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Efficient Energy Utilization And Conservation Using Battery Management System

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***Abstract*— In the face of energy crisis, it is imperative to manage the utilization of energy efficiently. The smallest units of energy sources are batteries used pervasively in all electronic devices. Battery Management Systems (BMS) are the control systems which monitor and manage the utilization of the battery pack. This paper reviews the control parameters, building blocks, topologies and progressive applications of the BMS.**

***Index Terms*-SOC, master-slave, wireless-charging, HEV, BMS ICs. coulomb-counter.**

I. INTRODUCTION

There is a disputed claim that the Bhagdad Battery was the earliest battery. If it were true, then the technology has been long forgotten. The more recent invention of the battery in 1800 by Allesandro Volta sparked off today's pervasive battery usage starting from the first mobile devices to PDA (Personal Digital Assistant) technology including Electric Vehicles. Battery dependency gave way to development of the Battery Management System (BMS) which is a collection of blocks which are coordinated to perform activities to monitor and manage the battery according to the need of the system or device. The sections which follow deal with the parameters which are considered to monitor battery activities and manage efficient usage of the battery charge. There are various configurations that these blocks in the BMS can be connected for different applications with their own pros and cons. This paper concludes with the possible futuristic technology of commercially viable and available BMS.

II. THE BUILDING BLOCKS OF A BMS

The objectives of a BMS are:

- To protect the cells or battery from damage
- To prolong the life of the battery
- To maintain the battery in a state which it can fulfil the functional requirement for which it was specified.

The basic parameters which have to be monitored are assigned a specific block. The objectives are met by employing all or a specific combination of the following blocks.

1) *Cell protection*
2) *Charge control*
3) *Demand management*
4) *SOC (State of charge) determination*
5) *SOH(State of health) determination*
6) *Cell Balancing*
7) *History(Log Book Function*
8) *Authentication and Identification*
9) *Communications*

The functions that the blocks perform is as given below:

1) *Cell protection:* Protecting battery from outside the prior set tolerance operating conditions.
2) *Charge control:* Preventing inappropriate charging, which damages the batteries. This is the most probable reason of battery degradation than any other cause.
3) *Demand management:* Though this is not directly realted to the battery operation itself, by incorporating power saving techniques into the applications circuitry will prolong the time between battery charges.
4) *SOC (State of charge) determination:* The user could be notified of the capacity left in the battery as compared to its full capacity. The control circuit would need this information to ensure optimum control of the charging process.
   There are many methods to determine the SOC of a battery.
   a. Coulomb counting
   b. Open Circuit Voltage (OCV)
   c. Impedance spectroscopy
   d. Discharge test

These algorithms along with more recent ones will be discussed in later sections.

5) *SOH(State of health) determination:* This indicates the number of times a battery can be charged and discharged before its life is terminated. It is an indication of the battery capability to deliver a specified output as compared to the capability of a fresh new battery.
   SOH is estimated by

$$SOH(\%) = \frac{Q_{act}}{Q_R} \times 100 \quad (1)$$

   where Q_{act} = Actual capacity of the battery
   Q_R = Rated capacity of the battery
6) *Cell Balancing:* The individual cells of the battery pack are different due to production tolerances and operating conditions. These differences become magnified with each charge/discharge cycle. Weaker cells become weaker due to this overstress and the battery fails prematurely. Cell balancing is identifying these differences and balancing the charge by equalizing to extend the life of the battery
7) *History(Log Book Function):* It is very important to estimate the life of the battery. SOH is a measure to estimate the life of the battery. This is not simple enough to be measured off the battery terminals. In order to make this measurement parameters such as number of cycles, maximum and minimum voltages and temperatures, maximum charging and discharging currents, can be recorded for subsequent evaluation and also for warranty claims. There parameters can be stored in a memory called the "History Chip" in the BMS and downloaded later for when required.
8) *Authentication and Identification:* Details such as manufacturer's type, designation and cell chemistry allow for automatic testing facility. Production related information such as batch or serial number and date of manufacture can be stored to facilitate traceability in case of cell failures.
9) *Communications:* A data link is employed for communication between the battery and charger carrying system control signals or signals which are used for performance monitoring, data logging, diagnostics and setting system parameters. The different types of buses are:
   a) RS232: Standard for serial transmission of data between two external devices. Cable length upto 50 feet. Separate transmit and receive lines. Full duplex communication. Data rates up to 20,000 bits per second.
   b) EIA-485: It is a standard for serial transmission of data between multiple devices. The cable lengths can run up to 4000 feet. It operates in half duplex. It uses differential balanced line over twisted pair for noise immunity. Any data protocol can be used. The data rates can be used up to 100K bits per second or 10M bits per second depending on the length of the cables.
   c) Inter - Integrated Circuit (I^2C) Bus: This bus a lows speed and it was originally designed for use between internal modules within a system. It is bidirectional and half duplex. It is a two wire synchronous bus. The data rates are up to 3.4 Mbits/s. It is suitable for Master - Slave applications. Multiple slaves are possible but only the master can initiate a data transfer.
   d) USB Universal Serial Bus: Data rates up to 3 Gigabits/sec. Up to 127 devices including hubs may be connected to the bus. Cable lengths are limited to 5 metres (16 feet). The host transmits data packets to, or receives data packets from, all the devices connected to it, but each device has a unique address so that only one device can actually receive or transmit data at any one time. In battery applications, the USB connection is used for monitoring the battery status or setting control limits.
   e) CAN Bus: The industry standard for on-board vehicle communications is the CAN (Controller Area Network) bus. It is a two wire, serial communications bus designed for networking intelligent sensors and actuators in a centralised multiplexing system. A high speed (1 MBaud) bus is used for rapid control devices for operations such as engine management and vehicle stability and motion control. For simple switching and control of functions such as lighting, windows, mirror adjustment and instrument displays a low speed (100 KBaud) bus is used. The CAN bus was designed to provide secure communications in the very harsh operating environments with high levels of electrical noise which are found in automotive systems. Automotive BMS uses the CAN bus as its main communications channel.
   f) LIN Bus: The LIN Bus is another automotive communications standard, initiated in 1998,

similar to the CAN Bus. Single wire Local Interconnect Network operating at 20 KBaud using distributed multipexers and standardised Smart Connectors based on standard UART/SCI IC hardware allowing for simple, low cost IC solutions. It uses more electronics than the CAN Bus but it is more flexible and uses less wiring. Its implementation is not confined to automotive uses and can be used to control complex household appliances such as dishwashers and washing machines.

g) FlexRay Bus: Developed recently to meet demands of sophisticated engine management systems planned for future automotive use. Fault tolerant 10Mbit/sec data rate on each of two channels enabling both synchronous and asynchronous data transfer. The FlexRay data payload per frame is 20 times greater than the CAN Bus. Time-triggered architecture known as Time Division Multiple Access (TDMA) where communication is organized into repetitive, predefined time slots which allows high priority signals to be guaranteed synchronous access to a channel in predetermined, cyclic time slots, while low priority signals, which are not needed continuously, are transmitted asynchronously and only gain access to the bus as required when the bus is free. Supports fast responding dynamic control systems rather than just the simpler sensors and actuators permitted with the CAN Bus.

h) SMBus: System Management Bus is a two wire, 100 KHz, serial bus designed for use with low power Smart Battery Systems (SBS) with the limited objectives of interconnecting Smart Batteries which have built in intelligence, with their associated chargers. Sometimes found in simple vehicle applications, it does not have the range of capabilities for controlling devices connected to the power lines which the CAN and LIN buses have.

III. SOC ALGORITHMS

A. Coulomb counting: Also called Ah counting. It is the most conventional methods of SOC estimation. The time integral of the terminal current determines the charge entering and leaving the battery terminals as compared to the full charging capacity of the battery. This method, however, is limited by the current sensor error which accumulates over time because of the integration process.

B. Open Circuit Voltage (OCV): In this method open circuit voltage of the battery is measured. This requires that the battery stay at rest (i.e., no charge or discharge) for as long as eight hours. This method makes it unsuitable for online applications such as EVs (Electrical Vehicles).

C. Impedance spectroscopy: In this method small current signals of different frequencies are applied to battery and the corresponding voltage is measured using Electromechanical Impedance Spectroscopy analyzer equipment. This method takes considerable time to make estimations and so is used only for offline analysis.

D. *Discharge test:* This involves measuring the battery voltage after discharging it to a level not below the safe lower limit and charging it back to maximum not exceeding its safe maximum limit. This test takes up to eight hours to discharge and up to three days to completely recharge. Because of the take taken this method, even though it is the traditional method of evaluating SOC, is not popular.

IV. TEMPERATURE MANAGEMENT

Hotter the battery, faster will be the chemical reactions, and faster the life ebbs from the battery. Scientifically it has been seen that every 10° C rise in temperature results in double the rate of self discharge. This makes the life of the battery reduce and once the battery capacity is reduced by heat it cannot be restored. It is therefore necessary that a BMS has the ability to control the temperature of a battery and keep it at an optimal level at different operating conditions. Electromechanical reactions generate heat and this heat needs to be dissipated. This becomes more serious when several cells are compacted in a battery pack. Thermal management uses heat-transfer analysis which determines the heat distribution inside the battery pack and channels are embedded to remove this heat using air or liquid.

V. TOPOLOGIES

There are many ways of implementing a BMS with different connection topologies. Here a Master-Slave, Star Topology and Daisy Chain, Ring Topology have been shown.

The advantages of the Master-Slave configuration is that it does not require printed circuit boards to connect the individual cells. More modules can be appended to operate high voltage batteries. And, since the main battery current does not pass through the slaves high current batteries can be used. Information sharing between the master and slaves is simplified by the management of information processing load. The information communication is carried by the I^2C bus.

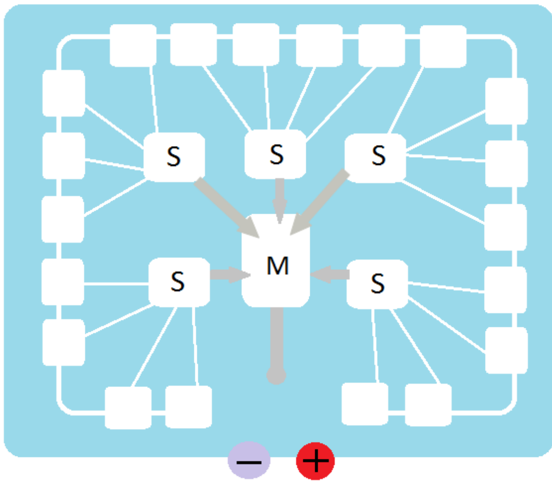

Fig. 1. Master-Slave, Star topology of cell connection

The disadvantages of the Master-Slave topology for BMS is that the sensor to slave connection is analogue and prone to noise as there are four sensor wires per cell. The noise problem is worse if there more number of cells as the wires connecting each cell and the slave multiply. Opto-isolation is required between the master and the slave since the voltage on the slaves would otherwise be higher progressively, up to the maximum limit of the battery voltage, as connections are taken from the higher cell chain.
Communication to the outside world is through the RS232 or USB serial connection.
Fig. 2. shows the Daisy chain, Ring topology. Ring topology BMS uses a simple small slave printed circuit board which is connected to each cell. This printed circuit board houses the voltage and temperature sensors along with an A to D converter. A current bypass switch enables cell balancing by charge shunting. A communications transceiver is also accommodated in the printed circuit board with built in capacitive isolation for receiving and transmitting data in digital form. The cell which is being monitored powers the slave. A single RS 485 three wire data bus connects the nodes from all the slaves to the master. The master polls each node in turn and requests for an update of its cell conditions. The slave carries out only the A to D conversion, and all the other work is carried out by the master along with all the monitoring, protection and communications functions.

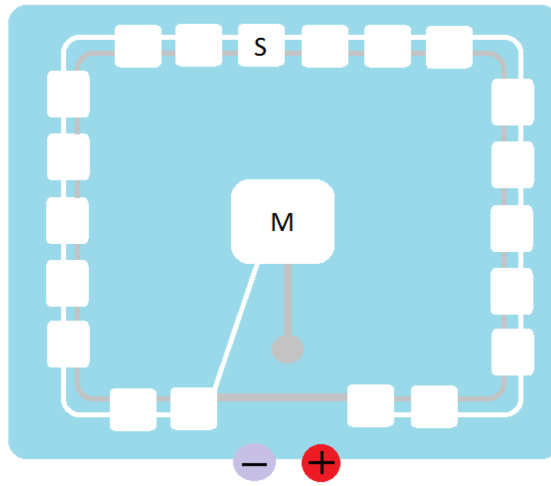

Fig. 2. Daisy chain, Ring topology of cell connection.

The advantages of the ring topology is that it is simpler in design and construction and it has potentially higher reliability in the automotive environment.
The disadvantages are that there are a large number of small printed circuit boards. Also, it is difficult to mount them on some cell structures. In addition to that the master has a higher signal processing load.

VI. PROGRESSES IN BMS TECHNOLOGY

A. *Automotive industry:* The increasing demand in EVs (Electric Vehicles), HEVs (Hybrid Electric Vehicals) and PHVs (Plug in Hybrid Vehicles) increases the demand of efficient battery management systems since the efficiency of the vehicle squarely depends on the efficiency of the BMS to manage and monitor the energy source for the vehicles which is the battery pack.

B. *Wireless Battery Management System:* The CAN bus (Control Area Network) carries the information between the battery control unit (BCU) and the cell sensor unit (CSU) and requires a large amount of additional wiring. The possibility of employing a wireless system to transit the sensor information to the BCU is being studied which reduces cost, weight, construction complexity, and galvanic isolation of cells.

C. *Predictive Battery Management System:* The BMS is made more intelligent by learning the time-of-usage tariff, hence storing charge when it is less expensive and use it at other times. Further improvement can be done by harvesting energy from renewable sources like solar PV panels and wind mills. By scheduling the battery actions the cost can be reduced and efficiency of the BMS can be improved.

VII. CONCLUSION

The battery management system efficiently utilizes the energy stored in the battery pack which is imperative in the mobile device environment. The battery management system circuits and algorithms coordinate to monitor, manage and control the battery and guarantees the safety and reliability of the energy storage devices. The algorithms for estimation of SOC and SOH and cell balancing are crucial in designing efficient battery management systems. This paper gives an elaborate overview of the existing and trending technologies of intelligent battery monitoring systems.

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