| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

|| Volume 9, Issue 6, June 2020 ||

An Efficient Battery Management System For A Series Connected Battery Pack using Arduino UNO

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ABSTRACT: With the technology of Electric Vehicles progressing swiftly, batteries have become the prominent device to store energy. Recent discussions in the field of EVs have shown that while the battery technology is developing rapidly, producing higher energy density, it is equally important to have an efficient Battery Management System for the safe and reliable operation of the battery pack. The proposed system aims at designing an efficient Battery Management System to monitor the operation of a series connected Li-ion battery pack. It uses an Op-Amp differential amplifier to measure individual cell voltage in a series connected pack. A Hall Effect sensor (ACS712) is used to measure the current flowing through the load. These values are read by Arduino UNO and then displayed on the LCD. The State of Charge of the battery is calculated using Current Integration method. The proposed work also aims at cell balancing to eliminate any voltage difference between the cells. An inductor based buck boost converter circuit is used to achieve active cell balancing. The proposed system is also capable of monitoring the voltage levels of the battery and disconnecting the load connected when the voltage level drops below the threshold value and thereby protecting the battery pack against deep discharging. The proposed system aims at optimizing the battery usage, reducing the risk of failure and increasing its lifetime.

KEYWORDS: Battery Management System, Op-amp Differential amplifier, ACS712 current sensor, Coulomb Counting, Active Cell Balancing, Deep discharge protection.

I.INTRODUCTION

In some applications like pure electric vehicles, portable power tools, personal electronic devices etc. batteries are the only paramount source of energy, it has to supply necessary power when required and therefore monitoring and protection of batteries becomes crucial. Electric vehicles are energized by a large number of battery cells hence a battery management system is necessary to maintain the battery cells in good and efficient operational condition while supplying the power required to the vehicles efficiently.

A Battery Management System (BMS) is an electronic system that monitors, controls and manages a battery pack or cell by recording the key operational parameters like voltage, current and temperature, calculating secondary data and controlling the environment of the battery, protecting it from operating in hazardous operating conditions. A BMS acts as a controller that collects the data (measured operating parameters) from the battery cells and the sensor and transmits them to the interface. When any hazardous or inefficient operating condition is detected the BMS will shut off the battery system and disconnect it from the load.

The main objectives of the proposed work - Battery voltage measurement, individual cell voltage measurement and current measurement, the State Of Charge estimation, Cell balancing, over discharge protection and Digital display. In order to ensure safe and efficient working of the battery various important parameters of battery like voltage, current and temperature should be monitored [1].

Individual cell voltages cannot be measured directly so differential amplifiers are used to measure individual cell voltages in a series connected battery pack [2]. ACS712 is a cheap, small package and accurate AC and DC current sensor, fitted for industrial and commercial use. It is a Hall Effect sensor which can be used for measurement of battery current [3].

Coulomb counting technique can be used for obtaining the State of Charge (SOC) of the battery. It is basically integration of discharge current over time to get the ampere-hour capacity of the battery. The known rated capacity and calculated remaining capacity can be used for obtaining the SOC of the battery [4].

Active cell balancing can be done using an inductor based buck- boost converter. The cell balancing circuit performs charge redistribution in bi-directional way to eliminate the voltage difference between the cells [5]. It is important to cut off the load connected to the battery when the voltage of the battery reduces below the prescribed threshold to avoid damage to the cells this can be done by using suitable over-discharge protection circuit [6].

The remainder of this paper is organized as follows: Second section discusses the block diagram of the BMS and introduces the basic functions of BMS. Section three discusses the proposed methodology and explains in detail about the voltage measurement, current measurement, State of charge (SOC) estimation, Cell balancing and Deep discharge protections which are main functions involved in BMS. Section four includes all the simulation work performed for checking the efficient working of the Cell balancing and Deep or Over- discharge protection circuit used and the results obtained. Section five discusses the outcome or results obtained. Finally, section six concludes the paper.

II.BLOCK DIAGRAM AND WORKING

The block diagram of Battery management system (BMS) is as shown in the Fig1.The various functional blocks involved are: Battery and individual cell voltage measurement module, ACS712 current sensor, SOC estimation module, Cell balancing module and Deep discharge protection module. The BMS should accurately estimate the current status of the battery using the current measured as well as be able to protect the battery from hazardous and inefficient operating conditions.

Op-Amp differential circuit which uses LM324 OP-Amp IC is used for battery voltage and individual cell voltage measurement. The battery current is measured using the Hall Effect sensor ACS712. The measured voltages from Op-Amp differential circuit and measured current from ACS712 sensor is given to the Arduino UNO. Using these measured parameters the SOC estimation is done by Arduino UNO using accurate State of charge (SOC) estimation algorithm .The individual cells in the battery pack are monitored continuously by the Cell balancing module which performs active cell balancing if voltage difference between cells exceeds the threshold value. The Deep-discharge protection module protects the battery and the load by disconnecting the battery from the load during over-discharge condition before any damage occurs to the load or battery. The Arduino UNO reads the measured parameters such as individual cell voltages, battery voltage and current and displays them on the LCD. The SOC which is estimated is also displayed on the LCD.

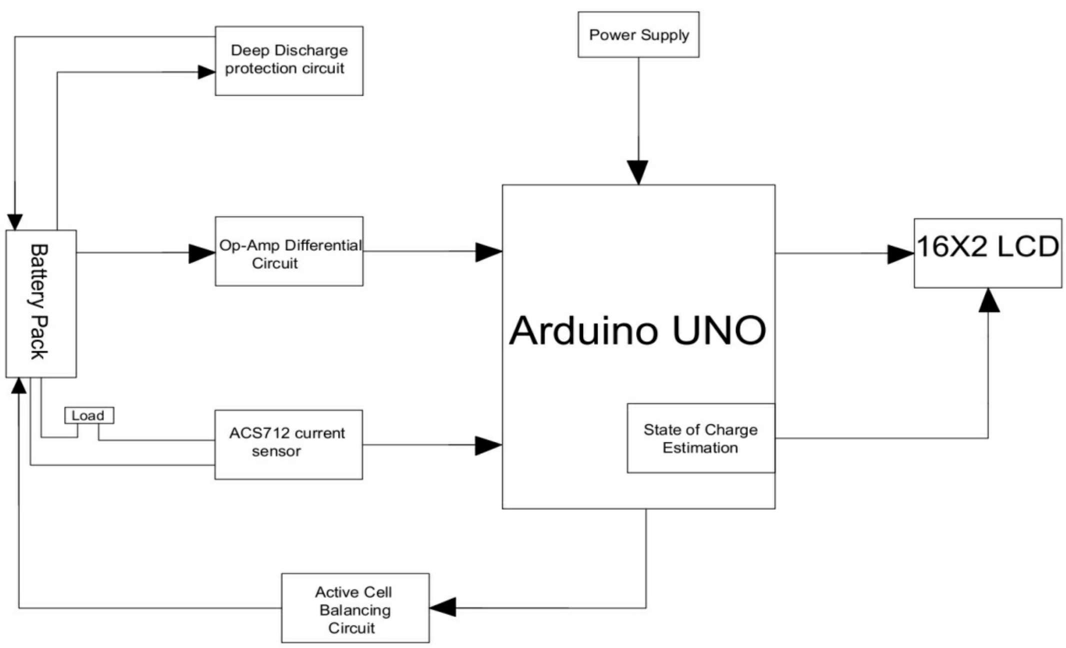

Fig. 1 – Block Diagram of a Battery Management System

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

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III.PROPOSED METHODOLOGY

A Battery Management System should be able to accurately estimate the status of the battery as well as be able to protect the battery from hazardous and inefficient operating conditions. It should primarily have the following functions - cell voltage measurement, battery voltage measurement, current measurement, and state of charge estimation, cell balancing and protection against over discharge. For the sake of the project we have connected four Li-ion (3.7V-4.2V) 18650 cells of 2600mAh capacity in series to form a simple battery pack.

3.1 Voltage Measurement

The voltage level of the battery pack represents its current condition. Thus, a BMS has to primarily measure the individual cell voltages as well as total battery voltage of a battery pack. The proposed work measures individual cell voltage as well as total battery voltage using an Op-Amp differential amplifier. It is difficult to measure individual cell voltage in a series connected battery pack since the reference point remains the same. The cell voltage that has one end connected to the ground could be measured directly. But, when we read the voltage of a cell that isn't directly connected to the ground it gives the voltage of that cell along with the voltages of the cells preceding it. The Fig.2 illustrates the difficulties faced while measuring the individual cell voltage in a series connected battery pack.

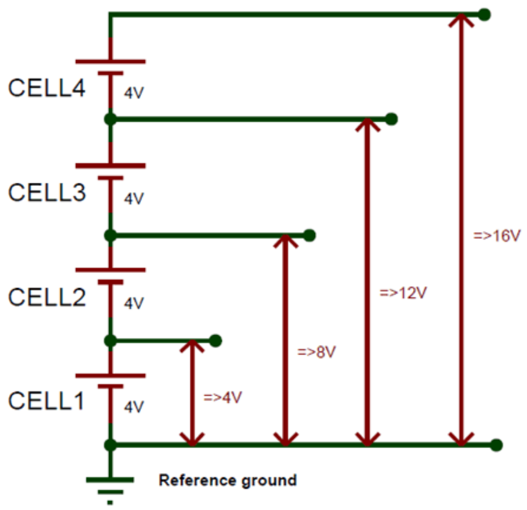

Fig. 2 – Individual Voltage measurement in series connected battery pack

Thus, we need an extra circuit in between the battery and a microcontroller that will help us measure the individual cell voltages. In the proposed work, an Op-Amp Differential amplifier is used to obtain the difference between each cell terminal to measure their respective individual voltages. An Op-amp differential amplifier gives the difference between the two voltage values provided to its inverting and non-inverting pin. The Fig.3 just depicts how we can measure the individual cell voltage using an Op-Amp as a differential amplifier. The actual circuit will need a lot more other components.

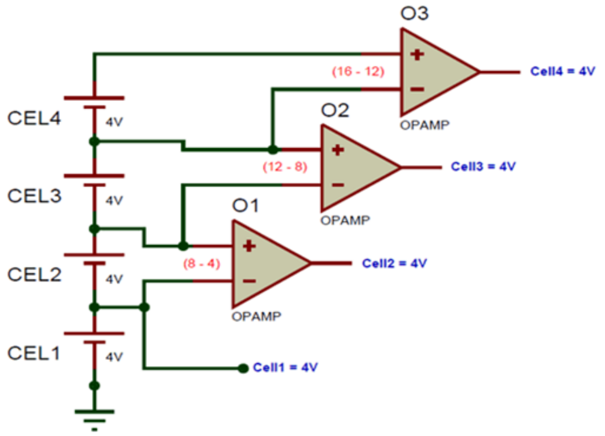

Fig. 3 - Individual cell voltage measurement using Op-Amp Differentiator

3.2 Current Measurement

Current measurement is very important, especially for the determination of the state of battery variables. It is an important parameter to calculate the State of Charge of the battery. In the proposed work, current measurement is done by ACS712 Hall Effect current sensor. It is a cheap, small package and accurate AC and DC current sensor, fitted for industrial and commercial use. Here, an LED in series with a resistor of value 1kΩ is considered as load. The output of the sensor is voltage proportional to the DC primary sensed current. The value read by Arduino is converted into current and displayed on the LCD. Fig. 4 shows the connection of ACS712 with the battery pack and Arduino UNO.

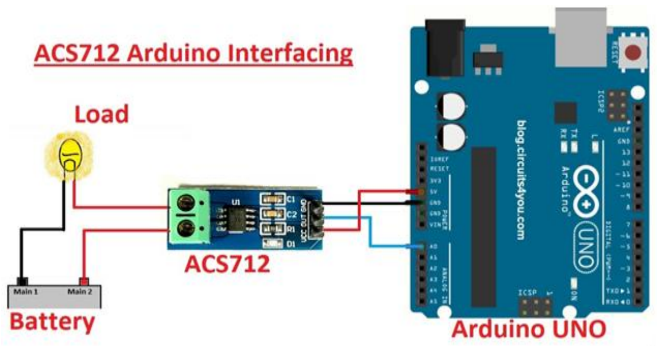

Fig. 4 - ACS712 Current sensor and Arduino Interfacing

3.3 State of Charge (SOC) Estimation

State of Charge (SOC) is an important parameter in BMS hence its estimation is one of the main functions of BMS. It basically represents the level of charge of an electric battery relative to its capacity. SOC of a battery can be calculated from the parameters which are measured like voltage and current since it cannot be measured directly. Estimation of the SOC accurately and its implementation is difficult, because battery models are limited and there are parametric uncertainties.

In the proposed work, SOC is estimated using the Coulomb Counting method which is also called the Current Integration method. The algorithm for estimation of SOC is as follow:

1. The rated capacity of the battery is taken as 2600mAh (mentioned by the manufacturer)
2. The current through the load is measured using the ACS712 sensor as explained in section 3.2
3. The mills () function of the Arduino is used to obtain the elapsed time.
4. The charge consumed by the load is calculated as -

Charge (Q) = Current (I in mA) × Time (t in hours) ----- in mAh

5. The remaining capacity of the battery is obtained by -

Remaining Capacity = Rated capacity - Charge consumed ----- in mAh

6. The charge left in the battery relative to its rated capacity (State of Charge) can be calculated as -

SOC = [(Remaining Capacity) / (Rated Capacity)] X 100

3.4 Cell Balancing

Cell balancing is one among the main processes or tasks performed in BMS. Cell balancing helps in optimally using the battery cell capacities by eliminating the differences in capacity among the battery cells. Cell balancing can be obtained either by passing the excess charge through a resistor (Passive balancing) or by redistributing the charge from highly charged cell to lowly charged cell using capacitors or inductors (Active balancing).

In the proposed work, the charge redistribution is obtained through an inductor based buck-boost converter. When Cell N has higher voltage than Cell N-1, MOSFET Sn is turned ON and the inductor is charged through capacitor Cn. The current flows from the inductor to Cell N-1 through Diode Dn-1, charging it when the MOSFET is turned OFF. Similarly, the charge flows from bottom to top cell. Thus, the circuit redistributes the charges in bi-directional way eliminating the voltage difference between them. Fig. 5 gives the inductor based buck boost converter circuit which is used for active cell balancing in the proposed work.

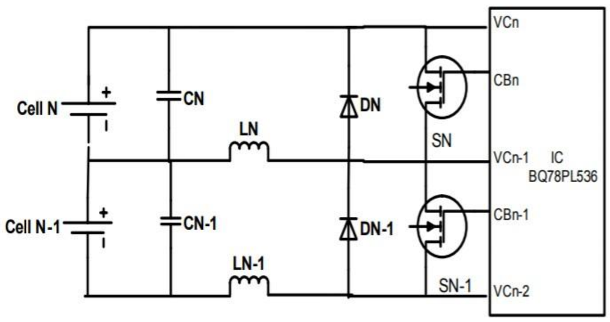

Fig. 5 - Inductor based Buck-Boost Converter for Active Cell Balancing

3.5 Deep Discharge Protection

Deep discharging commonly known as over-discharging occurs in a battery when it has been discharged at its full capacity. Protection of battery against deep discharging is crucial as the deeply discharged battery is difficult to recharge because of the increase in its internal resistance. The Fig. 6 shows the deep discharge protection circuit used in the proposed system. When the battery voltage drops below the cut-off voltage, the Zener diode with the breakdown voltage equal to cut-off voltage, will cut off the conduction and obstruct the flow of base current to NPN transistor, disconnecting battery from the load in order to avoid damage to load and battery.

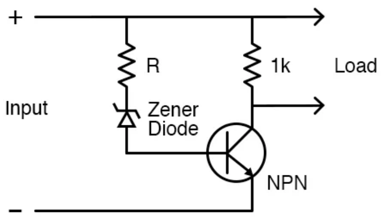

Fig.6 - Deep Discharge Protection

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

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IV.SIMULATION OF DEEP DISCHARGE PROTECTION AND CELL BALANCING CIRCUITS

1. The circuit shown in Fig. 6 was simulated using PSPICE for protection of 12V battery against deep discharge. When the voltage level of the battery drops below 8V, the zener diode breaks down and disconnects the load from the battery and thereby protecting it.

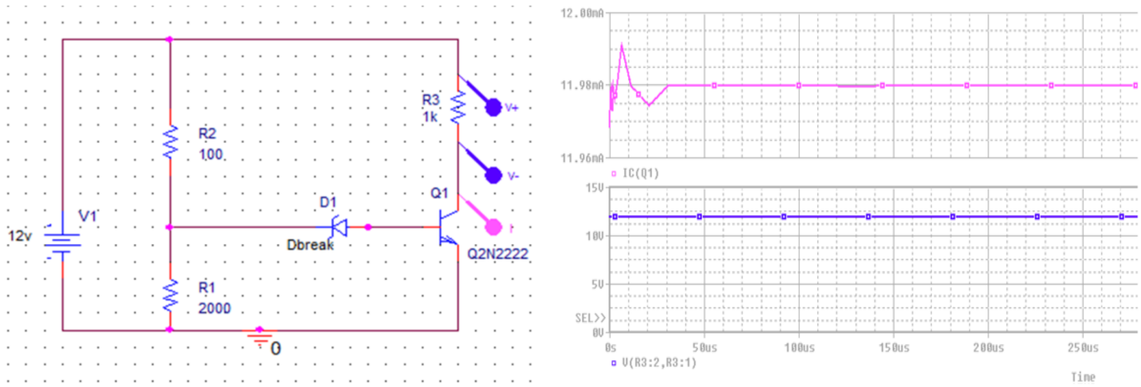

Fig. 7 - Simulation circuit, Load current and Voltage waveforms when battery is at 12V

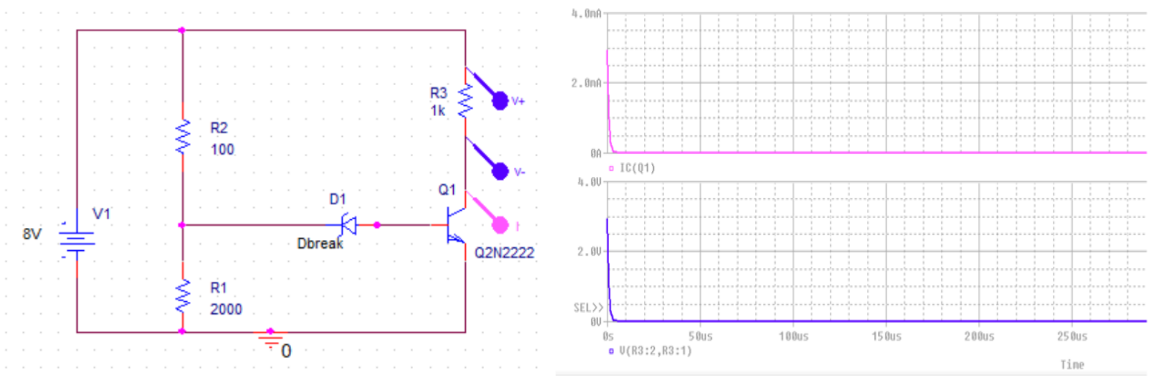

Fig. 8 – Simulation circuit, Load current and Voltage waveforms when battery is at 8V

2. The cell balancing circuit shown in Fig.5 was simulated using PSPICE for the charge flow from top to bottom cell and the results were validated. The Fig.10 shows that the current flows from V2 to V1 thereby balancing the cells.

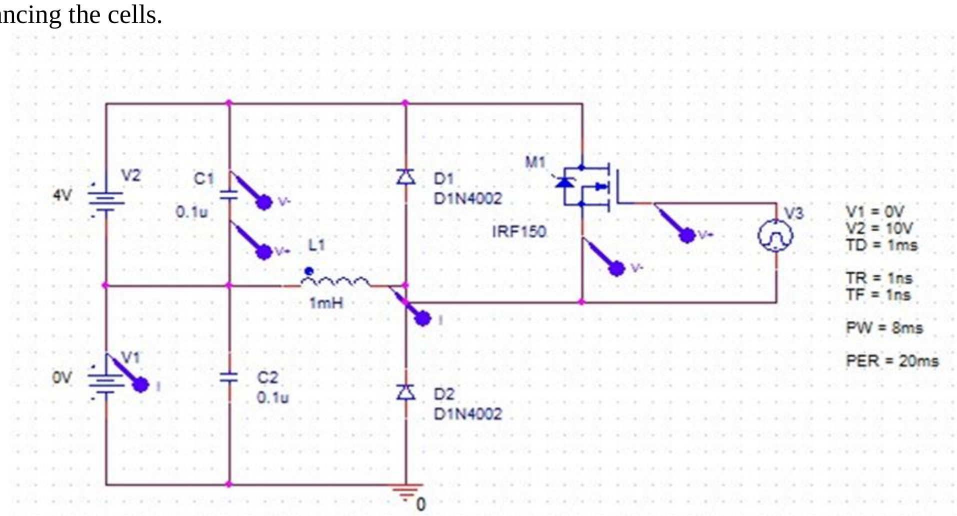

Fig. 9 - Simulation circuit for Active Cell Balancing

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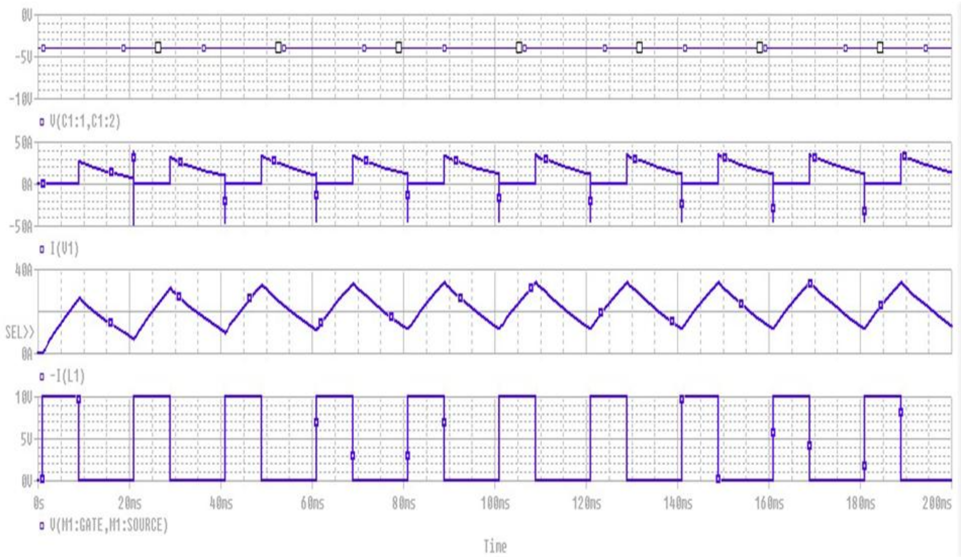

Fig. 10 -Top cell to bottom cell energy transfer

V. RESULTS AND DISCUSSION

The proposed system as expected measures various parameters of the battery and provides protection for safe and reliable operation. The successful hardware implementation of Op-amp differential amplifier for measurement of individual cell voltages has been done. The individual cell voltage and pack voltage were measured and displayed on LCD as explained in section 3.1. The cell voltages measured were added and compared with the total pack voltage measured. The measurement of discharge current flowing through a load was done and displayed on the LCD. Algorithm for estimation of State of charge (SOC) of the battery has been developed which uses the measured value of current. The working of active cell balancing circuit has been validated through simulation using the PSPICE model. The waveforms support the working explained. The testing of Deep-discharge or over-discharge protection circuit was successfully done. The deep-discharge protection circuit disconnects the load from the battery when the voltage level of a 12V battery drops below 8V. Waveforms obtained in simulation confirm the correct working of the circuit and validates the results. The Fig.11 and Fig.12 shows the individual cell voltages and total battery voltage that was displayed on the LCD using the Op-Amp differential amplifier as explained in section 3.1. The Fig.13 shows the discharge current measured using ACS712 as explained in section 3.2.

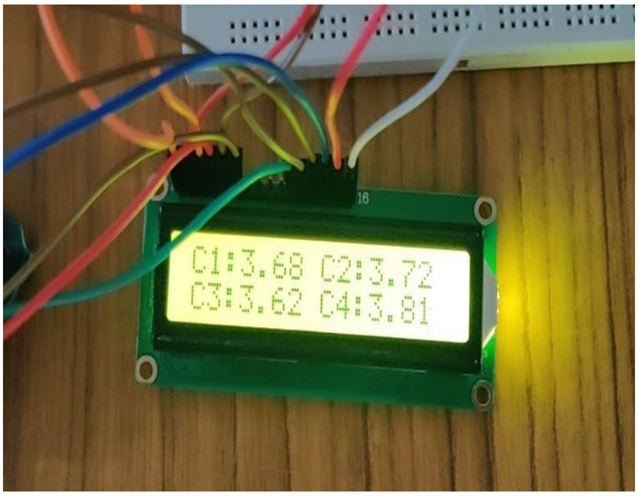

Fig. 11 – Individual Cell Voltage

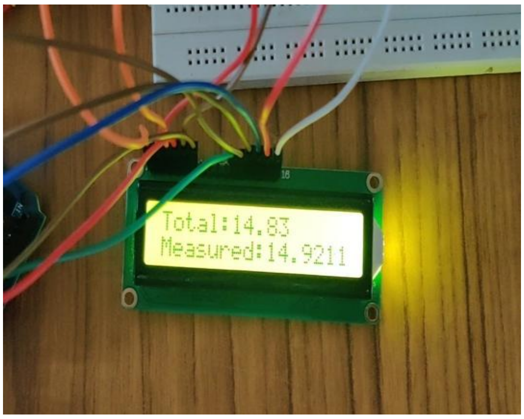

Fig. 12 – Pack Voltage

Fig. 13 – Discharge Current

VI.CONCLUSION

A Battery Management System (BMS) for efficient working of a battery pack with series connected cells was designed and implemented. The parameters like individual cell voltages, battery voltage and current were monitored and displayed. Active cell balancing and deep discharge protection circuit were successfully tested for their efficient working. The proposed model is for a simple battery pack which is used in Laptops or power banks but it can be used for an electric vehicle battery as well. Further extension of this system for monitoring various other parameters of a battery such as temperature of the pack can be done.

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