Determining Capacity Usage Rate of Series Lithium Ion Batteries after Full Shunting Balancing

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Abstract

There are lots of reasons of imbalance among in series connected batteries. The reasons originated from physical properties such as; differences of physical impedance, unintended varieties of internal resistances and capacity rate of battery. Full shunt circuit can be able to handle these problems. This paper indicates determination of usage rate of capacity after full shunt balancing in series connected Li-Ion batteries. Using full shunt circuit, diversity of rated capacity of batteries has been considered and a system with 6 batteries in different rated capacities has been formed. In this system, as soon as 4 of the batteries have reached to charge of 4V, current of the circuit will be broken and process of discharge will be started. The goal of this study is calculation of total state of charge of the system with 6 batteries when reached to fully charge of 4 batteries. As a result of this study, some advantages have been provided such as; saving time to users without waiting for fully charging of last 2 batteries and preventing difficulty of work at low voltages for the last 2 batteries current source.

Keywords: Full Shunting Balance Method, Battery Control, Battery Management System, Active Balance Method

1. Introduction

Batteries have been used for a long time especially for the high performance vehicles and have been provided a high safety for the users with the help of driving performance [1]. Batteries have an importance place in the global market with diversity of their chemicals and long term use [2]. Generally, there are batteries having different properties. Some of them are lead-acid, zinc oxide silver, lithium-ion, nickel-iron, nickel metal hybrid, nickel-cadmium, sodium nickel chloride, sodium-sulfide, and lithium-polymer. Although the batteries such as sodium nickel chloride and zinc oxide silver have high discharge rates, their energy density is low [3].

Today, batteries are used actively in every part of the life as the energy storage system. Lithium ion batteries are often preferred in especially electric cars and hybrid electric cars thanks to their high power density. So, this study was conducted with lithium ion batteries. Although control methods have less importance while operating with single cell batteries, smart control system has critical role for the series battery packs. Moreover, smart control systems became compulsory due to the dangerous chemical properties of lithium ion packs.

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The batteries used in electric and hybrid cars are known as the most sensitive section due to in vehicle explosion and fire risks. Lithium ion batteries may pose a danger in the case of overcharge and discharge. This case may shorten the life time of lithium ion batteries [4, 5]. In lithium ion batteries, $LiCoO_2$, $LiMn_2O_4$, $Li(Ni/Co/Mn)O_2$, $LiNiO_2$ and $LiFePO_4$ generally use as active matters in cathode. These materials have thermic chemical instability. These may create fatal dangers due to their instabilities in the case of fire, explosion, overcharge or discharge and short circuit [6].

In batteries, a battery management system is required in order to conduct the applications safely and prolong the life time of battery with the prevention of imbalances [5]. The battery management systems are the key factor for decreasing dangers to minimum level and determining critical lower and upper voltage levels in especially energy storage systems. Today, battery management systems are designed in a way to allow using output voltage by holding this voltage in a certain span through several integrates such as BMS integrates of Atmel (Atmel ATA6870N) [7] and TI-BQ(BQ76PL536 EVM) [8]. Moreover, these integrates performed the balancing system, which is the aim of this study, by preventing falling under a certain number of batteries.

Battery balancing systems are divided into two; non-dissipative balancing methods and dissipative balancing methods. Dissipative balancing methods are only used in the batteries based on lead-acid and nickel. There are numerous method in non-dissipative balancing and 4 different groups arise when this methods are grouped according to energy flow; consumption method, transition from single cell to pack method, transition from pack to single cell method and transition from single cell to single cell method. 3 different groups arise when non-dissipative balancing methods are grouped according to circuit diversity; shunting method, shuttle method and energy conversion method [9]. There is a little price difference in specified non-dissipative balancing methods [10].

In the study, a circuit was created with full shunting method and simulation studies in terms of calculation of charge rate were conducted with 6 batteries having different capacity rates. System was realized with the help of following components:

- Software Block,
- Ideal Current Source –The aim of using ideal current source is to express the current produced from fuel cell and model the engine as a current source at the stage of braking-,
- Batteries,
- N channel and P channel mosfets (metal oxide semiconductor field-effect transistors),
- Auxiliary components.

2. Battery Simulation Model

In this section, components which were used and integration of these components with each other were described.

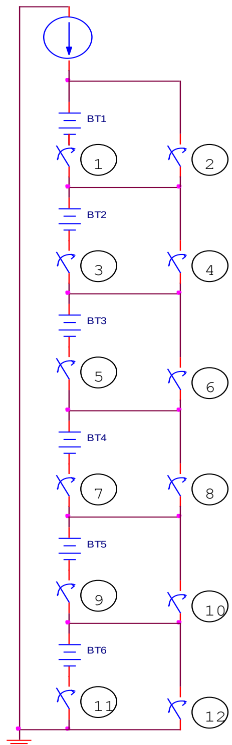

Figure1. Full Shunting Method

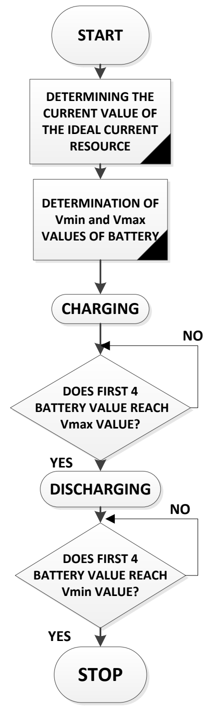

Figure2. Applied Flow Diagram

6 batteries coupled in series with full shunting method, ideal current source, N-channel and P-channel mosfet circuits take place in Figure 1. The most important part here is algorithm. The algorithm with which the processes were realized takes place in Figure 2. In lithium ion batteries which were used in simulations, upper and lower voltage limits were determined as 4V and 3.7V, respectively. Series battery pack was charged with 1A. When BT1 achieve 4V value, 1^{st} switch will be opened and 2^{nd} switch will be closed synchronously. Likewise, when BT2 achieve 4V value, 3^{rd} switch will be opened and 4^{th} switch will be closed synchronously. These processes will continue until the first 4 batteries achieve 4V charge level. As soon as the first 4 batteries achieve 4V, charging process will be ended and the circuit will proceed to the discharging process. In discharging process, when the battery called as BT1 falls to 3.7V, 1^{st} switch will be opened and 2^{nd} switch will be closed, synchronously. Similarly, when BT2 falls to 3.7V, 3^{rd} switch will be opened and 4^{th} switch will be closed. When the first 4 batteries fall to 3.7V, the system will be ended charging process and launch the charging process. This allowance given to falling of the system output voltage to a certain (minimum) level is available in TI BQ76PL536 whose commercial usage is permitted. Minimum voltage value which is provided by the system is designed as 7.2V in TI BQ76PL536 card [8]. It shows that the system whose simulation was performed may comply with the practical usage.

When the system above is operated effectively, output voltage interval will be fixed to a reasonable lower and upper limits, current source will not be used futile, an effective usage will be realized and the system will be able to use SOC with over 95% charge thanks to saving of time.

3. Simulation Studies

The system was created in Matlab Simulink and software block was generated through Matlab Function. Matlab Function is a multiple function for many systems including controlling batteries via software.

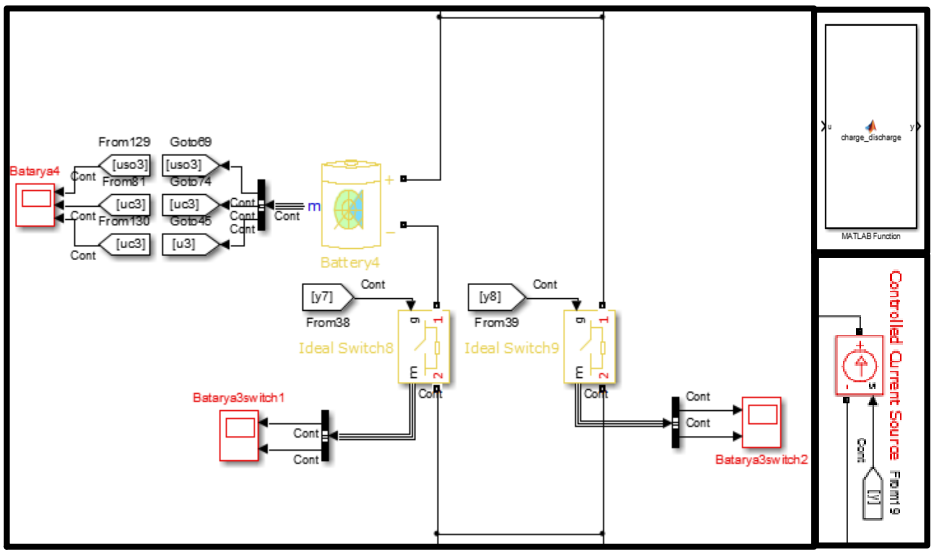

Figure3. A part of simulated circuit –Ideal Current Source-Matlab Function

A part of simulated circuit, ideal current source and Matlab Function used as a controller can be seen in Figure 3. Voltage measurement information of all the batteries in the system is sent to Matlab Function and decisions of switching status and launches charging-discharging processes are made here.

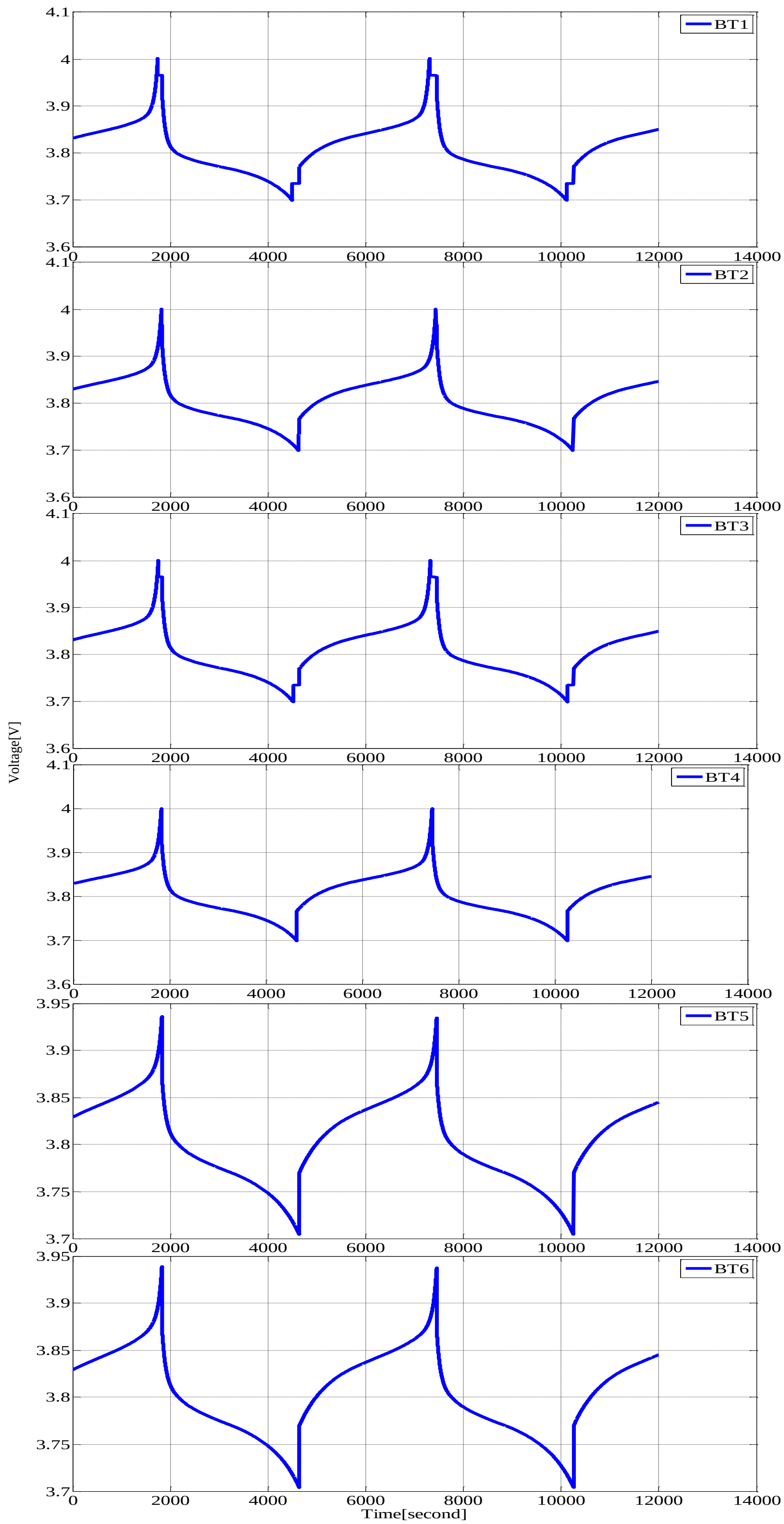

Figure4. Voltages of Series Batteries

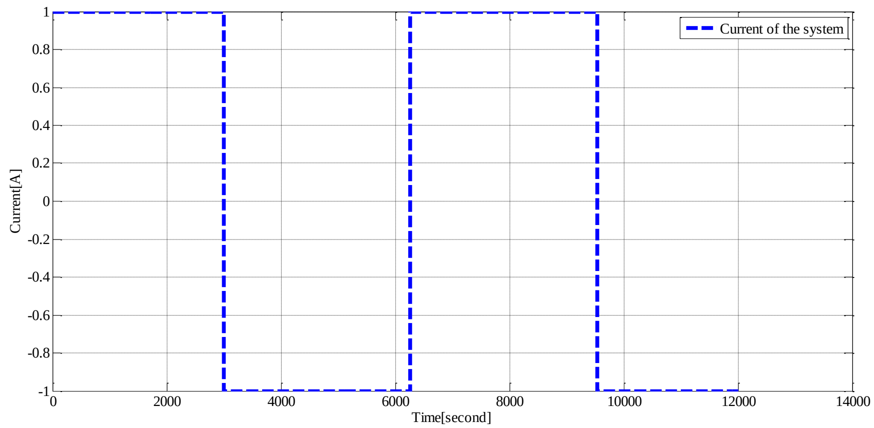

Figure5. Current behavior of the current source during charging and discharging

As specified in Battery Simulation Model part, voltage measurements of the batteries are conducted on controller. Once batteries fall to lower voltage value and exceed upper voltage limit, they are suspended with switches one by one. Therefore, charging of the cells is provided without cutting the charging process by separating the charged cell from the system. Voltage behaviors of series 6 batteries during charging and discharging in Figure 4. In Figure 5, charging and discharging transition processes of current source can be seen.

Two separate experiment groups were constituted for 6 batteries used in the system by considering differences of capacity rates of produced batteries. In the first experiment group, it was assumed that capacity rates of manufactured batteries were held in 10% change interval. This rate was held in 5% band width in the second experiment group. For each experiment group, five experiments were conducted by using a system with 6 batteries and obtained values for these experiments were found in Matlab randomly.

3.1. 1. Experiment Group

Table1. Random capacity values for batteries obtained from Matlab

	Bat1[Ah]	**Bat2[Ah]**	**Bat3[Ah]**	**Bat4[Ah]**	**Bat5[Ah]**	**Bat6[Ah]**
Expt1	1.251	1.206	1.102	1.133	1.190	1.208
Expt2	1.251	1.256	1.167	1.220	1.117	1.299
Expt3	1.176	1.287	1.132	1.153	1.146	1.116
Expt4	1.214	1.126	1.259	1.231	1.283	1.189
Expt5	1.115	1.214	1.162	1.238	1.130	1.121

Obtained values from Matlab were taken randomly for capacity values of 6 batteries. Obtained values were made to be calculated by considering a 10% value interval. Capacity values, which were taken from Matlab randomly, take place in Table 1. 5 experiments were conducted by entering capacity values in Table 1 to the batteries on simulation. As a result of these experiments, the system was switched off when the first 4 batteries achieved 4V charge level. It was seen that other 2 batteries achieved certain charge levels. The last values are indicated in Table 2 as the final case.

Table2. Final status of charge rates of batteries as a result of capacity rates assigned from Matlab randomly

	Bat1 SOC Final Case	Bat2 SOC Final Case	Bat3 SOC Final Case	Bat4 SOC Final Case	Bat5 SOC Final Case	Bat6 SOC Final Case	Avg
Expt1	96.6	98.3	98.3	98.3	98.3	98.2	98.0
Expt2	98.3	98.2	98.3	98.3	98.3	96.6	98.0
Expt3	97.4	93.3	98.3	98.3	98.3	98.3	97.3
Expt4	98.3	98.3	97.3	98.3	96.4	98.3	97.8
Expt5	98.3	96.3	98.3	95.4	98.3	98.3	97.48
The average of 5 cases							97.716

Simulation outputs which were generated with assigned data to capacity rates of batteries, which were taken from Matlab randomly, and charge rates of the batteries in their final statuses can be seen in Table 2. Each status completes the charging process in 97% and 98% charge rates when considering an evaluation of 5 statuses. Average value will be %97.716 for 5 statuses.

3.2. 2.Experiment Group

Table3. Random values assigned to capacity values of batteries from Matlab (Ah)

	Bat1[Ah]	Bat2[Ah]	Bat3[Ah]	Bat4[Ah]	Bat5[Ah]	Bat6[Ah]
Expt1	1.058	1.017	1.068	1.082	1.065	1.013
Expt2	1.018	1.098	1.004	1.072	1.080	1.017
Expt3	1.024	1.071	1.007	1.015	1.045	1.039
Expt4	1.089	1.050	1.052	1.066	1.043	1.083
Expt5	1.003	1.047	1.010	1.052	1.082	1.080

The values were randomly obtained from Matlab for capacity values of 6 batteries. Obtained values were made to be calculated by considering a 5% value interval. The values take place in Table 3. 5 experiments were conducted by entering capacity values in Table 3 to the batteries on simulation. As a result of these experiments, the system was switched off when the first 4 batteries achieved 4V charge level. It was seen that other 2 batteries achieved certain charge levels. The last values are indicated in Table 4 as the final status.

Table 4. Final status of charge rates of batteries as a result of capacity rates assigned from Matlab randomly

	Bat1 SOC Final Case	**Bat2 SOC Final Case**	**Bat3 SOC Final Case**	**Bat4 SOC Final Case**	**Bat5 SOC Final Case**	**Bat6 SOC Final Case**	**Avg**
Expt1	98.3	98.3	98.1	97.5	98.3	98.3	98.13
Expt2	98.3	97.1	98.3	98.3	97.9	98.3	98.03
Expt3	98.3	96.8	98.3	98.3	98.0	98.3	98
Expt4	97.2	98.3	98.3	98.3	98.3	97.5	97.98
Expt5	98.3	98.3	98.3	98.3	96.9	97.0	97.85
The average of 5 cases							97.99

Simulation outputs which were generated with assigned data to capacity rates of batteries, which were taken from Matlab randomly, can be seen in Table 4. Each status completes the charging process in approximately 98% charge rates when considering an evaluation of 5 statuses. Average value will be %97.99 for 5 statuses. When the systems with 10% and 5% value intervals are compared to each other, the difference is calculated as 0.274%.

4. Results

Total 10 simulations were conducted in two experiment groups called as 1st and 2nd experiment groups. In experiments, when the first 4 batteries achieved 4V value, charging process for other two batteries was not waited to be completed and system was launched to discharging process. When the results of these experiments are compared to each other, it can be seen that making balancing in batteries is important in terms of holding storage capacity in a certain level, effective usage of current source and controlling output voltage. Another advantage of balancing for the system is that excessive voltage surging and voltage drops will not be experienced and for this reason, possible dangers will be kept out of the system. According to the results, several changes were observed in capacity rates of batteries which are among the important parts of electric cars. In experiments with 10% and 5% value intervals, a difference with 0.274% was observed between two experiment groups and the rate is remarkable. Therefore, releasing the batteries having close capacity rates all together and using the balancing systems will provide a great advantage in terms of determination an appropriate band width for output voltage and effective usage of current source.

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