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Design and Analysis of Battery Management System using Passive Cell Balancing

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Abstract: Due to the increasing demand for Electric Vehicles (EVs) worldwide is an implication of economic-technological efforts to reduce fossil fuel challenges. Energy storage which powers electric vehicles is a very important component. Battery packs used as energy storage for electric vehicles use many battery cells connected in series and in parallel. These battery cells require a close monitoring and management system while operating in an electric vehicle. Such a system, called the Battery Management System (BMS). BMS and battery packs play a very important role for EVs to become the best technical and commercial alternative to gasoline-based vehicles. BMS improves battery performance, and extends battery life while ensuring a safe operating range. Cell voltage balancing with State of Charge (SOC) monitoring is part of an important function of BMS. This paper focuses on the design and analysis of a passive cell balancing method for lithium-ion (Li-Ion) batteries based on the Arduino-Nano controller. This paper also deals with the simulation to demonstrate the SOC estimation using Coulomb counting method and passive cell balancing mechanism using MATLAB and results were analysed.

Index Terms - **Electric Vehicles, battery Management System, Passive Cell Balancing, State of Charge, Coulomb Counting, MATLAB.**

I. INTRODUCTION

In the recent years, EV's have gained considerable popularity. They are attractive mainly due to the integration of many smart applications and efficient energy saving technology, thereby addressing bigger problems associated with fossil fuels. EV Technology is considered as a potential solution to reduce emissions influence and depletion of petroleum resource reservoirs. As Electric Vehicle technology develops, many of its components and subsystems are getting better and better. Even then, mostly challenges are faced in design and development of Energy Storage Source (ESS). Frequently used ESS in EVs is the battery. Energy Storage Systems play a critical function within the fields of EVs. Li-ion batteries are more advantages as compared to the opposite rechargeable battery like Lead-acid, Nickel-Cadmium, Nickel-metal-hydride, etc. Lithium-ion batteries have the benefits of high energy density, long life, low self-discharge rate, no memory effect, non-toxic, comparatively low maintenance, fast charging, etc. over their contemporaries. They can supply large amounts of current for high-power applications, which has been traditional. For a Li-ion cell, the nominal voltage is 3.7V, maximum voltage is 4.2V and minimum voltage is 2.6V. If the intense battery limits are violated, i.e., any cell is overcharged to over 4.2V or discharged to but 2.7V, this will result in unstable battery condition and even causes fire hazard.

Therefore, the look of balancing system is essential to advance battery pack energy efficiency, cycle life and safety. The excess energy dissipation whether within the sort of heat, balancing mode are often divided into active balancing (non-dissipative) and passive balancing (dissipative). Active balancing can transfer energy to eliminate the inconsistencies between the batteries by employ inductors, capacitors, transformers, external power, and other modes. This sort of equalization method can achieve higher energy utilization, while the circuit is complex, and the cost is higher. Passive balancing dissipates excess energy within the type of heat through a parallel resistor. This equalization method is straightforward, convenient, flexible, low price and small, but this technology has disadvantages involving energy waste and causing burden to thermal management.

This article presents the design details of Arduino controlled BMS with passive cell balancing method. This system protects the Lithium-ion cells against the asymmetrical cell voltages and SOC. For effective functioning of BMS, an accurate SOC estimation of each battery cell of the pack is necessary. Multiple algorithms for estimation of SOC are suggested in literature. These are categorized into various types such as direct methods, Book-keeping methods, model-based methods, etc. In this article, an important method of SOC estimation using Coulombs counting has been considered.

II. BATTEY CELL BALANCING

Cell balancing methods can be classified into passive balancing and active balancing. The passive cell balancing method is simple, inexpensive, and easy to implement. It is therefore the most common and widely used method in industries today. Passive cell balancing is accomplished by dissipating the energy of overcharged cells with an external resistor until all cell voltages match. On the other hand, the active cell balancing circuit transfers excess energy from the cell with higher load to the cell with lower load. This excess cellular energy is transferred by the means of energy converters connected across each of the cells. Active cell balancing circuit provides higher battery efficiency and shorter cell balancing time compared to passive cell balancing. Due to the inclusion of converters in each cell, battery packs become very expensive and complex [6].

In this article, only the passive cell balanced method has been considered and is described in detail below.

2.1 Passive Cell balancing

Passive Cell Balancing, in this topology, excess charge is removed from the over charged cell by the controlled operation of power switches (SW1, SW2, and SW3) such as MOSFETs which is enabled via the microcontroller. When there is an imbalance between cells, the microcontroller decides which switch should be activated. When the switch is on, the resistor gets shunted across that cell and dissipates the excess of charge [4]. The circuit diagram of passive cell balancing is as shown in Fig. 2.1.

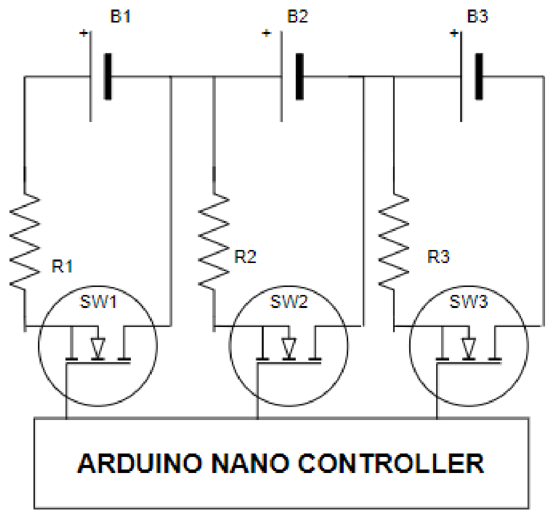

FIG.2.1 CIRCUIT SCHEMATIC OF PASSIVE CELL BALANCING.

Passive balancing method has a higher energy loss, but this method is still widely used in industries due to its reliability and simplicity. The control method is simple and cheaper when it is used for low power applications and is easy to implement with small size. This method is suitable for both Hybrid Electric Vehicle (HEV) and EV.

III. BATTERY SOC ESTIMATION

The SOC refers to the level available capacity of the battery as compared to its rated capacity. It is usually expressed as a percentage between 0% and 100%, recommended from a completely depleted battery to a fully charged one. To calculate SOC, the voltage at the cell terminals, the current in the cell and the temperature of each cell is necessary.

The various SOC estimation methods have been proposed which are classified mainly as Direct and Indirect methods. Coulomb Counting Method is considered as one of the direct methods implemented in this work is described below.

3.1 Coulomb counting Method of SOC Estimation

Coulomb counting method is also known as battery current integration method. In this method, SOC is estimated current integration terms represent the total amount of charge transferred during charging and discharging conditions.

This is represented mathematical representation as shown in the equation below [1].

$$\mathrm{SOC(T)\%} = \mathrm{SOC(To)} + \frac{1}{\mathrm{Qrated}} \int_{t0}^{to+t} \mathrm{I(dt)}(s) * 100\text{----------} \quad (1)$$

From (1), the rated capacity of the battery (Qrated) can be obtained from the manufacturer's specifications and sum to the initial state of charge SOC (To) [10].

IV. SOFTWARE IMPLEMENTATION

In simulation, the design of a passive cell balancing was realized for 3 cells of Lithium-Ion batteries with SOC estimation algorithm coded Aurdino-nano controller. Fig. 4.1, represents the SOC estimation algorithm. It primarily involves defining variables and Input parameters. In a string of series-connected cells B1-B3, if the cells voltage is less than 13, then the SOC is estimated by (1). If the condition goes false, then the SOC estimation is terminated.

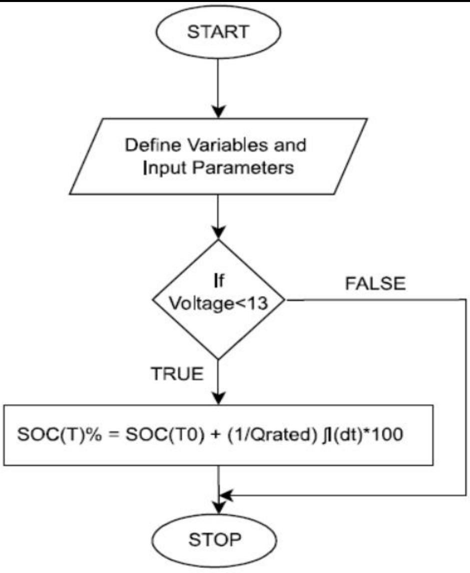

FIG. 4.1 SOC ESTIMATION ALGORITHM.

Fig. 4.2 represents the simulation of SOC estimation using Coulomb Counting method in MATLAB. It involves calculation of current in each sample and integrates with the charging and discharging currents over the operating periods. However, the remaining charge is always less than the stored charge in the charging and discharging cycle.

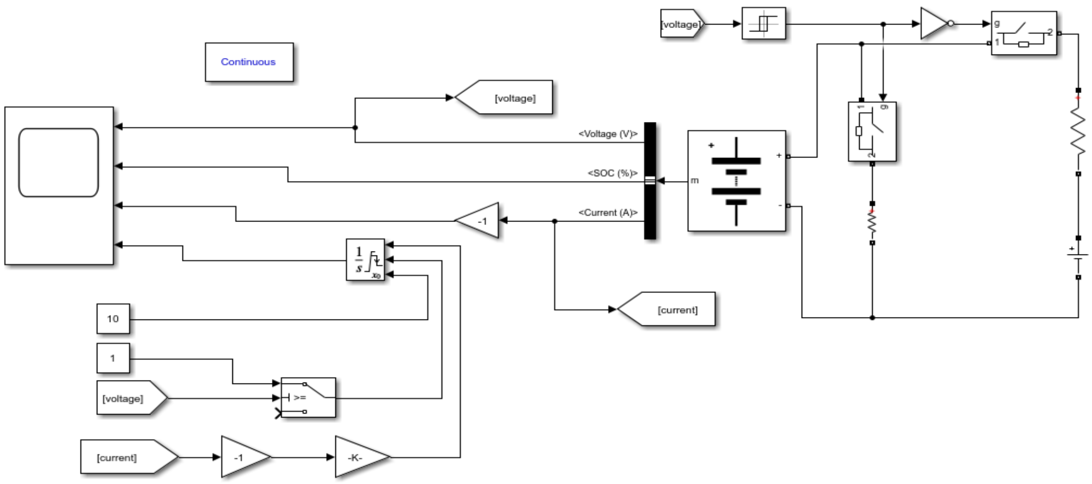

FIG.4.2.SIMULATION MODEL FOR SOC ESTIMATION.

Fig. 4.3(a) represents the Voltage cure were the voltage is increased during charging till the threshold value 4.2 V and voltage decreased during discharging till the minimum value 2.6 V of Battery cells. Fig. 4.3(b) indicates the SOC of the battery is maintained at 20% initially and during charging the SOC of the battery increases approximately to 97% and during discharging the SOC level of the battery decreases to 8% and Fig. 4.3(c) symbolize current during charging of the battery is positive and current is negative during discharging cycle.

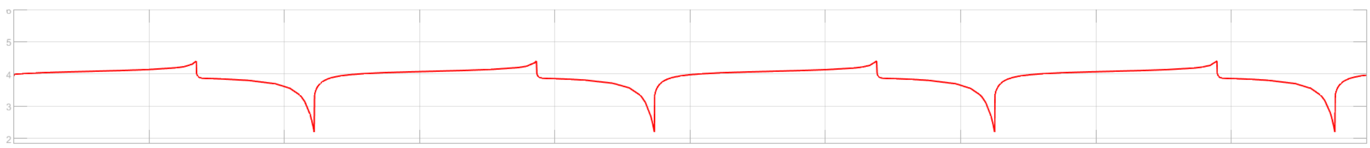

FIG. 4.3(A) VOLTAGE CURVES DURING CHARGING AND DISCHARGING OPERATION OF BATTERY CELLS.

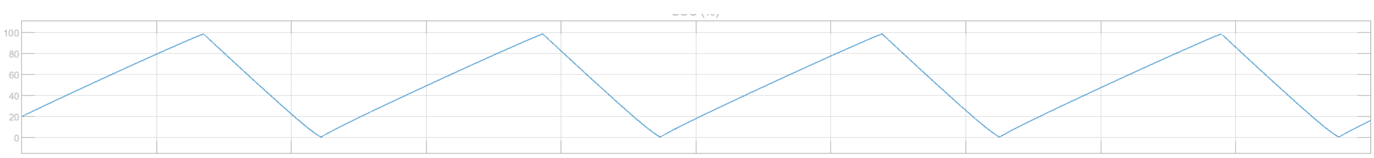

FIG. 4.3(B) SOC ESTIMATED CURVES DURING CHARGING AND DISCHARGING OPERATION BATTERY CELLS.

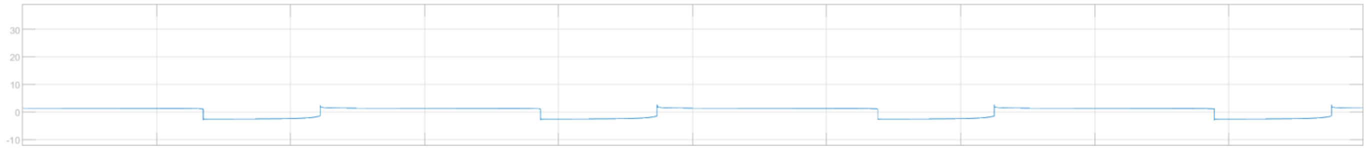

FIG. 4.3(B) CURRENT WAVEFORMS DURING CHARGING AND DISCHARGING OPERATION BATTERY CELLS.

Fig. 4.4 shows the proposed cell balancing algorithm implemented. It involves the continuous monitoring of the SOC of each cell B1-B3. In a string of series-connected cells B1-B3, the cell with the highest SOC is identified as compared to the SOC of other cells. Any cell having the positive differential SOC compared to other, the MOSFET switch in that cell circuit is triggered ON. Thus, the resistor gets connected across the cell leading to the discharge of the cell until the time it matches with the voltage rest of the cells. To prevent the continuous switching operation of MOSFETs, the cell balancing algorithm is implemented such that MOSFETs will be turned on only when the voltage difference between any of the cells is ≤ 20mV. Or else, the cell balancing operation is kept idle.

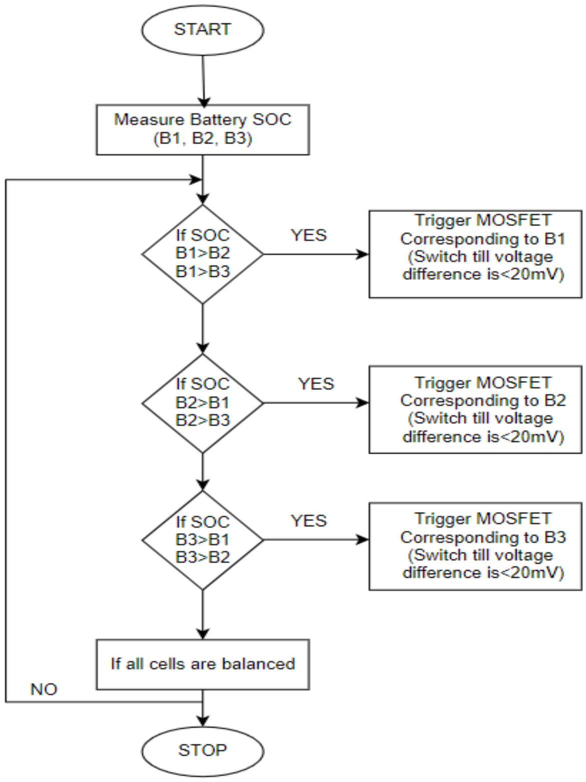

FIG. 4.4 CELL BALANCING ALGORITHM.

The proposed cell balancing circuit is simulated using MATLAB tool which carried out for two cases viz, during charging, discharging conditions as shown in Fig. 4.5(a). To demonstrate battery balancing, the State of Charge (SOC) of the cells is initialized with the difference of 5% between adjacent cells. MATLAB model was created for the 3cells Li-ion battery pack. Battery Cell specification was set according to the Li-Ion cell manufacturer datasheet. The simulation of SOC based cell balancing using a MOSFET and a resistor placed in parallel with each cell is realized. MOSFET corresponding to each battery is triggered ON when there is a voltage difference (i.e., ≤ 20mV) which determines the following condition based on the algorithm. Fig. 4.5(b) Voltage Function Block and Pulse Generation Block, MATLAB Simulation Model for Passive Cell Balancing. A Battery cell SOC is greater than other battery cells SOC in the string: MOSFET is triggered simultaneously and when all the cells are balanced, triggering is STOP corresponding to that MOSFET. The resistor value is taken as 10Ω to operate the circuit. These values have been calculated considering the losses occurring in MOSFETS and resistors. The circuit operation is based on a control algorithm as shown in Fig. 4.4. When the B1 SOC is greater than B2, the switch across the B1 is turned ON. Thus, similar logic is for B2 and B3. The simulation results were recorded for cells during charging, discharging conditions. The following section provides the simulation results obtained under the above-mentioned conditions and the discussion based on the same.

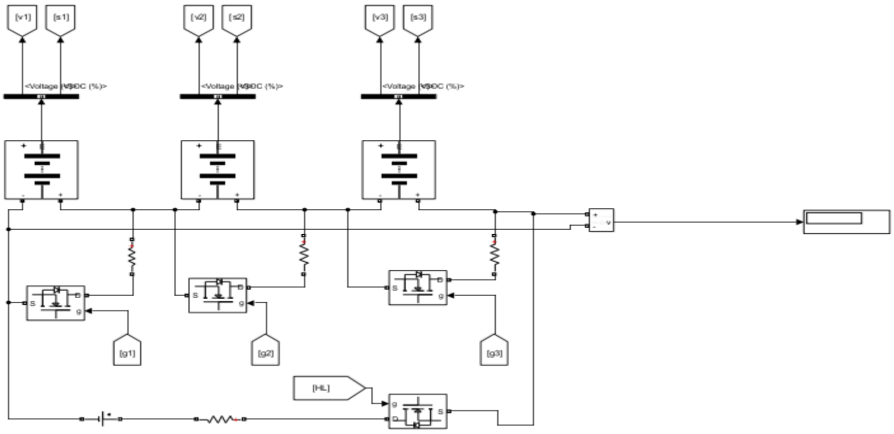

FIG. 4.5(A) MATLAB SIMULATION MODEL FOR PASSIVE CELL BALANCING.

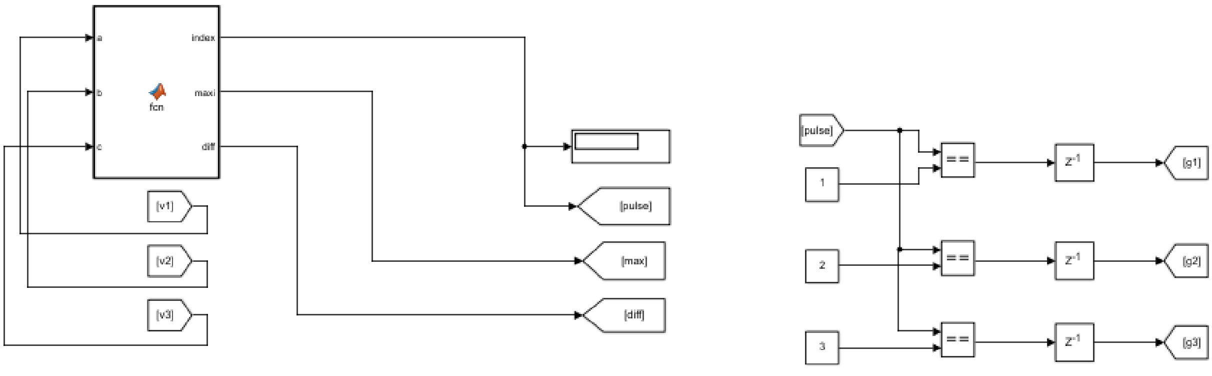

FIG. 4.5(B) VOLTAGE FUNCTION BLOCK AND PULSE GENERATION BLOCK, MATLAB SIMULATION MODEL FOR PASSIVE CELL BALANCING.

The initial cell voltages are 3.9, 3.93, 3.97 and SOC was initialized as 65%, 70% and 75% for cells B1, B2, and B3 respectively with a variation of 5% between B1 to B3. When the cells were balanced the SOC of all cells reached 97%. To balance 5% variation at the beginning charging till the time reaches 4.2 i.e., cells reach the maximum value. The time taken was 5000 sec in overall 1600sec. During discharging operation, a load resistor is shunted across the battery pack. The cell voltages are compared. The cell with least voltage level is identified and the remaining two battery cells are discharges to the same levels. When the cells were balanced with the SOC of all cells was reached 20%. To balance 5% variation with SOC and the time taken was 1600sec in overall 3000sec of circuit operation as shown in Fig. 4.6.

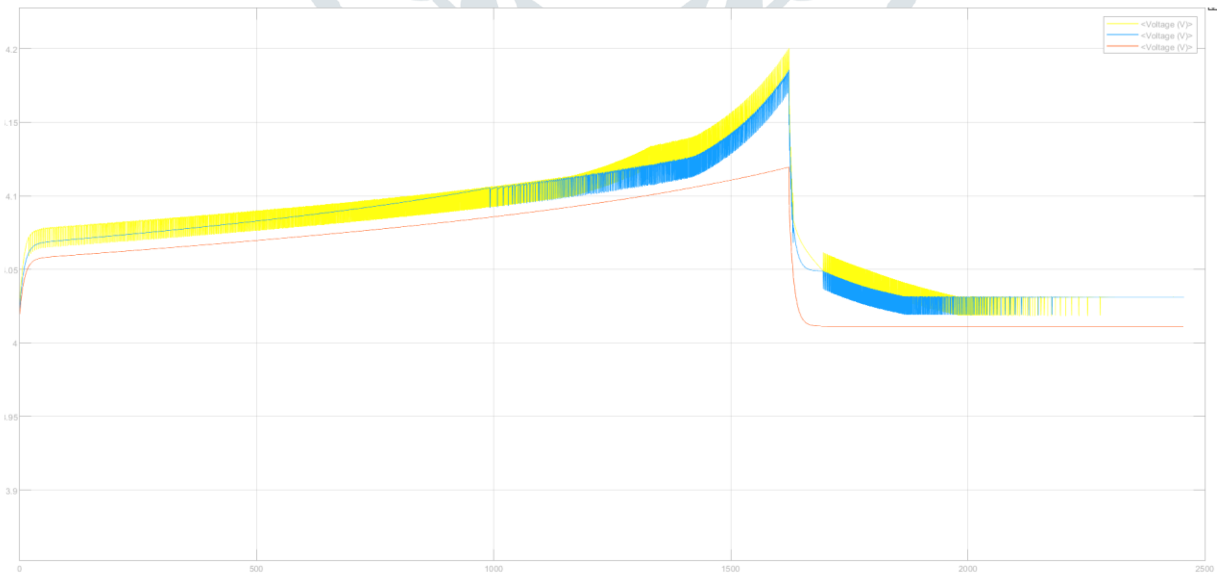

FIG. 4.6 CELL BALANCING CURVES DURING CHARGING AND DISCHARGING OPERATION OF BATTERY CELLS.

V. Conclusion

BMS is required for the EV battery pack to protect the battery and improve its life and performance. The work presented in this paper illustrates the use of Arduino-nano controller features, but the lower cost in BMS can provide the desired functionalities of the BMS. The passive cell balancing method is simple and cost-effective solution to be used in an EV battery pack. Therefore, it is one of the common methods which are followed by industries.

This paper presents the simulation results for BMS based passive cell balancing circuit with the Coulomb counting method of SOC estimation. This is followed by battery modelling using equivalent circuit and the charge and discharge graph, which is explained with the help of the equivalent circuit model. MATLAB/Simulink modelling of three cells and with their charge and discharge graphs are discussed after balancing techniques. These results showed that battery balancing, and SOC estimation will be effectively achieved using this topology.

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