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Improvement of Li-ion Battery Active Balancer Using PI-Controller

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Abstract

This paper presents simulation and design for the improvement of Li-ion battery active balancer using PI controller. The growing market for lithium ion (Li-ion) battery cells has made a positive impact towards electrical energy storage (EES) system throughout the advancing technological and scientific world. Balancing in a battery pack has become a main priority to avoid over-charging and over-discharging while also improving the Li-ion battery life. Unlike passive balancing, active balancing transfers the energy from one cell to another or controls the cell's output, thus improving its efficiency. This paper presents how previous work was accomplished by many scholars in order to avail themselves of the active balancing project. A cell model was shown in this paper that was built based on energy transfer circuit theories. A capacitor(C), inductor (L), MOSFET (M) and Diode (D) were used in the circuit build in order to balance the cells of different State-of-Charge (SOC). A PI controller was added with circuit to improve the voltage efficiency. After adding PI controller, the voltage balance of the cell was seen improved.

Keywords

PI controller, *State-of-Charge,* MOSFET, Lithium, Diode, Cell balancing

1. Introduction

Individual cells in a battery pack have varying capacities, therefore they may be at different states of charge over the course of charge and SOC. Variations in capacity are caused by manufacturing variances, assembly variances cells from one production run mixed with others, cell ageing, impurities, or environmental exposure of some Cells [1].

Cell pack balancing helps to maximize the pack's capacity and service life by ensuring that each cell maintains a similar state-of-charge throughout the largest feasible range, despite their varied capacities. Only packs containing many cells are required balancing due to parallel cells are physically connected to one another, they will naturally balance, but groups of parallel wired cells interconnected in series or parallel-series connection must be balanced [10].

The battery management system ought to monitor the condition of individual cells operational characteristics such as temperature, voltage, and current drawn through it is often measured through the entire cell pack rather than measuring individual cell and possibly with protection at the cell level against abnormally high current such as in a short or other fault. An active cell balancer, however, will not monitor the characteristics mentioned but will balance a cell efficiently during charging & Discharging. Failure to do so will result in permanent cell damage and, in extreme cases, cell polarity reversal, internal gas generation, thermal runaway and other catastrophic failures. There is a possibility that it will happen. If the cell is not balanced so that the upper and lower cutoff frequencies match at least the state of the cell with the Lowest capacity, the energy that can be withdrawn from the battery and returned to the battery is limited [11].

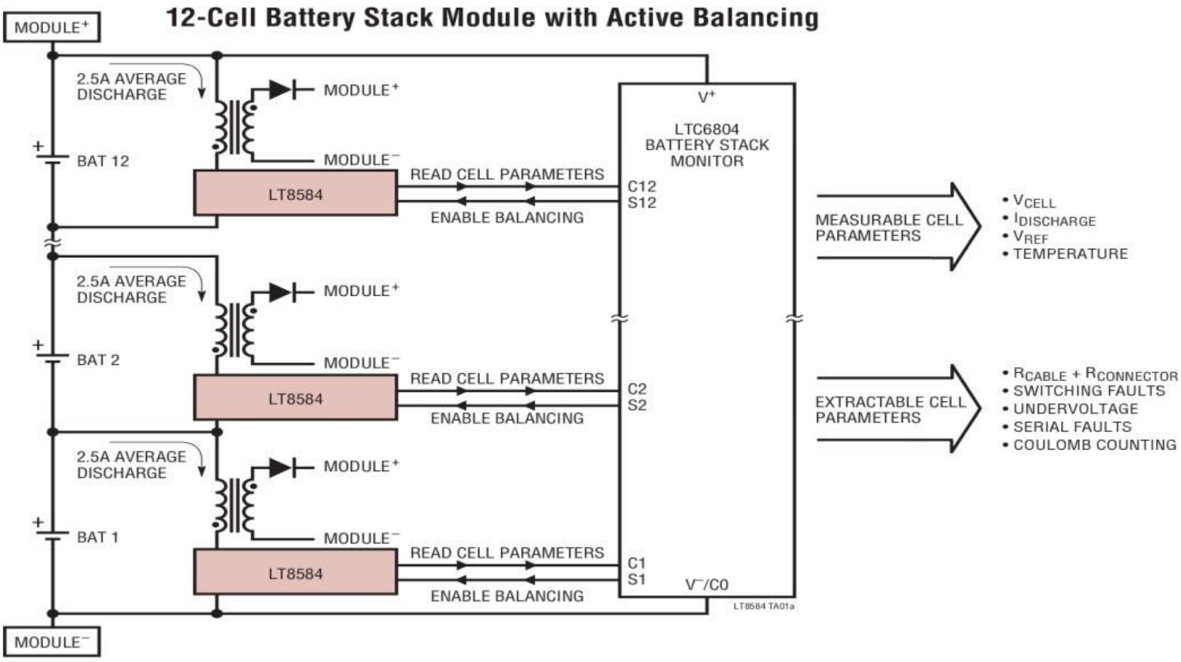

Figure 1. Modern active balancing unit

Lithium cells are susceptible to increased cell breakdown if they are overheated or overcharged. If a lithium-ion battery voltage reaches 4.2 V by even a few hundred milli-volts, they can catch fire or explode due to thermal runaway. Cell balance is required for a variety of reasons. Even when cells are well-matched when they are first integrated into a battery pack, different types of deterioration occur at different rates. Due to production tolerances, the actual lithium content may vary significantly [11] perating temperature, temperature distribution uniformity, vibration, and vibration distribution uniformity between the various cells in a battery pack can all cause varied rates of cell breakdown in the field. Temperature is a significant aspect in optimizing cell lifetimes because temperature is generally the most important component. Cell balance is critical to optimize battery pack performance and lifetimes, regardless of how effectively temperature, vibration, and other issues are regulated [6]

2. Active Battery Balancer

Lithium-ion cells are made of both positive, negative electrode, a separator and two current collectors. The lithium-ion particle and electron will move, thus generating electricity from the chemical energies [2]. Lithium-ion cells are used in everyday small electronic items to heavy machinery. However, lithium-ion cells are susceptible to increased cell breakdown if they are overheated or overcharged. An active cell balancing circuit is used to prevent this from happening. An advanced BMS is also used to monitor the fault operation of the cells, but it requires more cost, and it cannot handle large amount of cells, this is where an active cell balancer shine [3].

Testing is the execution of code mistreatment mixtures of input and state chosen to reveal bugs. In this section we tend to introduce manual testing and automatic testing. In orders to scale back the price of manual computer code testing researchers are operating towards increasing the automation of software testing.

3. System Identification

Many active cell balancing strategies have been developed to minimize Significant energy losses such as in heat energy in passive cell balancing. The primary principle of active balancing is to collect charges from a cell with higher SOC level and transfer those high energy to the cell with lower SOC using energy storage components such as capacitors and inductors. Active balancing offers the advantage of maximizing battery energy utilization, but it always necessitates more sophisticated calculations [11].

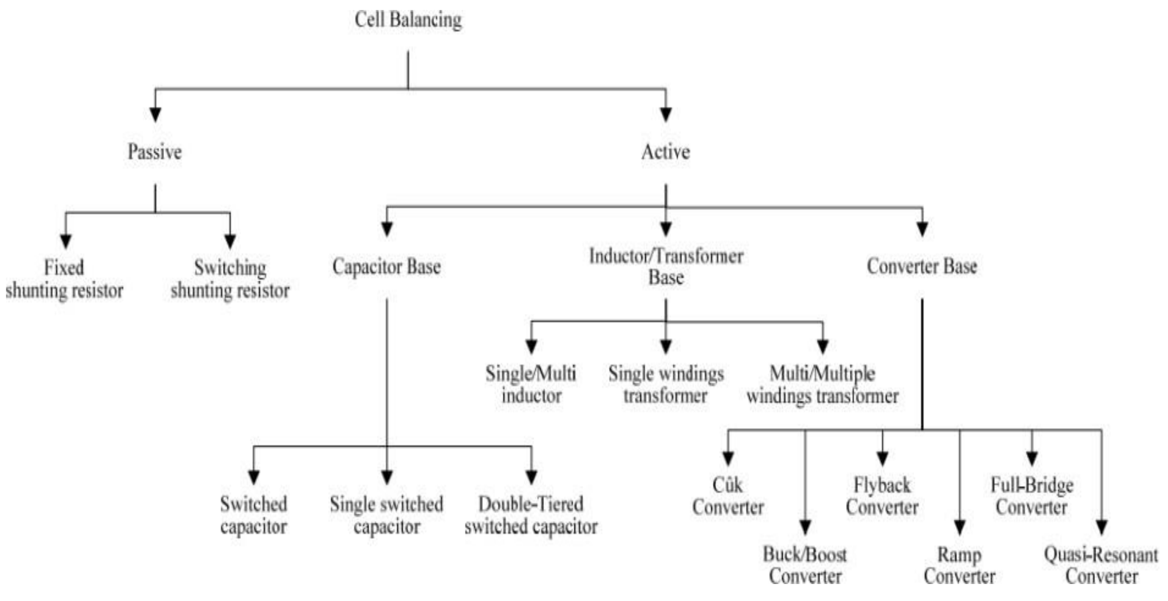

Figure 2. Active balancing types

4. Pi-Controller

A PI controller in figure 3.is inserted to the base model figure 4 to improve the Voltage balancing time of the cells. FROM block A and B indicates the voltage measurement of cell 1 and cell 2 is connected to a subtract block to identify the voltage difference between the 2 cells which is identified as the voltage measure (Vmes). A constant block with value of 0 is then connected to a comparator sum block. The constant block is used as a reference voltage in order to compare it with the voltage difference value of both cells. A gain block of 1/24 value is set, and an integrator block of 1/s is added for the PI control system. The PWM generator block outputs a pulse to fire the MOSFET switch mainly on a one-quadrant converter (buck or boost). The output is then connected to a sum block along with the Vmes.

The output for this is then connected along with a triangle wave generator to be decided by the relational operator, which is connected to the switches. The M1 switch will turn on or off whether the triangle wave value is higher or lower respectively than Vmes.

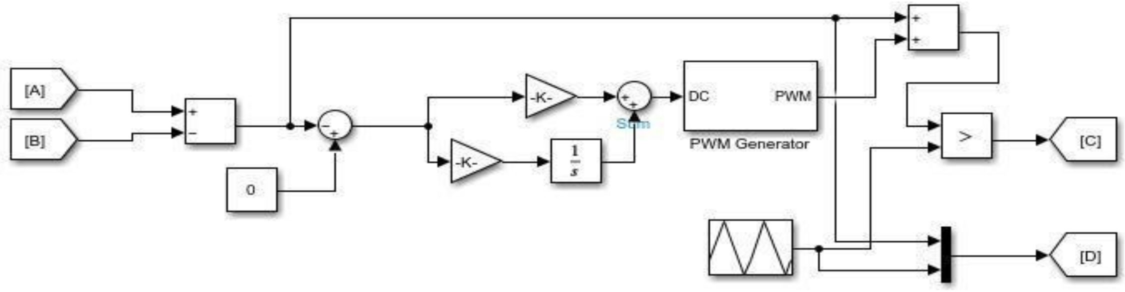

Figure 3. PI controller

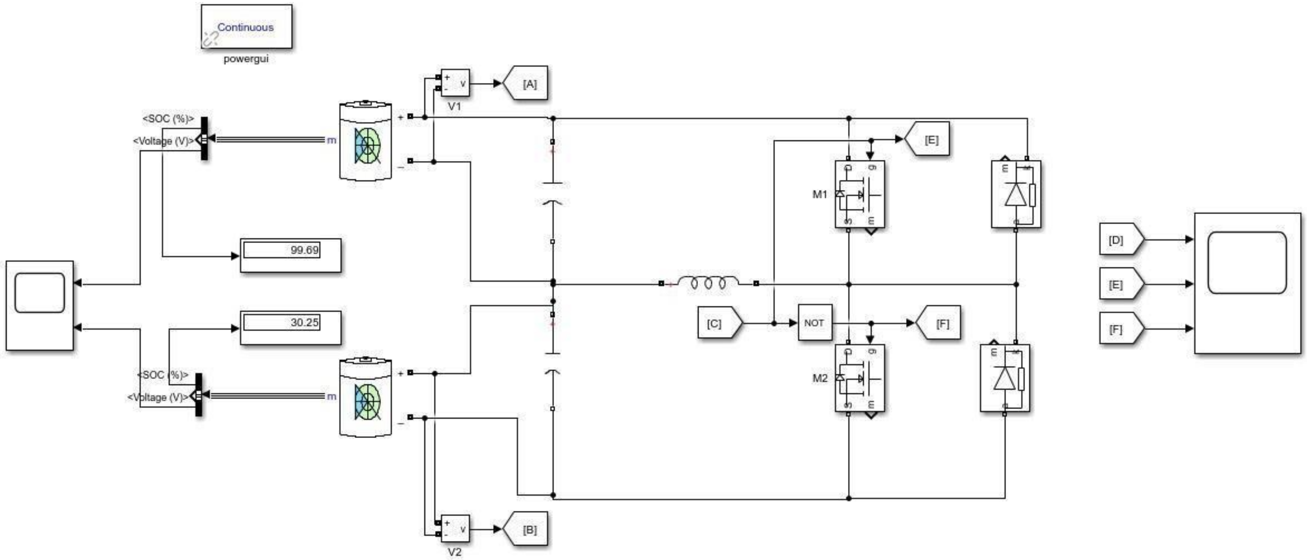

Figure 4. PI controller connection to the base model

5. Proposed design and simulation

The data analyzed by the proposed circuit and was collected by the simulation done in the MATLAB/SIMULINK. The data being collected is the basic operation of the Li-ion battery model. MOSFET switches. The simulated circuit model has to include a Li-ion battery model, capacitor, inductor, MOSFET, DIODE, pulse generator and scope to complete the simulation the first step of the system identification flowchart is to create a model of active battery balancer. This can be done by referring to previous models done such as the capacitor and inductor-based balancers.

MATLAB/SIMULINK Software was used to initiate this project. The drawing of the model circuit is initiated by adding these block parameters, the quantity of the block parameters will be varied later after the first simulation as shown in table1 below.

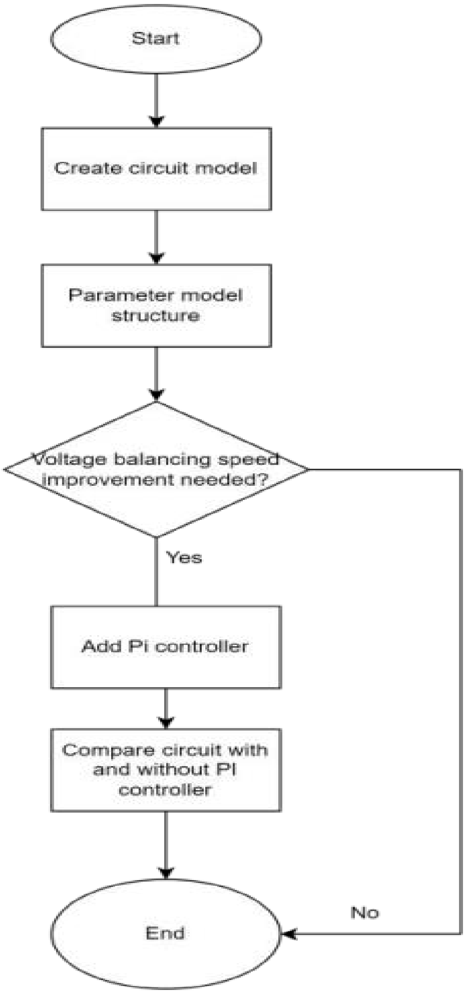

Figure 5. System identification flow chart

Table 1. Table of parameter

No	Block diagram	Quantity	Value
1	Li-Ion battery Cells	2-4	3.7V ,0.8A
2	MOSFET	2-4	-
3	Diode	2-4	-
4	Capacitor	2-4	20mF
5	Inductor	1-2	200mH
6	PulseGenerator	1	1KHZ
7	Scope	Atleast1	-

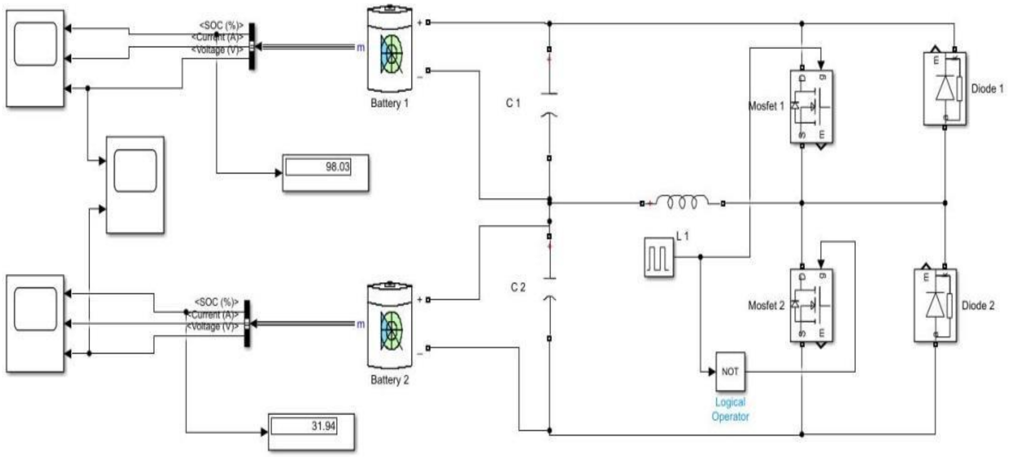

Figure 6. Testing of 2 battery cell.

The proposed circuit model is a capacitor and inductor based active balancing. The battery cell nominal voltage and current is set to the same value of 3.7V and 800mA respectively, while each cell SOC differs from each other. To make the result visible, the SOC is set to a fully charge state of 100% for cell1 and 30% SOC for cell 2. A pulse generator has been added to create square waves from the MOSFET switches. Frequency was set to1kHz that was set as 0.001sin period, amplitude of 1 and a pulse width of 50% period, with a NOT gate that is connected to gate M2 to invert the signal, where M1 will be turned on while M2 is turned off.

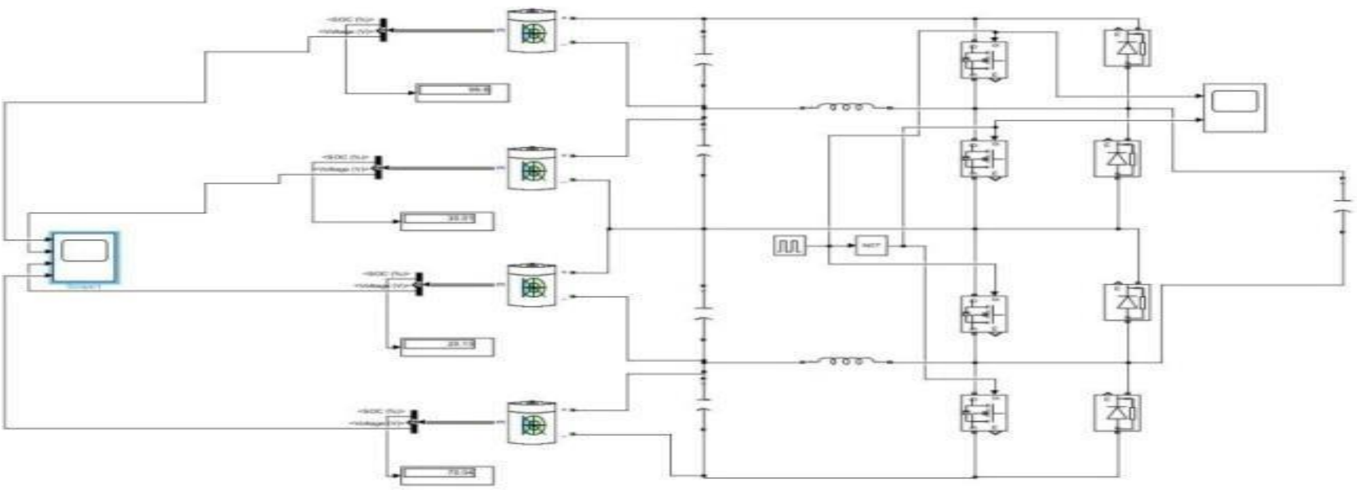

Figure 7. Testing of 4 battery cells

The figure above shows the voltage of cell 1 and cell 2 with yellow and blue color respectively, almost colliding with each other. Thus, both of the Li-ion cells will reach a similar voltage within a certain amount of time. After the initial circuit is created, a similar model with added battery cells is connected to observe the different states of voltage and SOC of multiple Li-ion battery models at once. In this part, an additional 2 Li-ion battery cells are added from the previous circuit with their respective components. Moreover, an additional capacitor is also added in the circuit by parallel connection meshed with the corresponding inductors in the circuit. Cell 3 is set to 20 SOC while cell 4 is set to 70 SOC, a similar concept implemented in the previous circuit model with only 2 cells.

6. Simulation and Comparison

This section will compare the performance of the circuit with and without PI controller acquired from the system identification.

6.1. Switch Waves

Based on table above the switching has been improved by adding the PI controller in terms of switch speed. The switch in the base model switches in between on and off in 1s interval while the switch with PI-controllerswitchesonandoffin0.001s interval. Based on the table below, both cell 1 and cell 2 have faster balancing speed if added the PI controller. The PI controller voltage balanced within 2.4s while the base model voltage balanced in 40s.

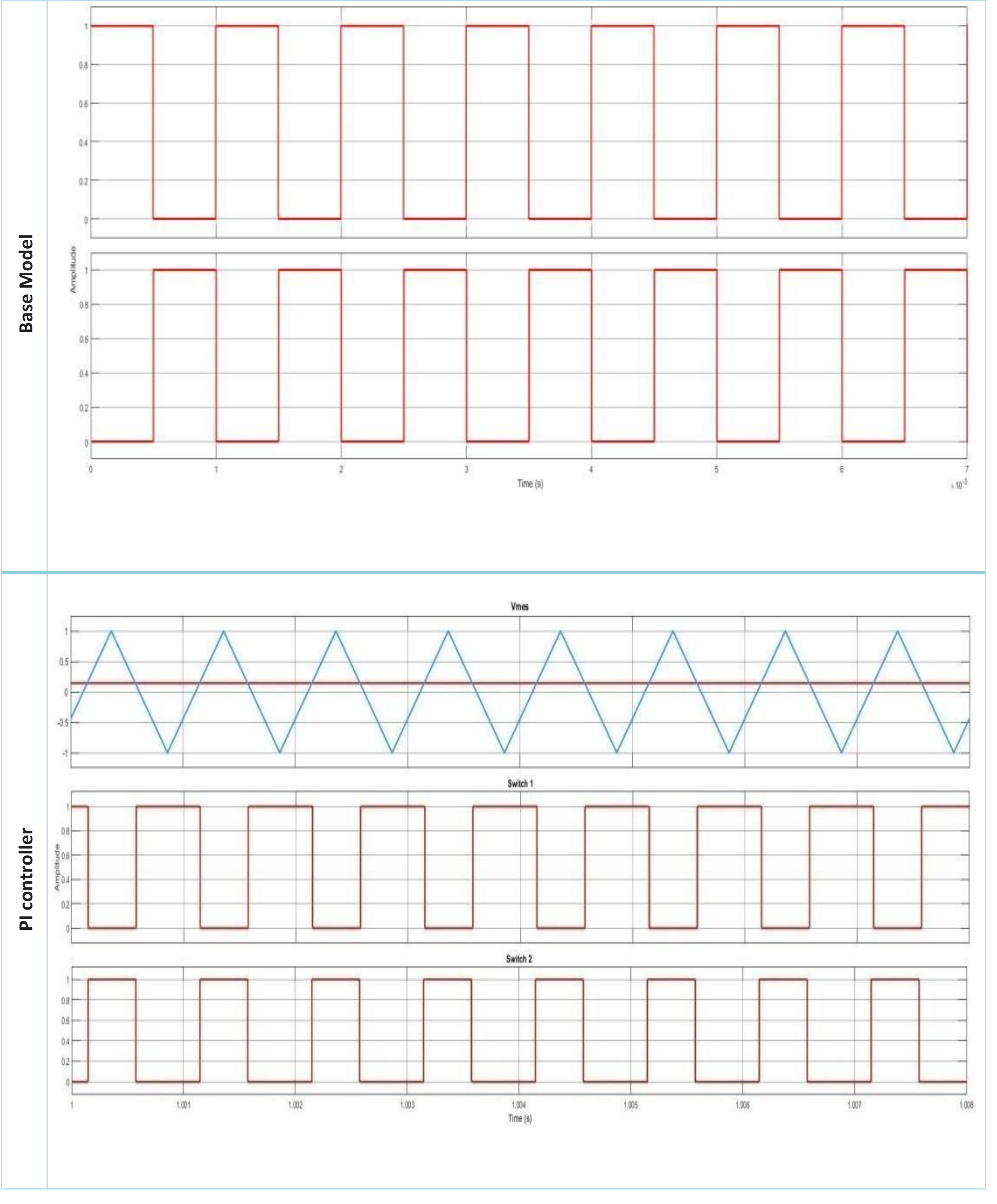

Figure 8. PI-controller wave and switch model.

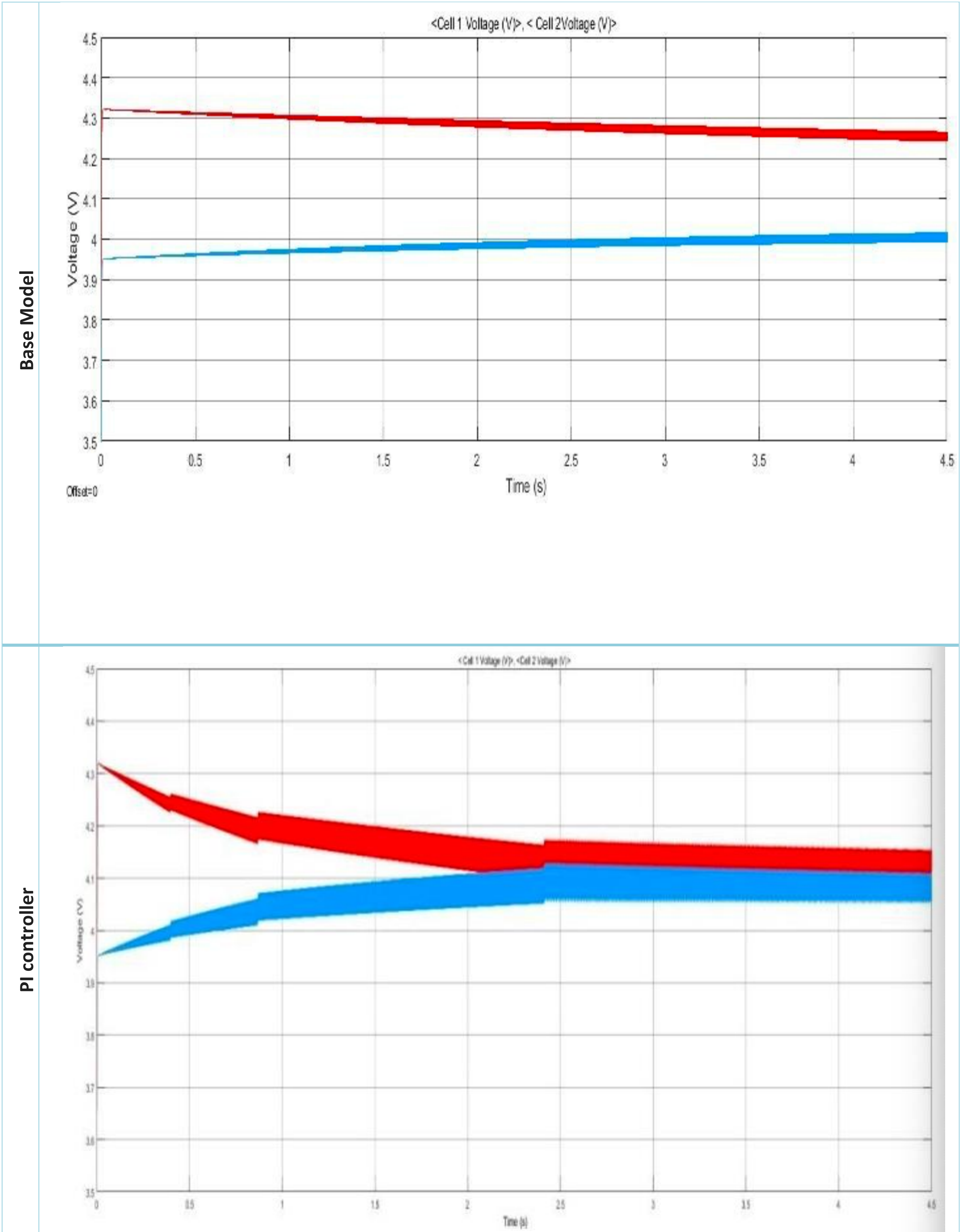

Figure 9. Voltage Graph

Table 2. Steady State

Base Model				With PI controller			
	Time		Value		Time		Value
1	40.844		4.129e+00	1	30.031		4.071e+00
2	66.531		4.100e+00	2	69.969		4.051e+00
ΔT	25.688 s	ΔY	2.859e-02	ΔT	39.938 s	ΔY	1.957e-02

The steady state is observed by the cell voltage receiving no significant changes in value in a specific amount of time. The PI controller achieved steady state 10s faster than the base model. Not only that, but the voltage balance improves drastically for the PI controller than the base model.

7. Conclusion

In conclusion, this paper tries to explain the role of active battery balancers, their types and the proposed circuit built in the simulation. In this paper, a base model containing a basic active battery balancer was created to compare its performance with an added PI controller on the base model. An improvement in balancing speed was observed by both of the circuit models through the switch duty cycles and time taken to achieved voltage balancing for the cells.

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