Study of imbalanced internal resistance on drop voltage of $LiFePO_4$ battery system connected in parallel

Fengky Adie Perdana[1], Agus Supriyanto[2], Agus Purwanto[3], Anif Jamaluddin[4]

[1,2]Physics Department, Sebelas Maret University
Jl.Ir Sutami 36 A Surakarta Indonesia
[3]Chemical Engineering, Sebelas Maret University
Jl.Ir Sutami 36 A Surakarta Indonesia
[4]Physics Education Program, Sebelas Maret University
Jl.Ir Sutami 36 A Surakarta Indonesia

[1]fengkyadieperdana@gmail.com, [2]agusf77@yahoo.com, [3]aguspur@uns.ac.id, [4]elhanif@uns.ac.id

Abstract. The purpose of this research focuses on the effect of imbalanced internal resistance for the drop voltage of $LiFePO_4$ 18650 battery system connected in parallel. The battery pack has been assembled consist of two cell battery $LiFePO_4$ 18650 that has difference combination of internal resistance. Battery pack was tested with 1/C constant current charging, 3,65V per group sel, 3,65V constant voltage charging, 5 minutes of rest time between charge and discharge process, 1/2C Constant current discharge until 2,2V, 26 cycle of measurement test, and 4320 minutes rest time after the last charge cycle. We can conclude that the difference combination of internal resistance on the battery pack seriously influence the drop voltage of a battery. Theoretical and experimental result show that the imbalance of internal resistance during cycling are mainly responsible for the drop voltage of $LiFePO_4$ parallel batteries. It is thus a good way to avoid drop voltage fade of parallel battery system by suppressing variations of internal resistance.

1. Introduction

$LiFePO_4$ battery is the future of energy storage systems and become the most commonly adopted to many systems. To develop li-ion battery cell into battery packs, we must assemble them that connect with multiple series or parallel in order to fulfill the voltage required and power demand of battery packs. [1]. To achieve the required voltage level, the battery cells connected in series. Then to achieve the required energy capacity, the battery cells connected in parallel. [2], [3]. The module battery that assembly in parallel if comparing with any single battery during high power discharge it has higher discharge efficiency and had better discharge performance. Then, a module battery that assembly in a battery pack that connect with series or parallel consists of several battery cells. a battery pack that assembly in series or parallel can be considered as one single battery with large capacity and high voltage, if there is no difference between battery cells. The variations of battery cell parameter cannot be neglected, so the inconsistent manufacturing processes and the in homogeneous operating environments.[4], [5].

The state of health (SOH) and state of charge (SOC) are two main streams that usage to monitoring battery cell and battery pack. [6]. The percentage of the remaining charge to the maximum capacity

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that show the real information about a battery's remaining energy called State of Charge (SOC). [7], [8]. Then, State of Health (SOH) is used to estimate the remaining performance of a battery and to characterise the current health status. Because it can for describes the physical health condition of a battery compared to a another battery fresh one. To know the State of Health/State of Health requires the methodes for ampere-hour counting and precise capacity evaluation of battery cell that frequently used for this.[9]. The adaptive extended Kalman filter used to measuring voltage and battery current for estimating the battery state-parameter proposed an equivalent of circuit models the battery cell.[10].

Initial SOC, difference branch of capacity and internal resistance are affected the state of health (SOH) battery pack with parallel components. Internal resistance is a number that states the value of resistance that exists within the battery components, so that will determine the speed of ion exchange from the anode to the cathode. The detrimental effect of internal resistance imbalance between parallel-connected cells arises because differences in internal resistance lead to uneven current distribution within the cells, the resulting unexpectedly high currents decrease battery pack life. [11].

Herein, the author studied the detrimental effect of imbalance internal resistance on drop voltage of $LiFePO_4$ battery pack that connected with a double cell in parallel. The capacity fade of battery pack 18650 lithium-ion that connected in parallel using 1/2C discharge rates up to 26 cycles. Parameters obtained through internal resistance tester and battery analyzer 8-channel used to identify the drop voltage of the whole lithium-ion battery pack.

2. Numerical Methods

For identical lithium ferric phosphate ($LiFePO_4$) performance, we used internal resistance (IR) tester EQ-MSK-BK300 for measure the internal resistance (IR) of battery pack $LiFePO_4$, furthermore to know the performance of battery pack we used battery analyser BST8-3, and software TC5.3. There is 5 type of battery pack that connected in parallel which has difference combination of internal resistance that observed. Figure 1. Showed the experimental method in this study.

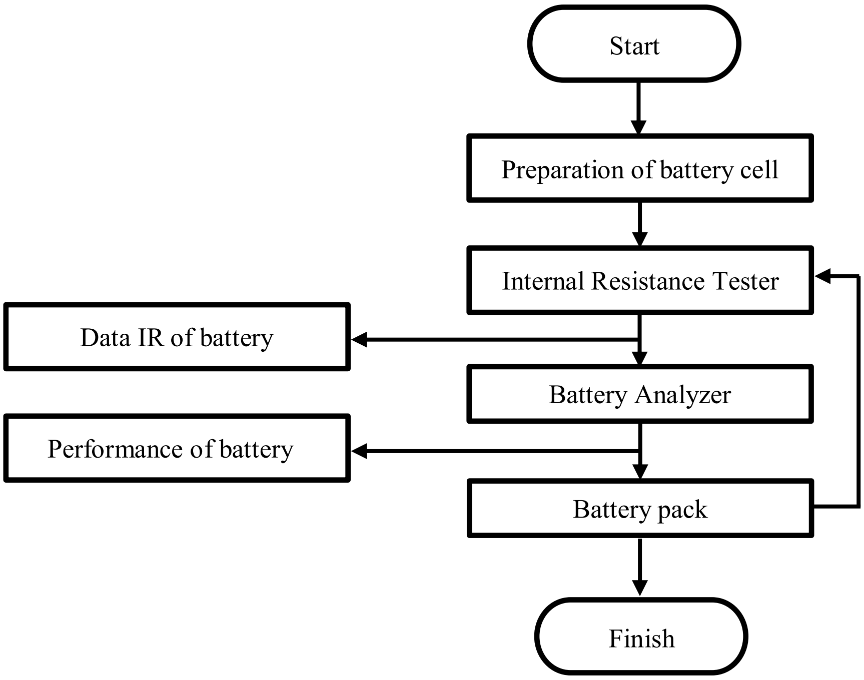

Figure 1. Experimental method

The battery cell that used in this experiment were commercially available cylindrical LiFePO4 3,2Volt 18650 1,5Ah. L*ithium ferri phosphate* ($LiFePO_4$), has many advantages. It has a good cycle, high safety, stable, long cycle life, inexpensive material, relatively low lifetime costs and environment-friendly. [12].

The internal resistance of battery cell was tested with EQ MSK BK300 internal resistance tester and the performance battery was tested with battery analyzer BST8.3. Internal resistance EQ MSK BK300 is a precision internal resistance meter tool for Quality Control (QC) or Research and Development (RnD) process of all rechargeable batteries. It can measure the Open Circuit Voltage (OCV) and Internal Resistance of almost all of the commercial batteries such as Li-ion battery. The accuracy of this internal resistance tester up to 1 mΩ and can measure another battery from 0-19.99V and applicable for measure the internal resistance of conventional capacitance single battery and battery pack.

BST8.3. It is an eight-channel battery analyser that can analyse from 6.0 mA up to 3000 mA, and 5V voltage of battery pack. BST8.3 has independent constant-voltage source and constant-current and each channel of battery analyzer programmed, controlled and calibrated by TC5.3 computer software that includes to setting various working modes: constant voltage charge (CCV), constant current charge (CC), constant current discharge (CD), rest time, and battery cycles. Then, limited threshold conditions include : voltage, capacity, current, time, and the negative voltage slope. The test of battery performance is one of the applications in battery testing fields used battery analyser BST8.3. Moreover, it can use to electrode materials research, capability grading, the formation of a small-scale battery, single battery testing, and etc. The monitoring of data that integrated with graph/data windows are observed with real time, and the testing process can be observing more efficient and more directly.

From the data result of the battery cell, then we assembly a battery cell into the battery pack that consist of two battery cell. We assembly battery pack with different internal resistance for each battery. The specification of internal resistance and the capacity of battery pack that the tested shown in Tabel 1. Battery pack 1 has lowest difference of combination the internal resistance, then battery pack 5 has biggest difference combination of internal resistance.

Table 1. Capacity and Internal resistance battery cell

No	Battery	Internal Resistance (mΩ) (Battery 1-Battery 2)	IR Pack (mΩ)	Capacity (mAh)
1	Pack 1	30-30	16	3000
2	Pack 2	30-40	18	3000
3	Pack 3	30-50	20	3000
4	Pack 4	30-60	21	3000
5	Pack 5	30-70	24	3000

Figure 2. shows a circuit of LiFePO4 battery cell 18650 group tested in this experiment. 2 cell were grouped to build the used battery pack. Considering 3,2-volt for the cell nominal voltages, the pack has 3,2 volt nominal voltage and capacity 3000mAh. Five samples of battery packs that containing two cels connected in parallel were tested using the method described below. The data that recorded with real time is: current, voltage, capacity, energy, DCIR and time.
Parameters of the testing cycle:

- 1/2C (1500mAh) of Constant current charging (CC),
- 3,65 Volt of Constant voltage charging (CV),
- 5 minutes of rest time between charge and discharge process,
- 1/2C Constant current discharge until 2,2V,
- 26 cycle of measurement test,
- 4320 minutes rest time after the last charge cycle.

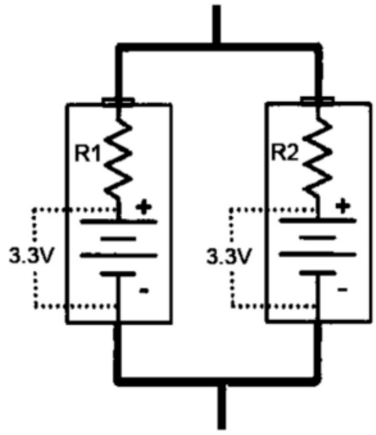

Figure 2. Circuit diagram of battery cell combination

3. Results and Discussion

The performance of battery pack can express by their resistance and capacity variations. [13]. All of the battery pack listed in Table 1. are assembled in parallel to develop 3,2 Volt, 3000mAh. The battery pack are charged and discharged under constant current charge and discharge condition. The capacities and the internal resistance of each battery cell and each battery pack are calibrated before the validation test.

Then, the current of battery pack and the voltage of battery pack are synchronously recorded 26 cycles test during every second. The capacities of five battery pack shown in Table 2. The capacities of the first battery pack is the maximum that same with initial battery pack capacities is 3000mAh. Linear with the difference of internal resistance, the last battery pack has minimum capacities. The initial at the 2nd cycle, and the end of 25th cycle.

Tabel 2. Comparison of capacity&voltage at initial&end cycles

No	Sample	Capacity (mAh)		Voltage Charge (v)		Voltage Discharge (v)	
		Initial	End	Initial	End	Initial	End
1	Sample 1	2922.7	2946.3	2.6680	3.6535	3.3804	2.1754
2	Sample 2	2914.6	2933.0	2.7374	3.6517	3.3556	2.1974
3	Sample 3	2498.9	2472.2	2.7619	3.6514	3.3457	2.1893
4	Sample 4	2463.5	2444.9	2.8537	3.6511	3.2641	2.1896
5	Sample 5	2307.3	2302.4	2.9086	3.6507	3.1959	2.1992

Table 2. shows the comparison inconsistent of start voltage and end voltage battery pack after charge and discharge process. The battery ageing is influenced by the imbalance of internal resistance that consists on the battery pack. This phenomenon can be leads to aged the voltage of the battery from standard one. Battery charge voltage V can be found by Kirchoff's voltage law [14]:

$$V = E_m + V_{Ro} + \sum_{i=1}^{n} V_{Ri}$$

Where V_{Ro} is the voltage of battery across the ohmic internal resistance R_0. V_{Ri} represents the voltage of battery across each polarisation resistance Ri, $i = 1 \dots n$.

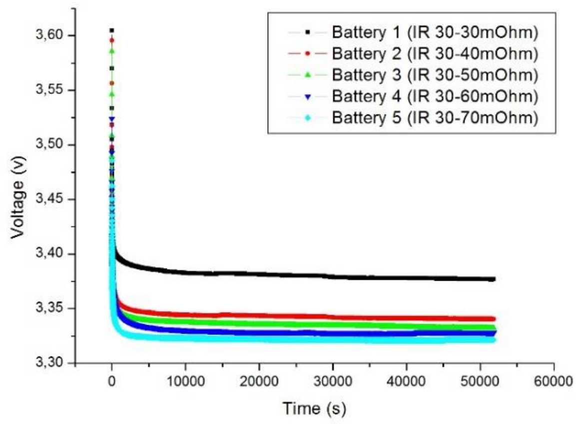

Figure 3. characteristic the rest of battery pack

A comparison of the drop voltage battery and time at rest time cycles is given by Figure.3. It presents the voltage drop at rest time after the last charge for 4320 minutes. The voltage drop changes drastically during rest time for each of battery pack. From the graph, the result drop voltage curves at rest time of all battery pack samples can be detected. In fact, The drop voltage of battery pack 1 that has same internal resistance combination is smallest from each other. Furthermore, the drop voltage of battery pack 5 that has a large combination of internal resistance is biggest from each other.

Table 3. Comparison the average of start voltage and end voltage

No	Sample	Rest after charge		Rest after discharge	
		Start voltage (v)	End voltage (v)	Start voltage (v)	End voltage (v)
1	Sample 1	3,6067	3,4240	2,3077	2,6149
2	Sample 2	3,5935	3,3990	2,3248	2,6453
3	Sample 3	3,5896	3,3946	2,3362	2,7235
4	Sample 4	3,5403	3,3895	2,3741	2,7112
5	Sample 5	3,5009	3,3698	2,4289	2,7750

Table 3 shows the average comparison of start voltage and ends voltage at rest time after charge and after discharge process. the start voltage end the ends voltage for each battery pack are different. The recorded data of drop voltage and the range of voltage can be described as deep of discharge (DOD) battery.

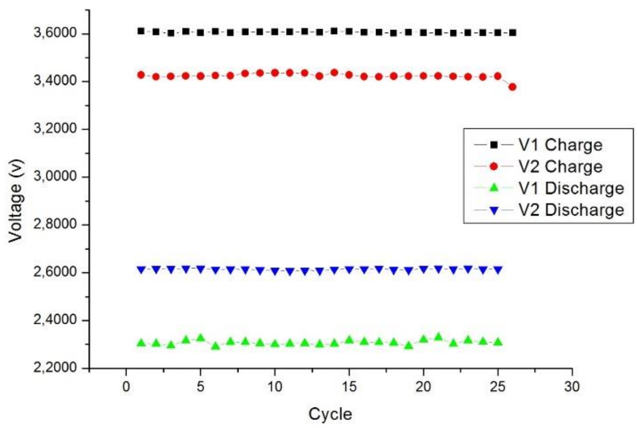

Figure 4. graph of battery voltage on sample 1 at rest cycle after charge and discharge process

In order to show the voltage drops at rest cycle after charge and discharge process, figure 5 give the comparison between voltage battery at each cycle. It shows voltage for 26 cycles of rest time battery. V1 charge that showing by black notation is the voltage battery after finish charge process, and the V2 Charge that showing by red notation is the last voltage from the rest time cycle. Furthermore, V1 discharge that showing by green notation is the voltage battery after finish discharge process, and the V2 discharge that showing by green notation is the last voltage from the rest time cycle.

4. Conclusion

In conclusion, this research study focuses on the effect of imbalanced internal resistance for the drop voltage of $LiFePO_4$ 18650 battery system connected in parallel. The imbalanced can lead to predicting the life cycle and drop voltage of battery pack. This experiment showed the impact of imbalanced internal resistance for drop voltage of battery pack that consist of two battery and assembly in parallel are more important to know than any effect of the resistance of single battery cell.

Binning and shorting the internal resistance of battery cell before assembly the battery pack is very important for a control of battery pack performance including charge and discharge profiles that their battery pack will experience, the average ability of battery pack life can be increasing, and the probability of exposure charge and discharge with very high C rates can be reduced. There are two obvious areas that very important and should be done then would be valuable. First, the imbalanced of internal resistance would affect the capacity of the battery pack. The degradation of capacity would avoid the lifetime battery decreased. Second, the imbalanced of internal resistance would give very interesting fundamental information of drop voltage profiles of parallel connected cells.

This work is potential future experiments, that used to optimise the processes of manufacturing. Combining the knowledge of how the imbalance of internal resistance affects the lifetime, capacity and drop voltage with the software and application of the battery testing that would make it to possible, for measuring the maxsimum tolerance of internal resistance of battery cell that will be an assembly in battery pack. So that, this is can reduced cost of manufacturing battery cell in high-volume, and can be used to increasing the performance ability of battery pack.

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