A New Approach on
Battery Management Systems

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Abstract

The existing Battery Management System (BMS) techniques are examined in this paper and a new design methodology for a reliable BMS is proposed. The main advantage of the proposed BMS compared to the existing systems is that it provides a fault-tolerant capability and battery protection.

1. Introduction

In high power systems, long battery strings of high capacity batteries are used and the probability of problem occurrence is increased as well as the repair costs. The low ratio of cell voltage to string voltage and the particularity of each battery string make battery management difficult in these systems. In spite of this, a number of sophisticated BMS solutions have been proposed [1-7] and although most of them are micro-controller-based solutions, none of them provides:

- Advanced fault tolerance,
- Maximization of the delivered battery energy and
- Battery protection.

The need of a generalized design method, which can be applied in every case of battery management requirements and which provides a state-of-the-art BMS, led to the development of the proposed methodology described in this paper. An experimental model of a typical Smart Battery Module (SBM) was developed and tested in order to verify the implementation problems and examine the real system behavior. The requirement for a state-of-the-art BMS design and the experience obtained from an experimental SBM and existing BMS studies [8,9], lead to the conclusion that the design considerations should be extended in order to include:

Full battery power equalization capability. A BMS must have bi-directional equalization capability, which will assure that all battery cells have uniform charging and that the energy delivered by the battery string is maximized. Full battery power equalization also provides fault tolerance capability by maintaining the terminal voltage of a disconnected battery cell under load conditions.

Battery cell disconnection capability. The BMS has inherently a very accurate "battery condition monitor" [10]. Battery protection must be a primary function of any BMS. Since battery cells are integral parts of batteries, it is impossible to disconnect a single cell when it is defective. However, when this occurs, the defective cell battery block can be isolated and since its equalizer can maintain the isolated battery block voltage, the operation of the battery string will not be interrupted. The best way to isolate a battery block is by using latch relays.

Operation in noisy environments. A high power equalization converter is utilized in the SBM and, unlike the existing BMS techniques, the proposed SBM has power and signal stages on the same printed circuit board. The printed circuit board must be designed in such a way that the signal circuitry will not be affected by ground noise, EMI and RFI, because the measurements accuracy of battery cell voltages must be in the order of few mV or few tenths of mV, indicating that a battery cell monitor is more sensitive in ground noise than other monitors of power electronics systems.

2. General BMS operation concepts

A BMS has to be "cell based" in order to be effective. Usually the cells are parts of larger battery blocks with nominal voltage of 6V or 12V. Most typical battery applications use voltages that are multiples of 12V [11], which is a convenient voltage for the operation of the SBM. This voltage is produced by six lead-acid cells or by ten alkaline-electrolyte cells.

Equalization in a BMS needs a second current path along the battery string, which is used for the current trade-off of the cells parallel current paths. The cells parallel current paths are used because during the equalization phase of a series string of battery cells, all cells are under the same voltage level. In order for this to happen, the cells absorb different currents and this can occur only if there exists a parallel path with each cell. Since these parallel currents represent power, it is convenient to convert this power and return it through another path to the total battery charging current. The communication and other system wiring can go next to this path and thus the minimization of the number of conductors may not be a primary design option in such a type of BMS.

A fault-tolerant BMS is more flexible, if all its SBMs are similar and a special master module is responsible for communication timing, system control and external requests. Otherwise, faults may not be detected on time. The number of measurements handled by such a type of SBM is about twice as many handled by a normal Battery Measurement Unit, while the speed requirements are also increased. The master module can measure the string voltage and current and thus prevent any malfunctions caused by communication delays of SBMs. The computation load should be evenly distributed to the microcontrollers in order to avoid computation overload in the master module and to minimize the traffic to the SBM communication network. Thus, each microcontroller can process its input data and pass only the necessary parameters to the master module. Measurements can be exchanged between modules, but only for test and calibration purposes.

Figure 1 shows a block diagram of the typical BMS topology. Each SBM is consisted of a microcontroller, the necessary circuitry to monitor the battery behavior, an equalization converter and adequate number of switches that are capable to totally disconnect the battery from the battery string. All the equalization converters are coupled and the operation of all the SBMs is controlled and supervised by the master module.

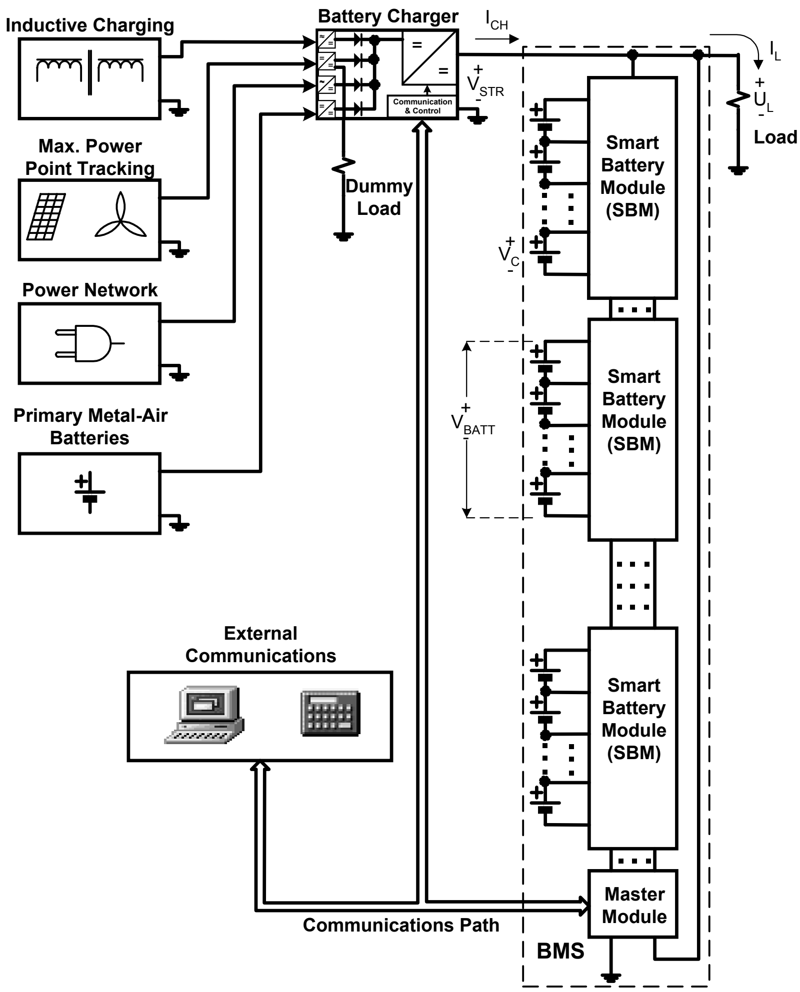

Fig. 1. Block diagram of a typical BMS topology.

The master module contains a microcontroller and measures the voltage and the current of the battery string. It controls the charger voltage and the main operation of the BMS. The master module manages all communications, both inside the BMS and outside. A computer or a LCD display and a keyboard, communicating with the master module, can be used to monitor BMS operational data or externally control the BMS operation.

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The battery string current equals the difference $I_{CH} - I_L$. Charging occurs only while $I_{CH} > I_L$.
For each specific application of the BMS, the program of the master module microcontroller has to take into account the characteristics of the power source in order to avoid, either memory effects in alkaline electrolyte cells, or long periods in deep discharge state for lead acid batteries.

3. The Proposed SBM

A block diagram of the proposed Smart Battery Module (SBM) is shown in Fig. 2. The battery cells are connected through latch-relay switches to the SBM. This topology allows battery block disconnection, in case of malfunction. If this happens, the equalizer retains the battery voltage with energy provided through the current trade-off path by the good battery cells.

The SBM can have two types of sensors, one with analog output multiplexed in order to drive an A/D converter and another with digital output capable of communicating with the micro-controller through one of the commonly used interfaces (1-wire, 2-wire, SPI, I^2C). The analog output sensors are current sensors and the digital interface sensors are mainly temperature sensors. The use of a limited wire interface gives the flexibility to adapt the system in every specific need by adding and removing sensors and minimizes the need to change other SBM hardware.

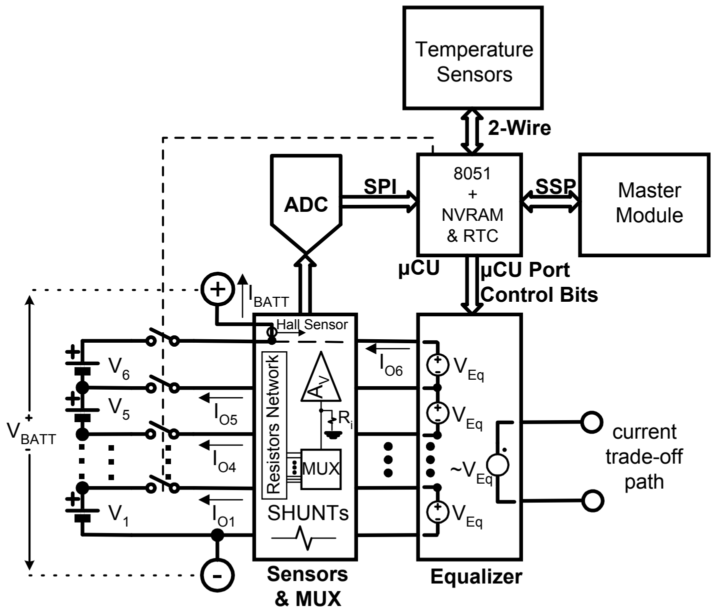

Fig. 2. Block diagram of the proposed Smart Battery Module (SBM).

The cell voltages and the current sensors outputs drive a resistors network, which weights appropriately their values. A multiplexer (MUX) selects sequentially each signal and drives an instrumentation amplifier feeding the A/D converter input. The microcontroller (μCU) controls the equalizer and scans all sensors sequentially. The μCU communicates by means of a Standard Serial Port (SSP) with the master module.

The microcontroller of the SBM can be chosen from the 8051 family. The final selection will depend on the exact algorithm used and on the number of cells that the SBM will manage. Since the measurements require more than two-byte numbers, the arithmetic operations must be done with a resolution of 32 bits or on floating point. This does not have to be implemented in hardware because the processing speed is limited mainly by the communication speed between the sensors and the microcontroller. A real time clock makes the system more advantageous and the coulomb-metric estimation more accurate. The clock may be placed in a microcontroller module or in a separate IC and may communicate with the microcontroller through a limited-wire interface.

The serial communications should be opto-isolated for better results. Thus, the loops formed by the serial communication wiring are de-coupled and the low power system is protected against any malfunction due to noise interference. The Master Module that can communicate with each module using a module number and a global ID number can control all communications.

In order to verify the theoretical design and identify the problems that show up in a real system, an experimental SBM prototype was constructed and tested in the laboratory.

4. SBM experimental results

The experimental SBM was connected to a 45-Ah lead-acid type battery. In the place of the Master Module, a small circuitry able to provide the equalization timing signal and a serial port of a PC were placed. A DOS based program was developed, in order to be able to communicate with the SBM and obtain measurements or give commands. If instead of measurement data, an error code came in, then a special routine was enabled specifically designed for error handling. The program had three parts: The first was able to show online the measurements obtained. This was very useful for the calibration of the sensors. The second part was able to request a full set of measurements, one every minute, and log it in a file, while the third was able to convert the log file in an MS-Excel-format file to enable the processing of the measurements under Windows.

Figure 3 shows the battery and the cell discharge behavior under an equalization scheme that starts the equalization at the moment that the cell voltage is reduced to 1.8V. This scheme of discharge equalization is effective and efficient because the equalization converter does not work continuously during discharge. The measurements were ended at the instant the processor supply voltage fell below 4.75V. As it can be seen from Fig. 3 the battery current curve is not proportional to the battery voltage curve during the last few minutes of measurements. This happened because the Hall-current sensor had a minimum working voltage of 8V, but this is not a drawback because in normal operation the battery voltage should not drop under 10V.

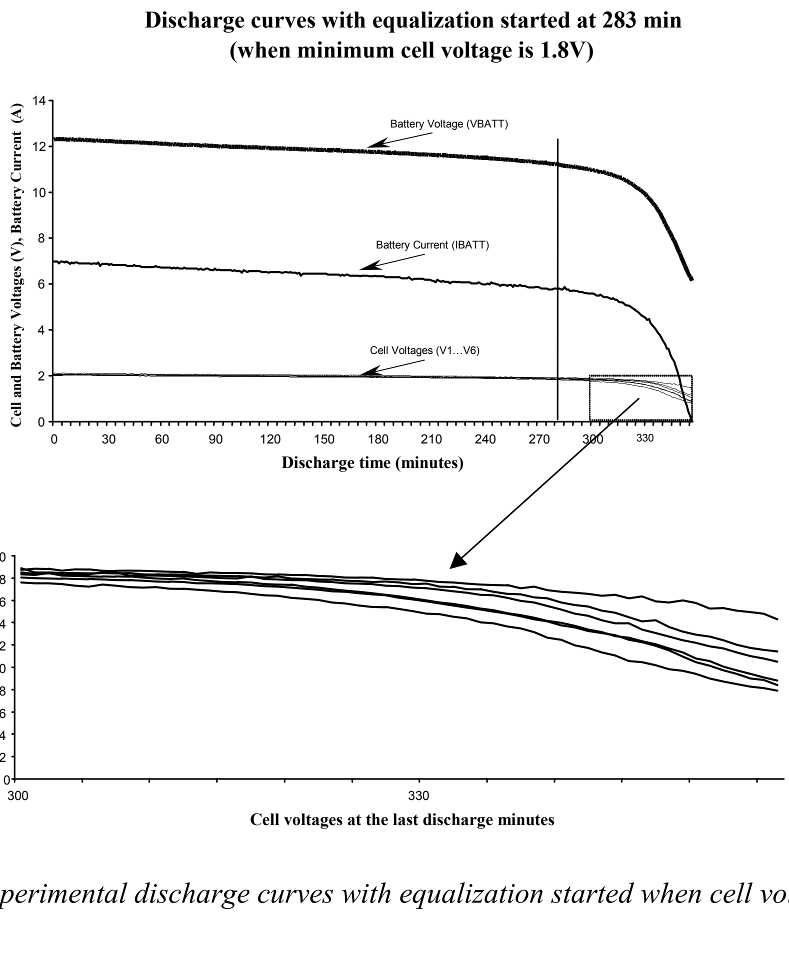

Fig. 3. Experimental discharge curves with equalization started when cell voltage is 1.8V

Figure 4 shows the battery discharge and the cell terminal voltages curves under equalization with one cell disconnected.

Discharge under equalization with one cell fully disconnected

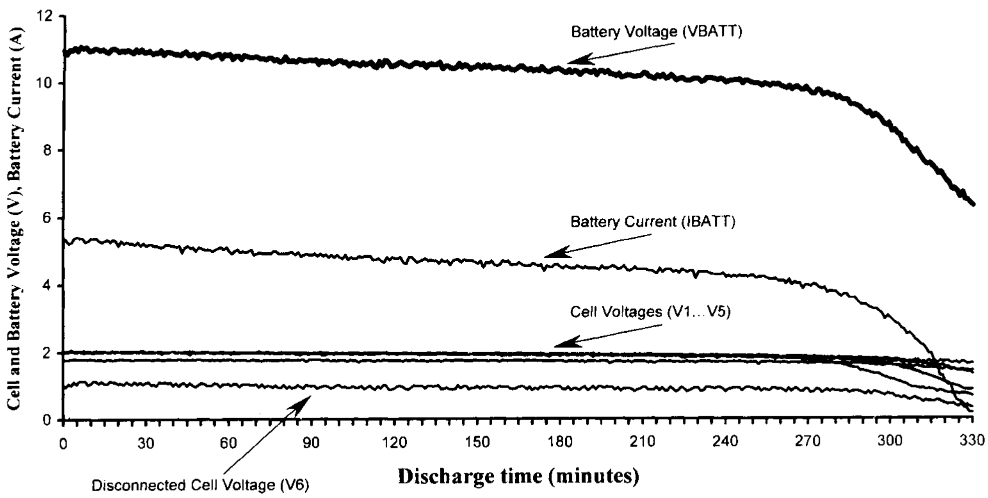

Fig. 4. Experimental discharge curves with one cell fully disconnected.

As it can be seen from the results of Fig. 4 the battery discharge curves are smooth and very similar to the single cell discharge curve, even under these circumstances. The disconnected cell terminal voltage remains positive until deep battery discharge. The voltage across the converter corresponding to the disconnected cell is lower than 2 V, because of the voltage drop on the converter internal resistance.

It must be noted that in a real system the battery operation must be terminated before such a deep discharge takes place and that the above measurements were taken only to show the effect and the operation of the equalization converter.

5. Conclusions

A design method for a novel generalized Battery Management System (BMS) has been presented and an experimental cell-based, modular, fault-tolerant system has been developed, capable of providing charge and discharge equalization and battery protection. A Smart Battery Module (SBM) capable of communicating with a PC through a serial port and a specially written computer program was designed and tested in the laboratory. All problems encountered during the test and operation procedure were solved and the battery discharge curves show the benefits of the discharge equalization schemes that were used.

6. References

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