Emulation of battery discharge behaviour using programmable power supply based on LabVIEW

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Abstract
This paper presents a battery simulator based on the actual electrical behaviour of the battery cells using power supply controlled by Laboratory Virtual Instrument Engineering Workbench (LabVIEW). Firstly, the behaviours of the battery are tested under experimental conditions including constant temperatures at 25°C and two different current loads at 0.5C and 1C. Secondly, the battery behaviours are analysed and applied in LabVIEW. The algorithms which are low pass filter, PID and others are implemented in LabVIEW to reduce standard deviations and errors. The current study found that the constant load at 0.5C and 1C, which controlled by the electronic load via LabVIEW, can emulate the battery voltage and the error relative is below 5 %. Further work is required to establish the optimization of the parameters in the battery management system (BMS) since a battery simulator uses power sources before the use of the battery management system (BMS) with a real battery.

Keywords: Simulation battery management system, Battery behaviour, LabVIEW simulation

1. Introduction
A lithium-ion (Li-ion) battery plays a key role in the rapid development of technology and is also considered a vital component in electrical vehicles (EVs). There is an evidence that Li-ion batteries used for EVs plays a crucial role in the battery pack system. A battery pack system comprises multiple batteries wired together (multicell), and a Battery Management System (BMS). BMS has a pivotal role in making the battery pack safe, reliable, and efficient.[1] By using algorithms, a key aspect of BMS is being used accurately to predict the state of charge (SOC), and state of health (SOH) to protect against any short circuit or fire hazard. Additionally, the multicell in the battery pack, which consists of several batteries connected in parallel and series, requires BMS for cell balancing due to issues during discharge and charge processes.

The issue occurs when some cells reach cut off voltage first causing a fault in the battery pack. In the same manner, some cells reach full charge ahead of the other cells and results in overvoltage of those cells, and this is the reason the BMS is necessary for EVs.
The BMS has several parameters which need to be adjusted for optimal function such as value resistance in passive balancing charge, value capacitor, frequency switching, and length of adjustment time. The development of BMS depends on different algorithms which apply to different EVs. One example of this is a study in algorithm concurrent cell balancing by M. Kuer et al. [2].

Even if the batteries are made in the same factory with the same materials, their electrical characteristics are not always the same. Thus, actual battery cells should be considered for the improvement as well as the development of BMS. There are various studies about simulated characteristics of battery cells and equivalent circuit models for Li-ion batteries. There are two of the studies in line with this work. The first one is “Comparative research on RC equivalent circuit models for lithium-ion batteries of electric vehicles”, L. Zhang, H. Peng, Z. Ning, Z. Mu, and C. Sun considering and discussing an equivalent circuit lithium-ion battery pack [3]. The second one is “Detailed Design of Second-Order Model of Lithium-Ion Battery Simulator Based on Experimental Measurements” by Institute of Electrical and Electronics Engineers, Universitatea Politehnică București [2] focusing on a second-order model of Li-ion battery simulator based on experiments. Souag et al. [4] working on the example of LabVIEW create power flow solution computing.

LabVIEW is used to emulate the battery behaviour based on the actual electrical discharge battery behaviours. The battery discharge behaviours under various discharge current rates are required to understand and quantify using a first-order equivalent circuit model. Therefore, the significant contribution of this research has two points. Firstly, a new battery cell model has been proposed to quantify the battery discharge behaviour under current load condition and provide a virtual battery instrument. Secondly, parameters in BMS can be adjusted without using the actual batteries.

2. Theory

2.1 Characterization of the battery cell

The tested cell here is a commercial 18650 lithium-ion cells with LiNiMnCoO$_2$ (NMC) and LiNiCoAlO$_2$ (NCA) cathodes. The specifications of the cell are listed in Table 1. The behaviour curves of battery during constant discharge mode shown in Figure 2.

2.2 Circuit-Based Models.

Figure 1 illustrates the Thevenin-based model [5, 6]. A series circuit consists of an open-circuit voltage ($V_{oc}$) as a function of the state of charge (SOC) with an ohmic internal resistor ($R_0$). A parallel circuit includes a resistor ($R_p$) and a capacitor ($C_p$), which used to predict battery respond to transient load events at a particular state of charge. The terminal voltage is the battery voltage ($V_b$). The terminal voltage equation of the battery is given in (1):

$$V_b(t) = V_{oc} - I_b \cdot (R_0 + R_p \cdot e^{-\frac{t}{\tau}})$$  \hspace{1cm} (1)

Where is $V_b(t)$ is the terminal voltage battery as a function of time, $I_b$ represents the current of pulse discharge, $R_0$ is the ohmic internal resistor, and $R_p$ is resistance polarization $\tau = R_p \cdot C_p$ time constant of between $R_p$ and $C_p$ which are parallelly connected. The values of $R_0$, $R_p$ and $C_p$ are determined from the pulse current measurement. The more detail is mentioned in section 2.3.

![Figure 1. First-order impedance circuit applied in cell battery simulation](image-url)
Figure 2. Characteristic curves of the battery in constant discharging mode

2.3 Model Parameter Determination.

The parameters of the Li-ion battery cell can be calculated from the experimental result, as shown in Figure 3. The calculation method is as follows:

1) The calculation of $V_{oc}$, in Figure 3. $V_{oc} = V_1$
2) Calculate $R_0$:

$$R_0 = \frac{V_1 - V_2}{I}$$ (2)

In Equation (2), $I$ is the current value of 0.5C a pulse discharge. $R_0$ describes the rapid voltage drop from $V_1$ to $V_2$ in Figure 3. The ohmic internal resistance of Li-ion cell batteries causes the terminal voltage to increase or decrease instantaneously during pulse charging and discharging. However, there are differences ohmic resistance between charge and discharge.

3) The formulas for calculating the RC respond are as follows, the parameters of $R_p$ and $C_p$ are shown in Figure 3.

$$R_p = \frac{V_2 - V_3}{I}$$ (3)

$$C_p = \frac{t_2 - t_1}{R_p}$$ (4)

The experimental details of Figure 3 can be explained as follows. Each cycle consists of

1) A 60 s pulse constant current discharge period, with 0.5C current load.
2) A 180 s pulse rest period.
Figure 3. Current and voltage of a cell battery during discharge pulse in a cycle.

![Figure 3](image)

Figure 4. Experimental data and fitted curves of the relationship between OCV and SOC

![Figure 4](image)

Table 2. Parameters of the cell battery

| DOD (%) | 0.5C          | IC            |
|---------|---------------|---------------|
|         | $R_0$ [mΩ] | $R_p$[mΩ] | $C_p$ [F] | $R_0$ [mΩ] | $R_p$ [mΩ] | $C_p$ [F] |
| 0       | 64.493       | 13.768       | 1016.842  | 57.971      | 14.130      | 990.769    |
| 10      | 55.072       | 10.870       | 1104.000  | 52.174      | 15.942      | 1442.727   |
| 20      | 54.348       | 17.391       | 1150.000  | 53.261      | 18.478      | 1461.176   |
| 30      | 55.797       | 18.116       | 1214.400  | 54.348      | 17.391      | 1552.500   |
| 40      | 53.623       | 17.391       | 1207.500  | 54.710      | 14.493      | 1794.000   |
| 50      | 54.348       | 10.145       | 1478.571  | 53.261      | 10.870      | 1748.000   |
| 60      | 54.348       | 7.246        | 1380.000  | 54.348      | 13.768      | 1888.421   |
| 70      | 55.797       | 7.971        | 1254.545  | 53.986      | 13.043      | 1916.667   |
| 80      | 56.522       | 7.246        | 1104.000  | 55.435      | 14.855      | 1750.244   |
| 90      | 62.319       | 23.913       | 1087.273  | 68.478      | 43.478      | 598.000    |
| 100     | 91.304       | 174.638      | 143.1535  | 94.203      | 77.536      | 116.0748   |

An accuracy of OCV is vital to improve the SOC estimate accuracy. Thus, this paper uses a ninth-order polynomial fitting method to enhance the model accuracy as shown in Equation (5), and the relationship between OCV and SOC is plotted, as shown in Figure 4.
\[ OCV = (9.5968 \cdot 10^{-16} SOC^9) - (4.3431 \cdot 10^{-13} SOC^8) + (8.2170 \cdot 10^{-11} SOC^7) - (8.4116 \cdot 10^{-9} SOC^6) + (5.0384 \cdot 10^{-7} SOC^5) - (1.7888 \cdot 10^{-5} SOC^4) + (3.6942 \cdot 10^{-3} SOC^3) - (0.0044 \cdot SOC^2) + (0.03916 \cdot SOC) + 3.26 \] (5)

(a) Battery cells testing experiment set up. 
(b) LabVIEW control power supply

**Figure 5.** The experimental equipment setup

**Figure 6.** Flow chart of an algorithm in LabVIEW
3. Methodology

Figure 5a illustrates the experiment of the battery cells testing set up for tested battery behaviour with pulse current. Figure 5b provides the LabVIEW control power supply. The flow chart of an algorithm in LabVIEW is presented in Figure 6. After staring the program, the voltage is read by the controller, then the difference of voltage is calculated. If the value is higher than 0.1 V, resistance ($R_0$) is computed. On the other hand, if the value is less than 0.1, the difference in voltage is repeatedly calculated. After the value of resistance ($R_0$) is accepted, the program continuously calculates polarization resistance ($R_p$) and capacitor ($C_p$). If the program does not accept the value of resistance ($R_0$), the program will not calculate $R_p$ and $C_p$. The program computes $R_p$ and $C_p$ when $m_1$ equals $m_2$. After $R_p$, $C_p$ and $R_0$ are obtained, the voltage of battery is determined using Equation (1).

3.1. Experimental setup and process

Toriyama-N18650CL-29 is attached to a battery analyser which is a battery tester. The BA553WIN software program is applied to both charge and discharge battery. Moreover, voltage and current under specific conditions are set out in the monitor. The collected data from the pulse current condition can be seen in Figure 7. Table 2 illustrates the battery parameters.

3.2. Programming in LabVIEW

This work is to study the battery behaviour and the emulation of the battery behaviour. The program is created based on the battery equivalent circuit and the Thevenin-based model using LabVIEW. The creation of an algorithm can calculate parameters based on Equations (2) - (4), and the output of battery voltage behaviour using Equation (1). Moreover, OCV can be calculated from Equation (5).

![Figure 7. Experimental data of the battery voltage during the current pulse test.](image)

(a) 0.5C constant current  
(b) 1C constant current.

![Figure 8. The result of the discharged battery voltage.](image)
4. Results and discussion
The constant loads at 0.5C and 1C are controlled by the electronic load via LabVIEW to emulate the battery voltage. In Figure 8a, the findings from the constant 0.5C load reveal the occurrence of the relative error which is less than 2%. The highest error occurs during 80% to 100% of DOD which is similar to the result of the constant of the 1C load. On the other hand, the findings from the constant 1C load indicate that overall error is higher than 0.5C load due to the value resistance of 1C load, which is higher than 0.5C load, as shown Figure 8b. The peak error reaches 3.68% during 100% and 90% of DOD period. However, the output from two different constant loads is in agreement with the data of the actual battery voltage, which is below the relative error 5%.

5. Conclusion
This study identifies the performance of the algorithm due to error is below five percent. This study also shows that different loads are satisfactory. The findings of this study suggest that this algorithm can replace the actual battery, and the performance has an excellent graphical interface in which it can efficiently run the computation. These findings have significant implications for the understanding of how to adjust the parameters in the BMS as a battery simulator using power sources before the use of the BMS with a real battery. This would be a fruitful area for further work.

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