Design of Battery Management System

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***Abstract*—The paper reviews the necessity and design of battery management circuitry and describes tests required for characterisation of *Li-ion* cell. The suggested design implements a novel cell balancing circuit comprising of only two active components. An individual cell monitoring board is economical when compared to open source solutions provided by Texas Instruments and Analog Devices, along with offering improved stack-ability. Design and analysis of cell balancing circuitry and electronic load, which can also be used as a battery-charger is discussed. The effect of the discharging rate on the capacity of a cell is analysed. The proposed design would aid to sustainable development and clean energy systems.**

***Index Terms*—Battery Management System (BMS), cell characterisation, electronic load, *Li-ion*, sustainable development**

I. Introduction

With the continual rise in average global temperatures, an alternative and eco-friendly source of transportation was required. Electric and hybrid-electric vehicles have proved to be efficient and environmentally friendly in the past decade. The most common power source for these vehicles is Lithium chemistry-based cells. Battery-packs made out of these cells needs continuous monitoring as they are hazardous and explosive when subjected to a hostile environment. Maintenance of these batteries is thus proving to be of paramount importance. Selection of appropriate battery chemistry is a very important factor in deciding the overall performance of the system. From today's perspective, *Li-ion* chemistry is the battery technology of choice due to its high energy density and power rating and charge/discharge efficiency in pulsed energy flow systems [4,5]. A *Li-ion* fails if overcharged, over-discharged or operated outside their safe operating temperature window. For this reason, it requires a Battery Management System (BMS) which will maintain each cell of the battery within the safe operating range. At present, numerous automobile firms have developed their BMS's. However, their designs are proprietary. Our goal is to develop a BMS which would serve the purpose of monitoring large battery-packs, with no compromise on the system and user's safety. The design would be open-sourced so that the entire community is benefited.

II. Requirements for Battery Monitoring and Management

Battery Monitoring is important for *Li-ion* chemistry for ensuring prolonged battery life as well as energy efficiency. The main parameters required for this task are voltage, current and temperature over time. Another important parameter to be taken into consideration is State-Of-Charge (SOC) [1]. The operational characteristics and cell life are strong functions of temperature. Abrupt cell temperature changes can indicate cell failure.

A. Cell Characteristics

Energy density is one of the key factors in which *Li-ion* outweighs its competitors. It requires low maintenance when compared to others and also has a low self-discharge rate. Since it's single cell voltage is nominally 3.6 V, it allows us to design a system using a single cell, resulting in compact systems. Even in its compact cylindrical structure, the cell manages to provide high current.

a) Internal Resistance: Internal resistance is a variable quantity which determines the health of a cell. Temperature changes might cause a temporary change in the cell resistance value. Permanent changes in the cell resistance occur due to internal corrosion which increases gradually as the cell ages [10]. But all these changes are minimal because *Li-ion* chemistry has new and better electrolyte additives.

b) State Of Charge: State-Of-Charge(SOC) determines the energy capacity of the battery, i.e. knowing the amount of energy left in battery compared with the energy it had when it was full. SOC estimates whether the cell is charged or discharged and let us know the present state of the battery. This is estimated by relating the open-circuit voltage of the cell to the specific value that is provided by the manufacturer of the cell. Comparing the maximum and minimum voltage value, the present open-circuit voltage of the battery gives us the SOC [2]. The open-circuit voltage varies with change in temperature, so accordingly after calculating it while considering the temperature variation we can determine the SOC.

B. Selection of BMS Architecture

Battery Management Systems are necessary for safe, reliable and efficient use of lithium-based batteries. Irrespective of the voltage, all lithium-based batteries require a BMS. Several types of BMS are available in the market having different topologies. Generally, these are classified into two categories, i.e. Centralized BMS and Decentralized BMS.

Selection of the right type is very important and we decided to choose Master-Slave BMS that is based on the Decentralized BMS architecture. Our BMS comprises of Master and Slave units where the slave unit does the job of monitoring, balancing and controlling a group of cells within the battery module. Using a communication interface master unit and slave unit communicate with each other. The state estimation, control of power distribution unit and external communication is done by the master unit. We chose the Decentralized BMS over the other because:

- The fundamental parameters like voltage, current and temperature whose measured values are critical are communicated over long wires in the Centralized BMS which are prone to disturbances such as noise. While in the case of Decentralized BMS short wires are used thereby reducing electromagnetic interference.
- The cell monitoring circuitry is placed close to the cells in the Decentralized architecture. This thus provides more precise readings of parameters such as temperature and the internal resistance of the cells, which may be affected due to the distance from the source or the wire length respectively.
- In a Centralized BMS, the number of cell monitoring inputs are fixed. While in the case of Decentralized BMS if later on the requirements changes, more inputs can be stacked together.

Therefore, the Decentralized Battery Management System architecture is more versatile as it has a provision for expansion of the system.

C. Comparative Study of Commercial BMS

To get a better understanding of system architecture, we analysed two open-source BMS namely TI-BQ76PL455A by Texas Instruments [8] and LTC 6811-1 by Analog Devices [9]. All the necessary features have been implemented in our design along with integrating CAN which is a common communication protocol in automobiles and UART for general purpose applications. A comparative study of our system with existing solutions has been summarised in Table 1.

III. Design of charger-discharger circuit

To a BMS, characteristics of the cell being used must be known. To obtain the cell characteristics, we have designed an electronic load which can discharge with different currents and profiles. The circuit uses a 1 Ω, 10 W equivalent resistor and FET's internal resistance to dissipate cell's energy in the form of heat. Current and cell voltage is monitored and stored in a log file. The circuit uses an STM32F103C8T6 development board for control and monitoring the process. The threshold voltages are set using the keypad before the start of the discharge cycle. A PI controller is implemented which adjusts the duty cycle to maintain constant discharge current.
When the cell is fully discharged, the process is halted. The cell temperature is monitored continuously so that the effects of temperature on cell characteristics is minimal.
The same set-up is used to charge a battery. The designed circuit can be used to charge batteries rated up-to 50 V with a charging current limit of 10 A. A relay is used to switch the battery between charge and discharge modes. Charger circuit rated up-to 150 V, 20 A is being developed.

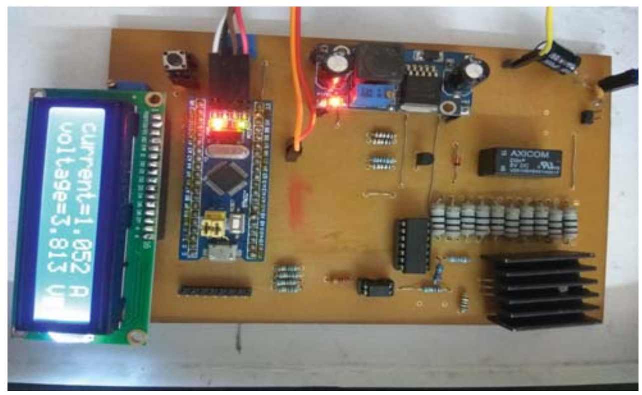

Fig. 1. Load circuit for cell characterisation.

IV. Cell characterisation using electronic load

A *Li-ion* cell was fully charged and allowed to stabilize for one hour. The cell was subjected to constant current discharge of 0.4 C and 0.75 C. The terminal voltage and charge discharged Ah were monitored until the cell reached the lower voltage threshold. The following parameters were continuously monitored.

A *Li-ion* cell was discharged at different rates and terminal voltage, discharge current and time were monitored continuously as depicted in Fig.2. The process was terminated when the terminal voltage reached the set threshold. The following were the results of the conducted tests.

It is evident from the tests that the capacity of a cell is a function of discharge rate. The total capacity of 2.6 Ah as specified in the datasheet [11].

V. Design and analysis of balancing circuit

During charging and discharging cycles of batteries, the voltage values for individual cells may vary. This leads to unequal voltage levels in cells all around the battery pack, which may further degrade the battery life. Hence, cell balancing is an important factor that helps us use the battery efficiently.

TABLE I
COMPARISON OF DIFFERENT MODULES

Parameters	TI-BQ76PL455A	LTC 6811-1	Our Design
Maximum Cell Inputs	16	12	16
Minimum Cell Inputs	6	1	1
Auxiliary Inputs	8	5	12
Communication Protocol	Differential UART	iso SPI	UART and CAN
Development Board Price (in INR)	21000	11000	750
IC price	1500	1500	280
Maximum Balancing Current per Channel	42 mA	127 mA	420 mA
Cost per cell monitoring (in INR)	1313	917	47

TABLE II
TESTING PARAMETERS

Parameters	Values
Cell Temperature	25 °C
Maximum terminal voltage	4.2 V
Minimum terminal voltage	2.8 V
Maximum discharge current	2.5 A

TABLE III
TEST RESULTS

Discharge Rate	Ah Discharged	Relative Capacity
0.4 C (1 A)	2.494 Ah	96 %
0.75 C (2 A)	2.421 Ah	93 %

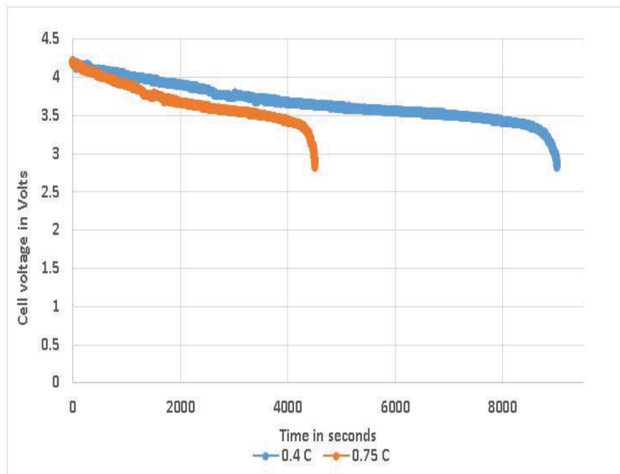

Fig. 2. Voltage v/s Time graph obtained during cell characterisation.

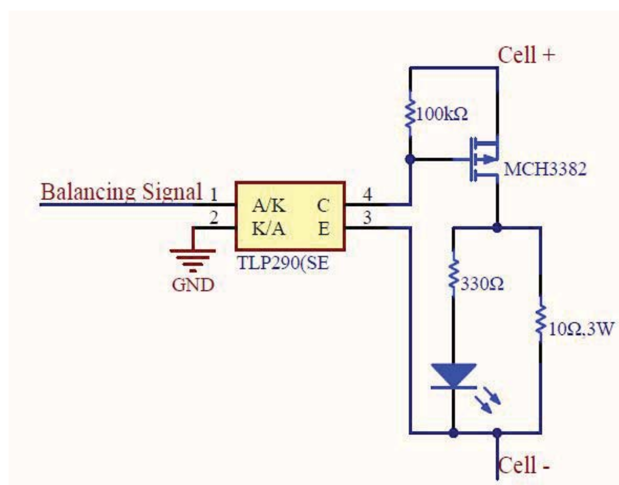

Fig. 3. Balancing circuit for individual cell balancing.

A. Balancing circuit

The choice of balancing circuit was determined after analysing various methods used for balancing as discussed in this paper [6]. Passive balancing circuits are highly reliable, economical and are simple to control [7], therefore passive balancing method was chosen. The balancing circuit involves three major components: a 10 Ω bleeder resistor, a P-channel MOSFET and an opto-coupler to drive the P-channel MOSFET. The circuit is tested to ensure that the FET is operated within its capabilities. The 100k Ω pull-up resistor ensures that the FET is not turned on due to noise. When an imbalance is detected, the opto-coupler turns on the FET by pulling the gate low.

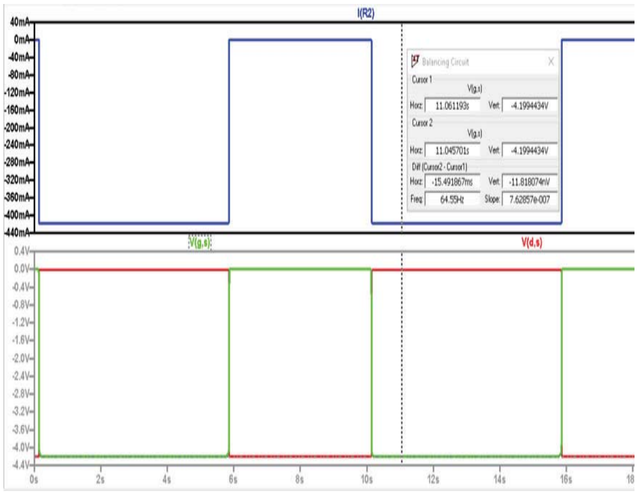

Fig. 4. Simulation results of Balancing Circuit.

The designed circuit was first validated using LTspice. FET voltages, drain current and power dissipation was measured and the circuit is implemented after ensuring the measurements were within FET ratings. The simulation results is shown in Fig.4.

VI. Battery Monitoring

To perform battery management functions, the voltage of the battery must be monitored continuously. As mentioned in [3], the most common method of measuring individual cell voltage is Channel Switching Polling method which uses Photoelectric Relay. Due to the use of large number of Photoelectric Relays, this method is not economical. In this BMS system, Voltage sensing of individual cells is measured using a voltage divider network (Fig.5) built using precision resistors. The resistor values are selected to be as large as possible to avoid any loss of current from the battery. The power rating of the resistors is 0.25 Watts ensuring minimal loss of heat. This data is further used to calculate the current.

Resistor networks are easy to implement circuits for voltage sensing and are low cost when compared to differential sensing using HV operational amplifiers. To save energy, the resistor networks are switched to the ground using an N-channel signal MOSFET while sensing.

A. CAN Interface

CAN is the most widely used communication protocol in the automobile sector owing to its advantages such as ease of scalability, noise immunity and 2-wire network. We have implemented CAN FD using an ATA6560 CAN transceiver and STM32F103c8t6 micro-controller. Since CAN uses differential communication, the need for optical isolation between multiple slaves can be eliminated as CAN transceivers have high common-mode input voltage ratings.

VII. Conclusions

With the advent of Electric Vehicles and other high-density energy storage solutions, the demand for a smart and affordable Battery Management System has increased exponentially. In the coming future each and every portable electronic device will be running on li-ion batteries or similar battery technologies as it is the most efficient and reliable power source as discussed above and also to ensure these power sources retain their capacity for a long time and run safely, the use of BMSs will be unavoidable. The BMS should be stackable and flexible to work with different systems with minimal alterations. A master-slave BMS model is easy to stack, reduces wiring harness length and provides necessary redundancy. A slave can be easily replaced in case of maloperations. Cell characterisation discussed is necessary to model the dynamic conditions during operation. A cell's characteristics can be extrapolated to obtain the dynamic behaviour of a battery pack. The project involves a PWM based closedloop discharge circuit for this purpose. The test conveys an important result that the capacity of a cell is a function of the discharge rate. This is an important parameter which affects SOC estimation

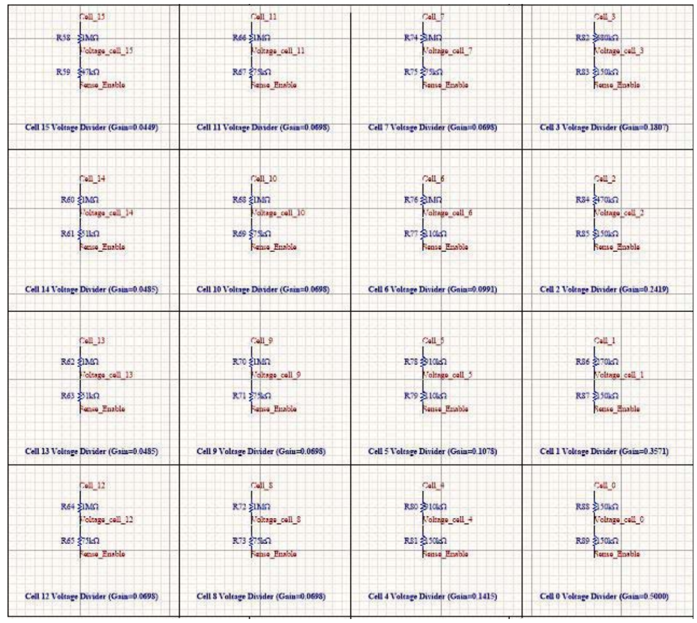

Fig. 5. Voltage Divider Network for Voltage Sensing.

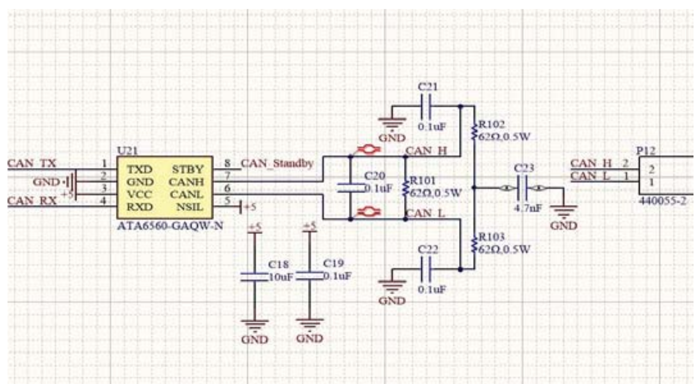

Fig. 6. CAN Circuit for master-slave communication.

in a dynamic condition like an Electric Vehicle. The passive balancing deployed is only limited to hardware design. This can be further optimised by using a balancing algorithm which will provide better cell balancing. This system can also be remotely monitored and controlled using IoT technology.

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