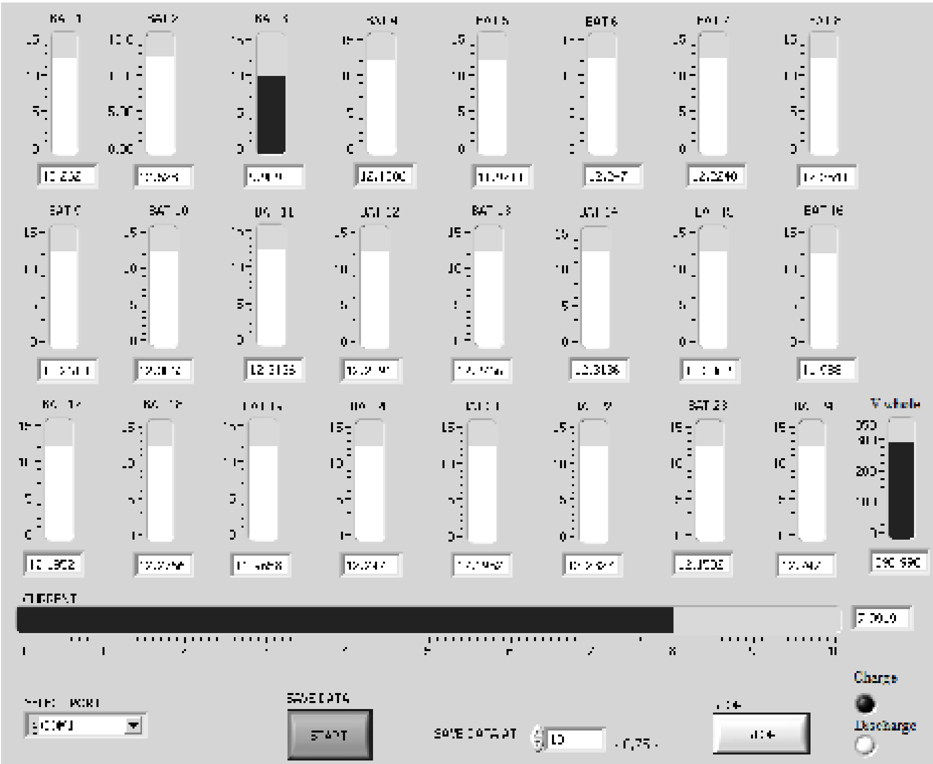

Fig. 3 – BMS LabVIEW interface.

The microcontroller system is one designed to monitor the voltage on each battery and to estimate the state of charge and state of health of each battery. Depending on the state of charge the BMS prescribes to the dc/dc converter the maximum charge or discharge current. A block diagram of the BMS integrated on the hybrid vehicle bench can be seen in Fig. 4.

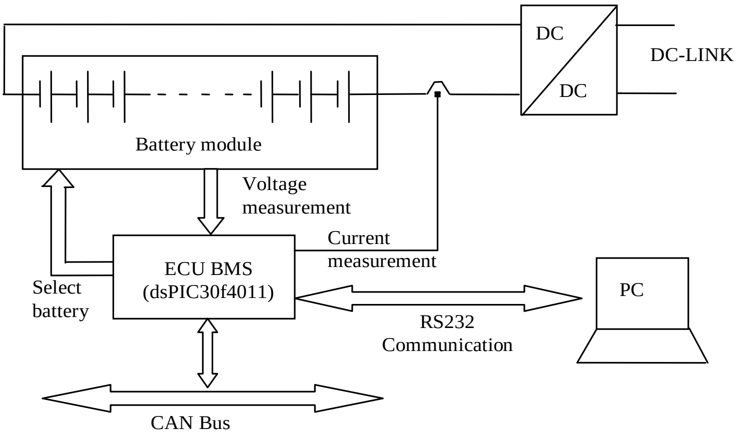

Fig. 4 – Block diagram of BMS.

2.2. State of Charge Determination

The presented battery monitoring system ensures the acquisition of the system's variables like voltage or current based on which the state of charge of the batteries can be estimated. State of charge is an important variable in the operation of a hybrid vehicle providing estimation of the available energy on the vehicle in any moment and also increasing the battery life through exploitation in certain ranges. Corban *et al.* (2007) identify the operating states of the energy storage system on a hybrid vehicle by: constant current charging, relaxation after charging, charging through recuperative braking, discharging at constant current, variable discharge current, cranking discharge. If the battery capacity is expressed as the amount of current supplied in a specific time interval (Amper-Hour), then the state of charge is defined as

$$\mathrm{SOC} = \frac{\mathrm{Available\_capacity\ [Ah]}}{\mathrm{Rated\_capacity\ [Ah]}} \cdot 100,\ [\%]. \quad (1)$$

There are many methods for estimating the state of charge (Vasebi & Bathaee, 2008) each with advantages and disadvantages. In this paper the current integration method is used to estimate the amount of energy gained or lost. It's been preferred this method because it is not influenced by chemical stabilization processes taking place in the battery with large time constants (hours) and can be used for dynamic processes met on hybrid vehicles.

According to this method state of charge is defined as

$$\mathrm{SOC} = \mathrm{SOC}_0 + \frac{\int_0^t i(t)\mathrm{d}t}{C_n} \cdot 100\ [\%], \quad (2)$$

where SOC_0 is the initial state of charge based on open circuit voltage (OCV), *i*(*t*) – the charged current (positive) or discharge current (negative), C_n – the rated battery capacity.

The algorithm used in this paper (Fig. 5) starts from an initial value estimated based on the open circuit voltage, voltage that has a linear variation (Fig. 6) compared with SOC for a Pb battery (a lookup table method has been implemented). The initial state of charge is dictated by the open circuit voltage. When a charge or discharge current is detected, the algorithm applies the current integral method. At the end of the charging or discharging process the last value of the SOC obtained through integral method is saved in the nonvolatile memory of the microcontroller. We have to keep in the memory the last data because after a process of charging or discharging the battery takes place a long stabilization process, so the SOC estimated based on OCV is not very precise.

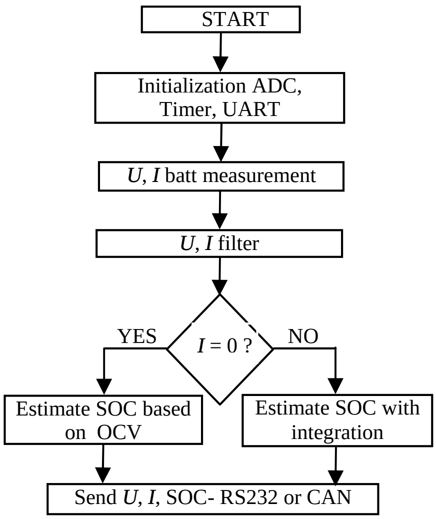

Fig. 5 – SOC estimation.

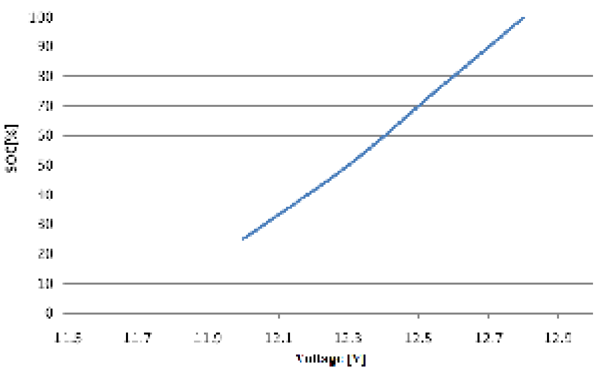

Fig. 6 – State of charge *vs.* OCV for a Pb battery.

3. Experiment and Results

Battery monitoring system has been tested on a 24 lead acid batteries pack with a rated capacity of 40 Ah, batteries that are integrated on the hybrid electric vehicle test bench. With the help of the design BMS the voltages and states of charge of the batteries have been monitored during charging and discharging. As seen in Figs. 7 and 8 we were able to identify the broken batteries (increased internal resistance, overcome life) for which the OCV (open

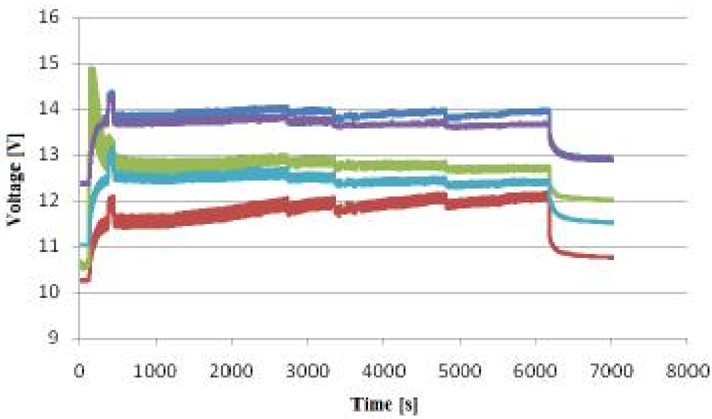

Fig. 7 – Batteries voltage evolution for a charging cycle.

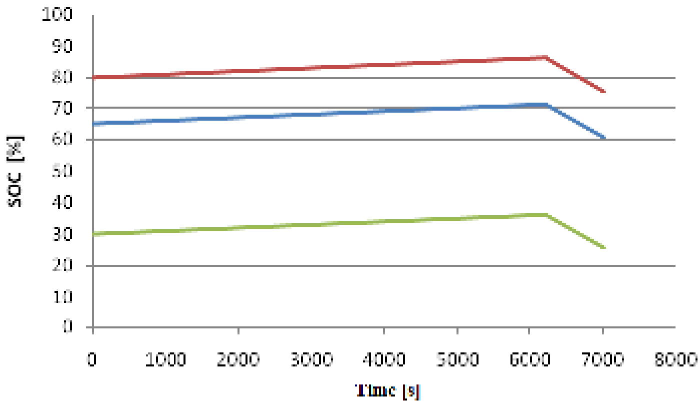

Fig. 8 – SOC evolution for a charging cycle.

circuit voltage) had unacceptable low values (below 12 V) and state of charge was below 50% (value not recommended by the manufacturer). The battery monitoring system allows estimating the maximum power available in any moment in the energy storage system, value which is absolute necessary for the driving algorithm of the hybrid vehicle. In Fig. 9 it can be seen the battery monitoring system integrated on the hybrid electric vehicle stand.

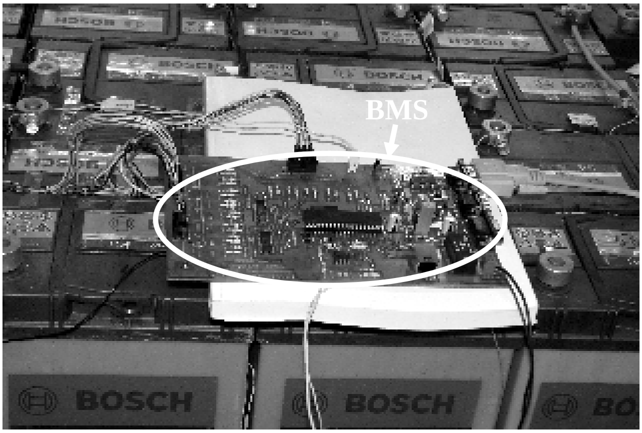

Fig. 9 – BMS integrated on the hybrid vehicle stand.

4. Conclusions

Battery monitoring system plays an important role in the life of the batteries and their protection, and for accurate information regarding the state of charge of each battery we have to monitor each battery separately. A battery management system must be very precise and be able to estimate the state of charge in any operating mode. The proposed system can be used to measure a large variety of batteries like lead acid, NiMH, Li-Ion, Li-Polymer. As seen in the presented graphs not all the batteries in the pack have the same SOC.

A further improvement of the proposed BMS will consist in development of a BMS with a potential equalization function (cell balancing), that allows connecting or disconnecting a battery from circuit depending on its SOC.

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SISTEMUL DE MANAGEMENT AL BATERIILOR PENTRU UN STAND DE VEHICUL ELECTRIC HIBRID

(Rezumat)

Scopul acestei lucrări este de a imagina şi realiza un sistem automat de monitorizare a bateriilor utilizat pentru monitorizarea în timp real a parametrilor bateriilor de pe un stand de vehicul hibrid. Sistemul de monitorizare a bateriilor joacă un rol important în funcţionarea optimă a unui vehicul hibrid, având sarcini diverse cum ar fi estimarea stării de încărcare, monitorizarea tensiunilor de pe baterii în timpul funcţionării, estimarea puterii instantanee disponibile.