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Smart Battery Management System with Active Cell Balancing

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Abstract

Background/Objectives: Batteries are extensively being used in transportation, military, aerospace and portable applications like mobile phones and laptops. Also, battery driven Electric Vehicles (EVs) are replacing conventional vehicles to reduce pollution and dependence on conventional energy resources like petroleum and diesel etc. **Methods/Statistical analysis:** Generally batteries operate in the form of battery packs consisting of string of cells in series and parallel manner providing high voltage, current and power as required for different applications. **Findings:** Batteries faces many problems like charge imbalance, thermal runaway, over voltage and under voltage due to high charge/discharge profile. Charge imbalance affects overall pack performance as well. An efficient and sophisticated Battery Management System (BMS) that monitors and controls the critical parameters of the battery for smooth running and better performance of a battery. An embedded system was designed using a battery monitoring fuel gauge IC (BQ76PL536) and a buck-boost converter for cell balancing. **Conclusion:** This paper demonstrates a novel battery management system which actively monitors the critical parameters like voltage, capacity and performs as an active balancing of cells in a battery pack whenever required. The system is integrated with MSP430 microcontroller for monitoring and controlling purpose. Proposed battery management system continuously monitors each cell voltage in a battery pack and performs cell balancing if voltage difference between cells exceeds the threshold value.

Keywords: Battery Management System, Cell Balancing, Fuel Gauge, IC BQ76pl536, Li-ion Battery

1. Introduction

Battery management system is an electronic system which manages a battery or a pack of cells. It monitors and controls battery critical parameters, estimate its state, balancing and make sure that they operate in recommended safe conditions[1,2]. A battery plays a key role in the fields of military, transportation, communication especially in portable devices like mobile phones, electric vehicles and appliances.

With advancement in technologies batteries are coming in the form of packs along with a battery management system as smart battery packs which can be directly integrated with main system as subsystem. Battery Management System (BMS) can be implemented in different topologies like centralized, distributed and modular methods[3]. Today different types of batteries are available in market with different chemistries and designs satisfying a wide range of applications. Batteries are generally distinguished into two types- primary cells and secondary cells.

Primary cells are non-rechargeable batteries which can be used once and after that they are thrown away which is why they are no longer used now. Secondary cells are rechargeable batteries which can be used several times by charging and discharging. Several types of rechargeable batteries are available like Lead acid, Ni-Cd, Ni-MH, Li-ion etc used in different applications. Amongst them Li-ion batteries are widely used in commercial applications due to their good performance,

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less memory effect, high specific capacity, high nominal voltage. Li-ion batteries are charged using Constant Current Constant Voltage (CCCV) mechanism. But battery performance degrades due to several problems like high charge/discharge cycles, imbalance, overcharging, under discharging, thermal runaway, memory effect, pressure built up inside battery etc. At the time of manufacturing all batteries will be identical with slight variations in capacity, voltage and internal impedance. Though battery can be used for several times but as the usage goes on performance of cells differ from one another. Some cells discharge quickly while some cells discharge slowly causing voltage and capacity imbalance.

Due to cell imbalance overall pack performance is largely affected [4]. Cell balancing has to be done to equalize the cell voltage and capacity. It can be implemented in two ways [5,6].

- Passive cell balancing.
- Active cell balancing.

In passive cell balancing, a threshold value is selected and if difference between any two cells exceeds that threshold then excess energy is wasted through bypass resistors using bypass resistors. Generally passive balancing is implemented while charging only. Active cell balancing is a charge redistribution method in which excess energy is distributed from highly charged cell to low charge cell using inductors or capacitors until both are equalized [7–9]. Over charging generates heat causing oxidative chemical reactions leading to thermal runaway and also it leads to internal short circuit of battery.

Battery management system must monitor batteries continuously and protect it from overcharging, under discharging, over current and thermal runaway. Centralized topology is chosen for the proposed project [10].

2. Design Methodology

2.1 BMS Block Diagram

The proposed BMS as shown in Figure 1 is implemented using battery monitor IC BQ76PL536 and MSP430 microcontroller [11]. Generally fuel gauge IC's and secondary protection IC's are used in design of BMS. They are analog front end devices which provide different functionalities such as analog to digital conversion, temporary storage of data, raising alerts.

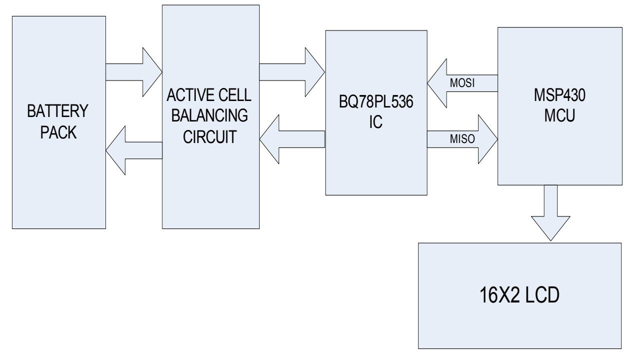

Figure 1. Block diagram.

2.2 IC BQ76PL536

Battery monitoring fuel gauge IC (BQ76PL536)[12] is battery monitor IC which can monitor from 3 to 6 series cells and can provide protection features like over-voltage, under-voltage and over temperature. It is especially qualified for automotive applications so it is used in EV's, HEV's and Uninterruptible Power Systems (UPS). It has 9 ADC inputs for measuring six cell voltages, one brick voltage, and two temperatures from thermistors. It has six dedicated outputs for cell balancing for each cell. It has several EEPROM registers to store intermediate values. Through vertical stack interface of this IC up to 192 cells can be monitored. It converts the analog cell voltage into digital values and sends them to MCU upon request through SPI communication interface [13].

Initially microcontroller sends a broadcast message to all the BQ devices connected to it. All the BQ devices respond to it by a reset. Now the microcontroller detects each and every IC and assigns a unique address to it. Each BQ device has north and south communication interface to communicate with other BQ devices. All the communication between IC and MCU occurs through SPI interface using this unique address. Communication happens in the form of data packets. The packet must contain IC address, register address to be read or written, number of bytes and Cyclic Redundancy Check (CRC). The microcontroller continuously read all cell voltage, packs voltage and pack temperature and displays it on LCD module. It also monitors voltage difference between the cells and balances them if cell imbalance threshold is reached.

2.3 Cell Balancing

The active cell balancing method used in this design as shown in Figure 2 is based on an inductor based buck-boost

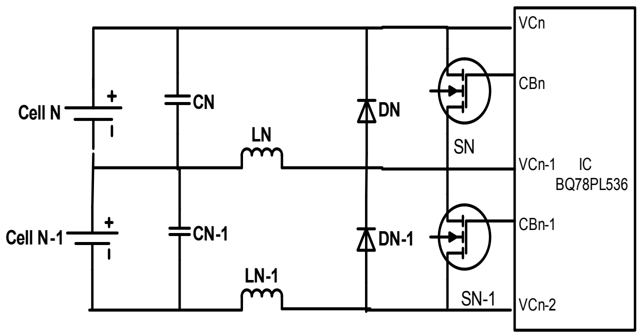

Figure 2. Cell balancing circuit.

converter[14] where the charge is shuffled through inductors from one cell to another cell through MOSFET switching. This can be applied to any number of cells.

This cell balancing circuit performs charge redistribution in bi-directional way from top cell to bottom cell and from bottom cell to top cell. The state of charge of each cell is continuously monitored and if the difference of their voltage exceeds the threshold, the controller switches on the corresponding MOSFET.

If charge has to be distributed from top cell to bottom cell then MOSFET S_N is switched on. During this period then charge passes through S_N into inductor (L_N) and inductor current linearly increases and it gets charged. When S_N is switched off the inductor stops charging and as diode D_{N-1} is forward biased and negative voltage is applied at the inductor it starts discharging which goes into bottom cell. If bottom cell has high capacity than top cell and needs to shuttle its energy then MOSFET S_{N-1} is switched on first then inductor L_N gets charged. When S_{N-1} is switched off then inductor discharges and charge passes through diode D_N to top cell.

Generally MOSFET switching voltage is minimum 3.3V. But for proper switching operation of MOSFET 12V is needed. So a gate driver circuit is needed which will amplify the 3.3V/5V coming from IC. The specifications of components required for the cell balancing circuit is given in Table 1.

Table 1. List of components

Component	Value
Inductor	10 mH
Capacitor	0.1 uf
Power diode	STTH 80
Power MOSFET	IRF 840

3. Design Flow

The design flow of system is described in Figure 3. The microcontroller initializes battery monitor IC and LCD. IC is initialized by setting a unique address to it by microcontroller. After initialization fuel gauge IC starts reading cell voltages, pack voltage, temperature and stores them in respective registers. The microcontroller continuously reads data from fuel gauge IC and compares it with threshold values as well as displays them on LCD. Here the cells under voltage and over voltage thresholds are set at 3.2V and 4.2V. If any cell voltage value exceeds the threshold value an alert will be displayed. Similarly pack operating temperature is set in the range of 20 ^{0}C – 45 ^{0}C and an alert will be displayed if pack temperature goes beyond operational range. Also if potential difference between any two cells exceeds the threshold value the cell balancing process starts automatically and continues until cells are balanced. The final circuit of battery management system is shown in Figure 4.

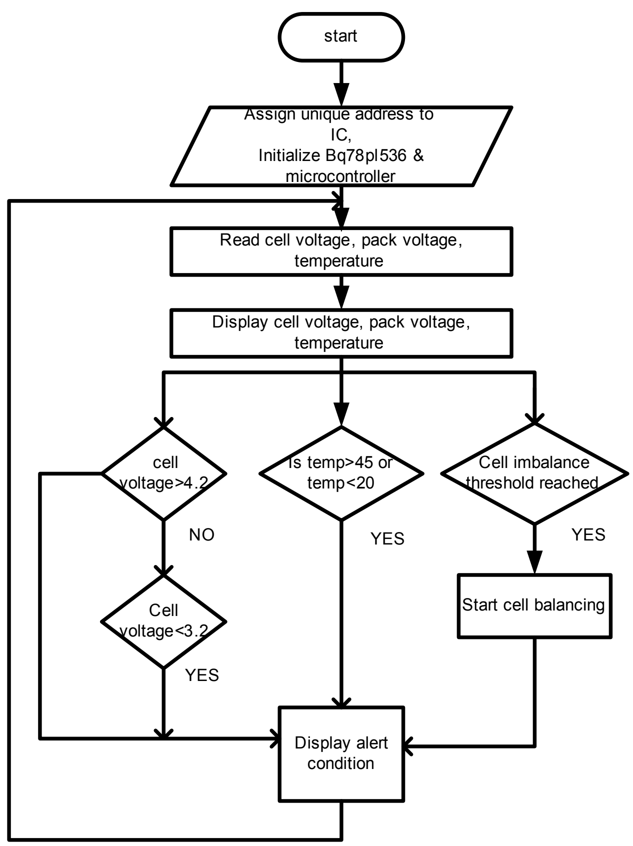

Figure 3. System design flow.

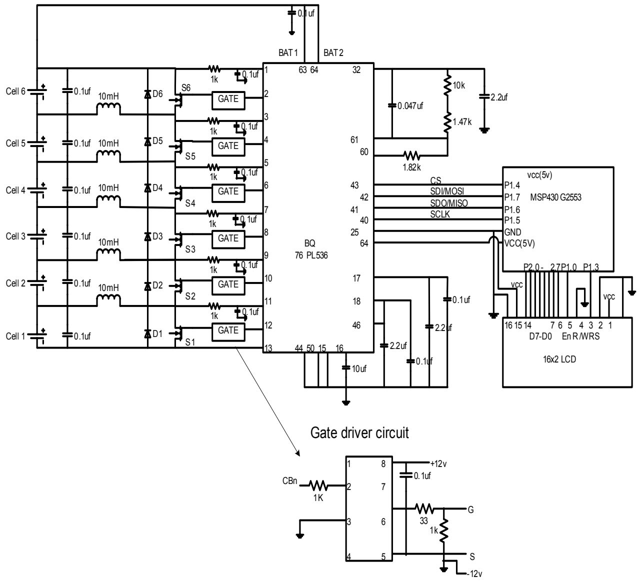

Figure 4. Final battery management system.

4. Simulation and Hardware Setup

The cell balancing circuit is simulated in PSPICE and results are validated as shown in Figure 5–8 before hardware system being developed. Further, referring to the success of the simulation results, in order to encounter the hardware realization, PCB layout was fabricated for the cell balancing circuit using Express PCB software. As per simulation circuit, the PCB hardware construction was performed having BQ76PL536, a fuel gauge battery monitor commerical IC which is interfaced with a cell balancing circuit through gate driver circuit in turn hooked with microcontroller and LCD. Lithium-ion batteries were connected to cell balancing circuit in series manner. The entire hardware setup is shown in Figure 9.

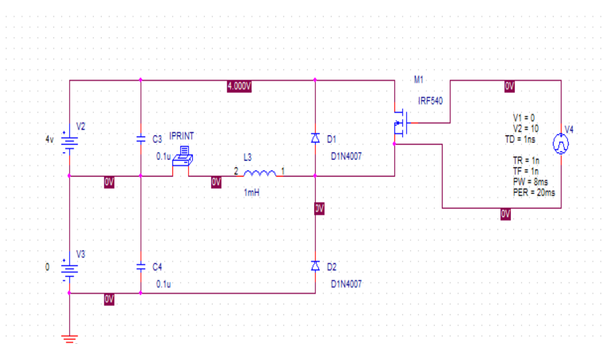

Figure 5. Top cell – bottom cell energy transfer circuit.

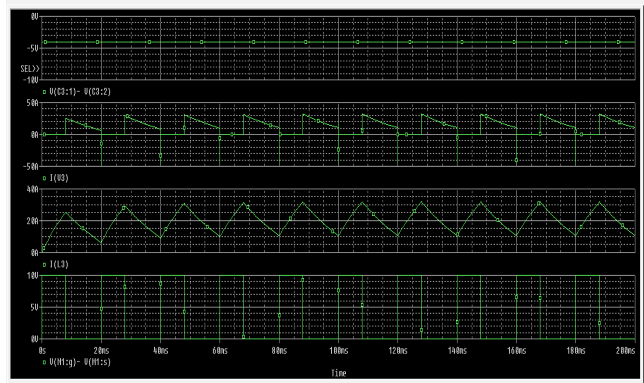

Figure 6. Top cell-bottom cell energy transfer.

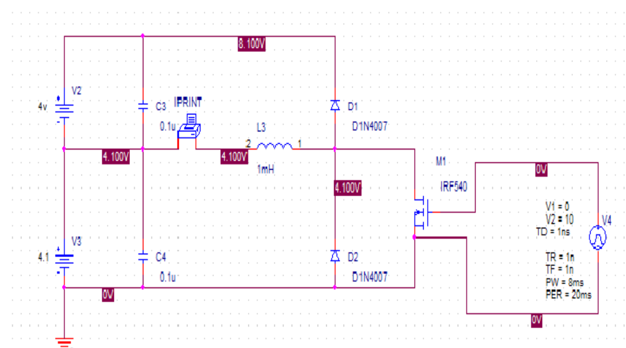

Figure 7. Bottom cell-top cell energy transfer circuit.

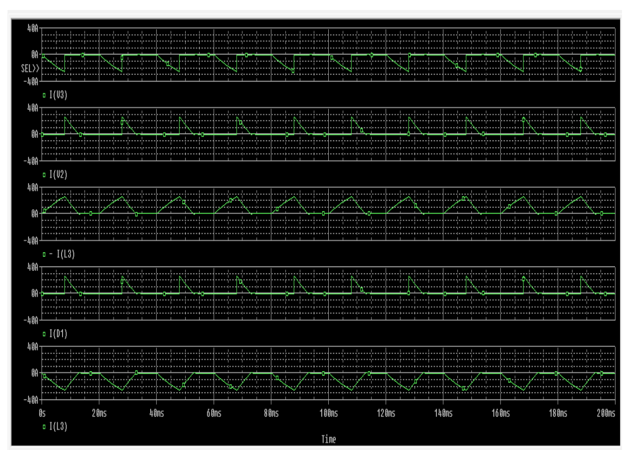

Figure 8. Bottom cell-top cell energy transfer.

5. Results and Discussion

As expected, BMS was able to monitor and control the cell voltages, pack voltage and temperature as shown in Figure 10. While testing the cell voltage difference between cell 2 and cell 3, it was found that the potential

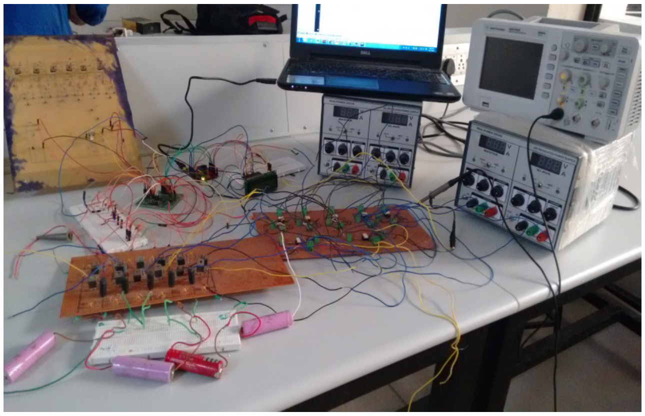

Figure 9. Hardware design and Testing.

Figure 10. LCD outputs.

difference between cells exceeded the threshold value and cell 2 is overcharged than cell 3. This triggers the MOSFET corresponding to cell 2 and it is switched on

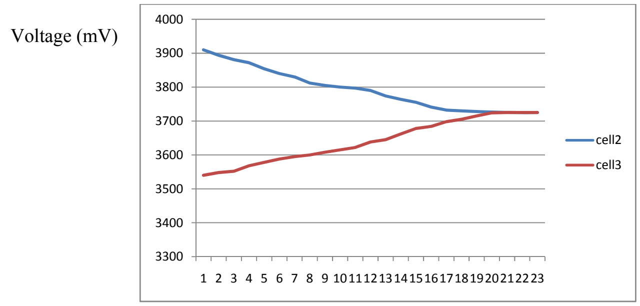

Figure 11. Cell balancing between cell 2 and cell3.

and off continuously by the microcontroller to transfer its energy to cell 3. The readings of both voltages are observed and plotted on a graph as depicted in Figure 11. In the same time, cell 2 voltage diminishes gradually while cell 3 voltage rises. This process continues until they reached the same voltage level, charge balancing ceases automatically.

6. Conclusion

Design and validation of an efficient battery management system has been successfully accomplished. Several imperative tasks viz., cell voltage, pack voltage and temperature of battery pack have been monitored and displayed and the cell balancing circuit design has been successfully tested as well. This work can be further explored to design more advanced balancing circuits using magnetic coupled inductors for niche applications for instance an EV. Also BMS can be further extended to monitor other parameters like pressure inside battery, run lifetime etc.

7. Acknowledgement

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