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DESIGN AND IMPLEMENTATION OF BATTERY MANAGEMENT SYSTEM FOR LI-ION BATTERIES BASED ON DYNAMIC BATTERY CONDITIONS

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A B S T R A C T

In order to combat global warming, lithium-ion batteries are crucial. The Lithium-ion battery used is a Lithium iron phosphate battery, also known as an LFP battery. If this battery technology is utilized outside its operating range, it might be hazardous to operation. This paper defines the primary components of the battery management system (BMS) and provides its comprehensive layout. It is proposed that the algorithm implemented in the controller (Arduino) deal with reading the battery voltages and current, calculating the maximum and minimum cell voltage in a battery pack, charge and discharge control of the cells in the battery pack and finally displaying the required battery parameters on an LCD display. Hardware implementation of BMS including cell status monitoring, charge and discharge, cell protection and equalization is performed on a 12V, 360AH prismatic LFP battery with 4 series-connected and 3 parallel-connected cells. This evaluation should lead to increased efforts toward the creation of an improved Li-ion battery management system.

Keywords*: LFP battery, BMS, Cell equalization, Charge and discharge control, Arduino*

1. INTRODUCTION

With the highest energy density, minimum memory effect, and lowest self-discharge rate, lithium-ion batteries have worldwide market viability in EV applications due to their superior characteristics and advanced technology. Due to the aforesaid properties, lithium-ion batteries will be in high demand in the future for aviation and automotive applications. LPF (Lithium Iron Phosphate) offers superior thermal and chemical stability compared to other Lithium-ion technologies and is regarded as one of the safest cell chemistries.

The battery management system (BMS) ensures the battery's safe functioning, extending its lifespan and improving its overall health. Common functions of the battery management system are Battery Cell monitoring, Input/output Voltage and Current monitoring, Charge and discharge control, estimation of battery parameters, battery protection, cell balancing and equalization, power management control, temperature control, communication and networking, Data storage, Data acquisition, and Fault Diagnosis and evaluation [3]. Controlling battery charging and discharging is the BMS's most crucial function.

The optimal assessment of the battery's state of charge is required for increased performance and prolonged battery life. Balanced cell voltage permits the battery to reach a greater level of charge (SOC)

A battery pack's cells are stacked in series and parallel to obtain a greater current and higher voltage. The irregularity of the current distribution rises as the number of parallel cells grows, but reduces as the number of parallel cells increases [1]. Various Pack models have been developed for the series-connected cells in a battery pack, including Big cell models (BCM), V_{max}+V_{min} (VVM), and the Multi-Cell Model (MCM) [2]. Having a centralized BMS with a control method that combines cell monitoring, cell equalization, and power conversion makes the BMS more compact and cost-effective [5]. In case of a large-scale Energy storage applications having multiple battery packs operating in parallel then, a Decentralized BMS architecture is proposed which enables individual battery packs to communicate with each other independently [8]. There are two primary kinds of active and passive cell balancing techniques: active and passive. Passive devices, such as capacitors and inductors, are used in active balancing to transfer the excess charge from one cell to the other cells. Using a shunt resistor, the excess charge on a specific cell is dissipated during passive balancing [4]. In cell balancing, there are numerous extended topologies, such as the transformer with multiple secondary windings and the multiplexed DC/DC converter [6]. BMS may be constructed using a voltage divider circuit in the voltage measuring process, an opto-coupled relay board to turn off the electric current, an Arduino Uno controller as the data processor, and an LCD for display [7]. This is a cost-effective option that requires little complexity in circuit design. There are numerous SOC estimation techniques, such as direct measurement that considers the voltage/impedance for measurement, Bookkeeping estimation that includes the coulomb counting method, adaptive systems such as neural/fuzzy logic/Kalman filter, and hybrid methods that combine two SOC estimation strategies [9][10]. In section 2 the basic schematic and the software implementation of the controller (Arduino) algorithm is dealt. In the section 3 hardware implementation of the proposed BMS schematic is discussed followed by section 4 with the results and its associated considerations. In the last section relevant conclusions are made and the future scope is discussed

2. ABBREVIATIONS

- **BMS**: Battery Management System
- **BCM**: Big Cell Module
- **MCM**: Multi Cell Module
- **SOC**: State of Charge
- **DCCT**: Direct Current CT

3. METHODOLOGY AND SOFTWARE IMPLEMENTATION

The battery management system should basically compose of two main circuitries. They are the Monitoring and control circuit and Protection circuit. This is depicted in the figure below:

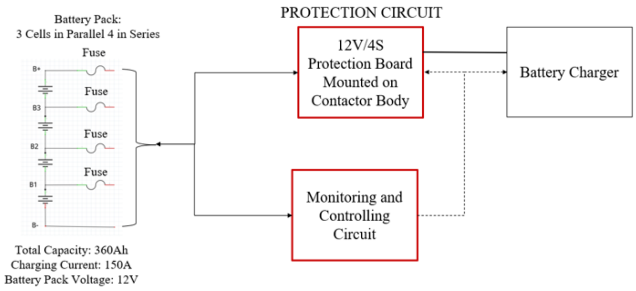


FIG. 1 - Schematic of BMS with Battery pack

The battery pack comprises of 3 parallel cells and 4 series cells. Each cell has a nominal voltage of 3.2 and a nominal capacity of 120Ah. This accounts for the pack's overall voltage of 12V and capacity of 360Ah. The complete battery pack is linked to two separate circuits. The Protection circuit is comprised of a 12V/4S protection board placed on a contactor for connecting and detaching the charger from the battery pack. This allows for the regulation of the charging and discharging cycle of a battery pack's cells at a predetermined voltage level. The specs of the batteries are shown in the table below.

Table 1 - Battery specification

Sl no	Parameter	Rating/Description
1	Cell Material	Lithium Phosphate (LiFePo4)
2	Type of cell	Prismatic
3	Nominal Capacity	120Ah
4	Nominal Voltage	3.2V
5	Internal Impedance	⩽2mΩ
6	Maximum Charge Voltage	3.65V
7	Discharge Cut-off Voltage	2.6V
8	Maximum Charge Current	200A (1C)
9	Operating Temperature	0-45℃ (Charging)
10	Cycle time	3000

As shown in the table above, the maximum charging voltage is 3.6V and the maximum discharging voltage is 2.6V. The monitoring and control circuit is comprised of the Processor Board (Arduino in this instance), opto-coupled relay board (8 Channel), DCCT (for measuring the current), and LCD (20-character 4-line display) for showing the battery data. This circuit measures the voltage and current of the battery pack, as well as provides control signals to the contactor to connect and detach the charger and regulating the charging current during the trickle charge. Below is a diagram of the Control and Monitoring circuit:

3. 1. Arduino Algorithm:

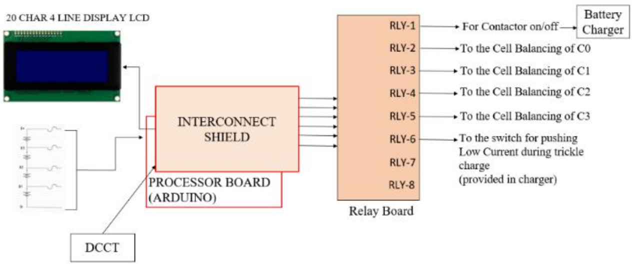


FIG. 2 - Monitoring and Control circuit schematic

The processor is the central element of the monitoring and control circuit (Arduino). It reads the pack voltage and current from DCCT, computes the maximum and minimum cell voltage in a battery pack, provides control signals for controlling charging and discharging (given to the relay board), initializes the cell balancing for cells (given to the relay board), estimates the state of charge, processes the value read by DCCT, and finally prints the necessary battery parameters on LCD.

The primary purposes of the Opto coupled relay board are to regulate the contactor and to execute cell balancing for each cell in the battery pack. Utilizing an 8-Channel opto-coupled relay board, the first relay channel is used to control the contactor, which is then connected to the charger, the next 4 channels are used for cell equalisation, and the sixth relay channel controls a switch to push a low current into the pack during trickle charging. Control of a trickle charge is given via the charger's control circuit. The 20-character, 4-line LCD display shows critical battery information, including Cell voltages, maximum and lowest cell voltage, SOC in percentage, and charging current.

In the previous section the main functions of the Arduino as the controller were being discussed. The specification of Arduino Uno is given in the table below:

Table 2 - Arduino specification

Sl no	Parameter	Rating/Description
1	Microcontroller	ATmega328P
2	Operating Voltage	5V
3	Input Voltage	7-12V
4	Digital I/O Pins	14
5	PWM Digital I/O Pins	6
6	Analog Input Pins	6
7	Flash Memory	32KB
8	Clock Speed	16MHz
9	SRAM	2KB
10	EEPROM	1KB

In this particular section we are discussing in-detail about the implementation of those functions as a flow chart. And in the upcoming discussion each of the process is described in detail with the necessary explanation and equations. The flow chart for the Arduino program is illustrated in figure 3. The first step in the flow chart is to initialize the pins were input or output modules are connected. Here initialization of the variables with the specific value which is used to store and process the required functions is also done. Inputs are basically to read the cell voltages in the battery pack and also the current from DCCT. Outputs are given to the relay board and to the LCD. The next step is to initialize the number of rows and columns for the LCD. Here since 20-character 4-line display LCD is used, hence initializing columns as 20 and rows as 4.

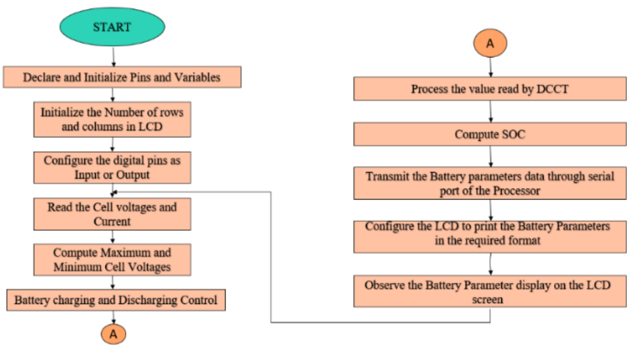


FIG. 3 - Flow chart for the Arduino Program

Initializing the pins to which input or output modules are connected is the first step in the flowchart. Here, the variables are also initialized with a specified value that is utilized to store and execute the needed functions. Inputs are mostly used to read the cell voltages in the battery pack as well as the DCCT current. The relay board and LCD both receive outputs.

Th next step is to initialize the LCD's number of rows and columns. we are using a 20-character, 4-line LCD panel. The associated input or output module must be set as an input or output. The whole program logic will continue in a loop from the following step until the system is unplugged. Then, we read the voltage from the cells in the battery pack and the current from the DCCT over the Arduino's analogue input channel. The maximum and lowest voltages among the four read cell voltages are determined by comparing the voltages of two cells in succession. Regarding charging and discharging, four control situations are observed. When one of the cell voltages surpasses the maximum cell voltage of 3.6V, the equalization circuit is engaged and the charger is disconnected from the whole battery pack via a contactor. When any cell voltage goes below 3.3V during self-discharge, the equalization circuit is disengaged and the charger is reconnected to the battery pack. When the battery pack is connected to a load and there is a significant amount of discharge, the cell voltage is not allowed to fall below the minimum voltage of 2.4V, at which point the main contactor is turned off, but a low current is allowed to pass through the charger manually until 2.4V is reached, after which point the charger is pushed into fast charging mode (150A). The fourth situation involves pack management during trickle charging. If any cell voltage hits 3.5V, the main contactor is maintained on and the charger is set to trickle charge by manipulating a switch in the charger that directs the minimum current via a resistor from the charger to the battery pack. And if the cell voltage exceeds 3.3V, trickle charging is removed and the charging current is increased. Following the supervision of charging and discharging, estimate and calculation commence. The DCCT value read is processed. The whole range of 0-5V on the Analog pin is translated to 0-1023 in the digital domain. In the digital domain, 1023/2 = 506 translates to 2.5V in the analog domain. Positive current is flowing when voltage rises from 2.5V to 5V (Charging). Negative current is current flowing when voltage lowers from 2.5V to 0V (Discharging). The illustration is as follows:

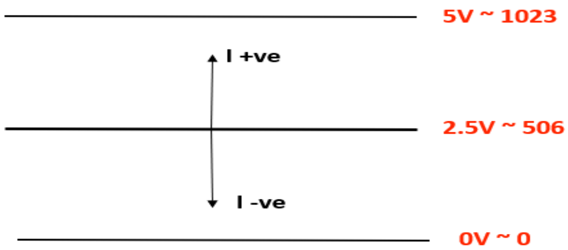


FIG. 4 - Illustration of Charge/discharge current computation

In the next step SOC using the terminal voltage method is computed. The voltage range between 3.45V and 2.8V is taken where in this range the voltage and SOC almost have a linear relationship. Then SOC of 100% is mapped to 3.45V and SOC of 10% to 2.8V. With this information two separate linear equation is obtained which upon solving a single equation is obtained. This is depicted as follows:

$$10 = m(2.8) + c \qquad (1)$$

$$100 = m(3.45) + c \qquad (2)$$

$$y = m(138) - 376 \qquad (3)$$

Upon solving eq (1) and (2) the final equation (3) is arrived. Here the variable m is taken as the minimum cell voltage obtained earlier. Then the estimated values stored in a variable is sent through the serial port in the processor for the purpose of printing the values on LCD. The values to be printed on LCD is configured to appear on a particular row/column on the display. Finally, the battery parameters are observed on the LCD display. After this step the program logic repeats itself from the point where the voltages and current are read in a loop pattern

4. HARDWARE IMPLEMENTATION

The BMS schematic mentioned is the previous section is implemented in this section. Starting with LFP battery chosen for BMS.

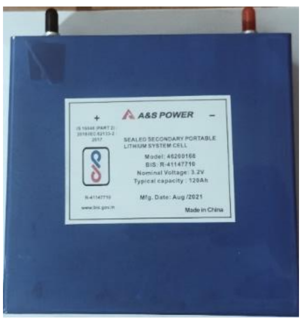


FIG. 5 -Individual LFP Cell

Figure 5 represents a Prismatic LFP (Lithium Iron Phosphate) cell with nominal voltage of 3.2V and Capacity of 120Ah. The battery pack shown in figure 6 has 3 cells in parallel and 4 cells in series.

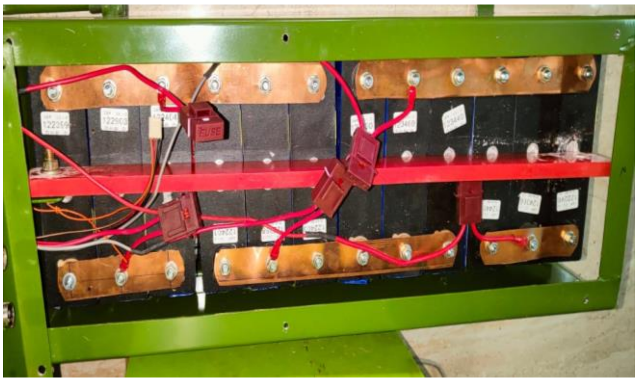
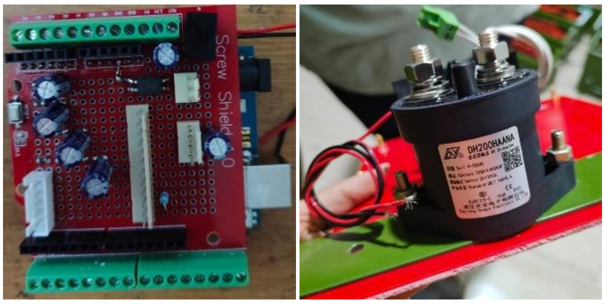


FIG. 6 - Battery pack with 3 in parallel and 4 in series

Figure 7(a) represents Interconnect shield is mounted on the Processor (Arduino) for the purpose of providing pin out. Fig 7(b) represents the 400A contactor energized by 12V coil.



(a) (b)

FIG. 7 - (a) Interconnect shield mounted on Arduino (b) DC contactor

Capacitors are provided on the interconnection shield for the purpose of protection during the surges under faulty condition. Among these 5 pins comes from the cells in the battery pack. Upon passing through capacitors, it is fed to the analog pins of Arduino. 7 pins are connected to the relay board. 12 pins are connected to LCD terminals. 3 Pins are reserved for communication with the host and 4 pins to the DCCT. Fig 7(b) which represents contactor helps to connect and disconnect the battery pack from charger.

Figure 8 represents the 8 Channel opto-coupled relay board with each of the relay rated at 5V DC. It provides control signals for the contactor to connect/disconnect from charger, cell equalization and also to the switch to initiate trickle charging which is provided in the charger. The relay board has resistors for implementing cell balancing. Each resistor is a power resistor with rating of 3ohm. This drops the voltage across the cell when the voltage increases above 3.6V. optocoupler is used for the purpose of isolation of the power and control circuit so that any disturbances on the power circuit does not affect the control circuit.

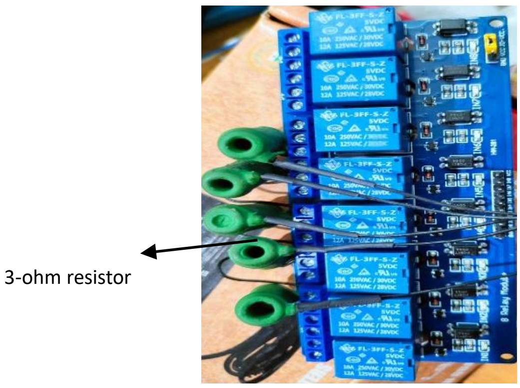


FIG. 8 – 8 Channel opto-coupled Relay board with resistor for cell balancing

The above-mentioned components are assembled together to complete the entire BMS circuitry as shown in the figure 9.

FIG. 9 - Entire BMS setup

5. RESULTS AND DISCUSSION

Upon building the BMS circuitry the results obtained on the LCD is illustrated in the figure given below:

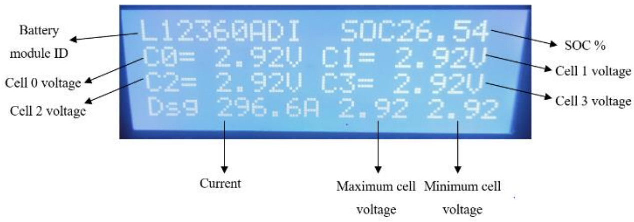


FIG. 10 – LCD display

The output of the battery parameters viewed on the liquid crystal display is shown in figure 8. Upon successful implementation of the BMS circuitry, the necessary battery parameters are transmitted to the LCD for display, which simplifies the monitoring and troubleshooting processes. Battery module ID, individual cell voltage, maximum and lowest cell voltage, State of Charge (SOC) in percentage, and current are presented as battery parameters. This allows us to determine whether or not the cell voltages are within the acceptable range, indicating that charge and discharge control has been properly implemented. Observing and validating precise SOC is also possible using theoretical computations. As we can see from the graphic above that the current is in the digital domain. Here, the only significant current measurement is whether the cells in the battery pack are being charged or discharged. With the help of an ammeter, the charger provides an accurate analogue current reading.

6. CONCLUSION

In the current literature, we have noticed the fundamental terminology used in BMS design and the primary BMS functions. In order to gain a better understanding of designing and implementing the BMS in an efficient manner, as well as the various advancements in estimation techniques, a variety of additional literatures have been reviewed. The presentation then went on to the BMS schematic and numerous critical components included in the design of a BMS. The protection and Control circuit is given in sufficient detail. The processor (Arduino) which is an integral part of the monitoring and control circuit is discussed in detail, and the flow chart for implementing the program is described with suitable explanations and equations in order to gain a better understanding of each process. This includes various functions such as reading voltage and current, performing computations and estimations, controlling the relay board, and printing the necessary battery parameters for monitoring. The technique used for determining SOC which by employing Terminal voltage approach is discussed with the assistance of equations. Using the method of passive balancing, the cells are equalized. The hardware implementation of the BMS circuits is then shown using the appropriate diagrams. The output is seen on the LCD display. This entire BMS control is the most cost-effective and can be implemented with ease.

As future work, a technique of estimating the SOC that improves computation accuracy and decreases computational weight should be described in detail. The most efficient approach for getting a non-dissipative method of cell equalization must be developed so as to increase circuit efficiency and decrease its complexity.

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