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Development of Single Cell Lithium Ion Battery Model Using Scilab/Xcos

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Abstract. In this research, a lithium battery model, as a component in a simulation environment, was developed and implemented using Scicos/Xcos graphical language programming. Scicos used in this research was actually Xcos that is a variant of Scicos which is embedded in Scilab. The equivalent circuit model used in modeling the battery was Double Polarization (DP) model. DP model consists of one open circuit voltage (V_{OC}), one internal resistance (R_i), and two parallel RC circuits. The parameters of the battery were extracted using Hybrid Power Pulse Characterization (HPPC) testing. In this experiment, the Double Polarization (DP) electrical circuit model was used to describe the lithium battery dynamic behavior. The results of simulation of the model were validated with the experimental results. Using simple error analysis, it was found out that the biggest error was 0.275 Volt. It was occurred mostly at the low end of the state of charge (SOC).

INTRODUCTION

Actually, there are basically only two types of battery models: 1) Electrochemical model and 2) Electrical circuit model since other types of battery models are usually derived from these two basic models, e.g.: Dynamic battery model is actually combination between simplified electrochemical model and electrical circuit model [1- 3]. However, there are references that classify battery model into three or four types of models [2], [3]. The other models are classified into mathematical and analytical model. Mathematical model is basically a simplified electrochemical model such as Shepherd's equation, Unnewehr universal model, Nernst model, and Combined model. On the other hand, analytical model is based on empirical data such as modified Peukert's equation that include integrating current to improve the battery model.

In this research, electrical circuit model would be used to make lithium battery model since electrochemical model would produce a set of nonlinear partial differential equations with a large number of unknown parameters which needs a lot of resources and computation time of a computer to simulate it. The simulation would take hours or days. Therefore, electrochemical model could not be used for BMS application since it needs real-time data to monitor and control the system.

Mostly, electrical circuit models are divided into three types: 1) Rint model, 2) Thevenin model, and 3) Double Polarization (DP) model. Nevertheless, other electrical circuit models can be derived from these three models [4]. Furthermore, in this research DP model would be used since it is quite simple so the time needed to calculate the parameter states of interest would be fast but it is also a little bit complex, it uses only two parallel RC circuits, so it can model the dynamics of lithium battery quite accurately. Moreover, according to [5], DP model is the best model among the models that were compared. It has low errors and low RMSE (Root Mean Square Error) among other models with the lowest complexity of the models. Figure 1 shows those three electrical circuit models. V_{OC} is open circuit voltage which usually depends on the state of charge (SOC) of the battery, Ri is internal resistance of the battery, R_S and C_S are the parallel RC circuit that describe the fast dynamic response of the battery, finally R_L and C_L are the parallel RC circuit that describe the slow dynamic response of the battery.

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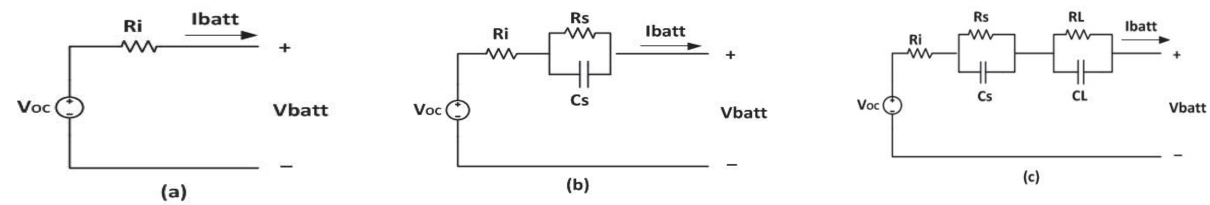


FIGURE 1. Electrical circuit models: **(a)** Rint Model, **(b)** Thevenin model, and **(c)** DP model

Scilab/Xcos is a free, open source software for systems simulation. It is very similar to MATLAB/Simulink but MATLAB/Simulink is a commercial software so it is not free. Hence, in this research Scilab/Xcos is used to develop the lithium battery model. Scilab/Xcos does not have a lithium battery model. MATLAB has one model in one of its toolboxes or library, i.e. SimPowerSystems which was suggested in [2]. However, this model is a dynamic model type which is actually a combination of Rint model and Shepherd's equation. The Shepherd's equation is used to calculate open circuit voltage of the Rint model based on battery data from the manufacturer. So it can be seen that the dynamic response of the battery is not capable in modeling non-linear phenomena since the RC parallel circuit is not included [6]. Most of the literatures on battery modeling using graphical programming language are using MATLAB/Simulink [1- 3] and [6 - 8]. So far, only one literature is dealing with battery model in Scilab/Xcos [9]. Moreover, the type of battery used in [9] is lead-acid battery, not lithium battery.

The paper is organized as follow. The next section will describe the proposed model in detail. After that, the process in extracting parameters of the lithium battery is discussed. Then, the model is validated with the experimental results in the section of experimental results and validation. Finally, the summary, results, and insight in this research are discussed in the conclusion section.

THE PROPOSED MODEL IN SCILAB/XCOS

The DP model in Fig. 1(c) is redrawn to include the block for calculating SOC and showing dependent of circuit parameters on SOC as shown in Fig. 2. The DP circuit model contains of a dc voltage source (V_{OC}) that depends on SOC, a series resistance (Ri) which represents internal dc resistance of the battery, and two parallel RC networks (R_S, C_S, R_L, C_L). All circuits' parameters also depend on SOC. The battery voltage and current are represented by V_{batt} and I_{batt} respectively. Figure 3 describes the proposed battery model block during discharging with constant current of 9.3 Ampere and initial SOC of 100%. SOC is recorded on a file while V_{batt} is plotted and recorded at the same time.

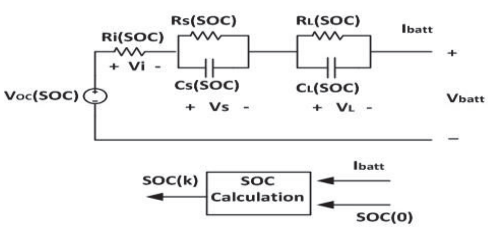


FIGURE 2. Circuit model used for developing lithium battery model

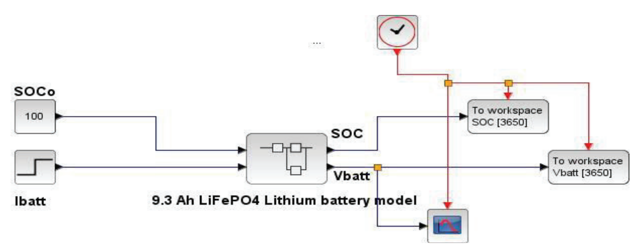


FIGURE 3. Lithium battery model with current input and initial 100% of SOC.

Figure 4 shows the inside of the proposed model in Scilab/Xcos. It consists mainly of five computing blocks for determining the battery voltage V_{batt} and SOC of the battery while the battery is driven by the load/charger current I_{batt}. Those blocks are SOC Calculation block, RC Calculation block, V_{OC} Calculation block, V_i Calculation block, and Voltage of RC Networks Calculation block. The inputs to the model are the load/charger current represented by I_{batt} and the initial state of charge represented by SOC_0 while the outputs are battery voltage represented by V_{batt} and real-time state of charge represented by SOC. All the parameters in the circuit are represented as polynomial function of SOC where the coefficients of polynomial functions are derived from curve fitting of the data from the experiments.

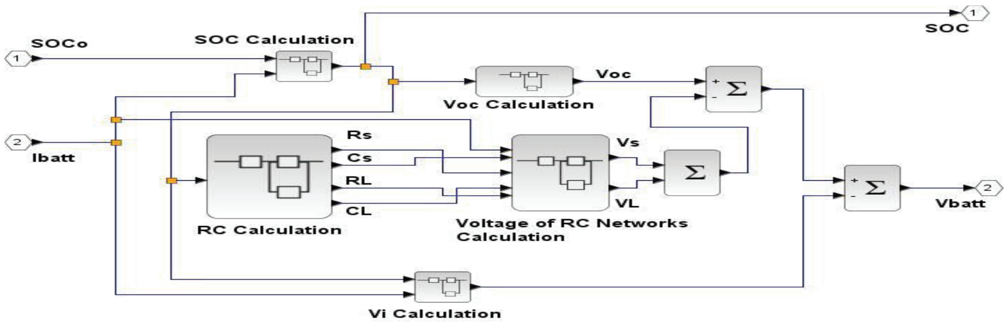


FIGURE 4. The proposed model of lithium battery in Scilab/Xcos.

To calculate SOC, equation (1) is used. SOC_0 is the initial value of SOC while I_{batt} is the battery current in Ampere unit. E_{ff} is the efficiency of the battery; usually it is close to 1 but, in our case, it is 0.99. C_{cap} is the usable capacity of the battery. In our experiment, it is 9.3 Ah so we need to change it into Ampere second by multiplying it with 3600. In addition, SOC is in percentage unit therefore we need to multiply it by 100. Figure 5 shows the inside of SOC calculation block.

$$SOC(t) = SOC_0 - \frac{E_{ff}}{C_{cap}} \int_{to}^{t} \frac{I_{batt} x100}{3600} dt \tag{1}$$

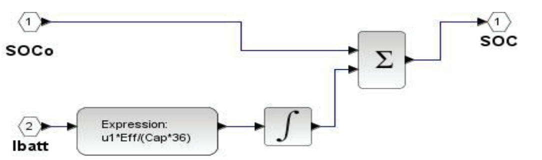


FIGURE 5. SOC Calculation

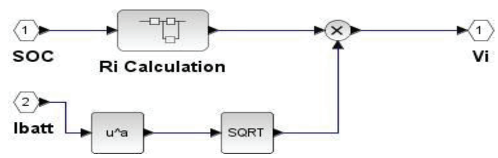


FIGURE 6. V_i Calculation

All parameters data are curve fitted using polynomial function therefore the values of V_{OC}, R_i, R_S, C_S, R_L, and C_L are calculated using their polynomial function with SOC as independent variables. Equation (2) shows the polynomial function used to calculate V_{OC}. The coefficients in that function were found by curve fitting the data.

$$V_{oc} = 2908.89 + 44.30 * SOC - 1.98316 * SOC^2 + 0.04162 * SOC^3 - 4.08 * 10^{-4} * SOC^4 + 1.51 * 10^{-5} * SOC^5 \tag{2}$$

V_i is calculated simply as the product of I_{batt} and R_i while R_i is calculated by using the polynomial function. V_i represents the voltage drop from dc internal resistance R_i. Equation (3) shows the equation for calculating V_i while Fig. 6 is showing the implementation in Scilab/Xcos.

$$V_i = I_{batt} R_i \tag{3}$$

RC values are needed to calculate the voltages of two RC parallel networks. The values of RC parallel networks are dependent only on SOC; they are evaluated by using polynomial function. Figure 8 shows the implementation of calculating RC values in Scilab/Xcos. Computing blocks in the Fig. 8 are used to calculate voltage of V_S and V_L using the values of calculated RC and Equation (4) and (5). Finally, the voltage of the battery is calculated using Equation (6) and implemented in Scilab/Xcos in Fig. 4.

$$\dot{V}_S = -\frac{V_S}{R_S C_S} + \frac{I_{batt}}{C_S} \tag{4}$$

$$\dot{V}_L = -\frac{V_L}{R_L C_L} + \frac{I_{batt}}{C_L} \tag{5}$$

$$V_{batt} = V_{OC} - I_{batt} R_i - V_S - V_L \tag{6}$$

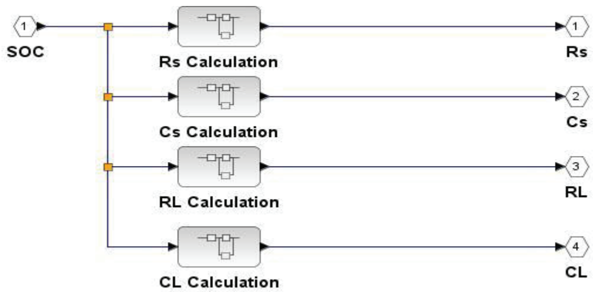


FIGURE 7. RC values calculation

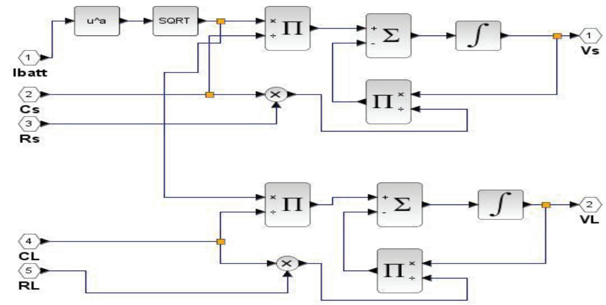


FIGURE 8. V_S and V_L calculation

EXPERIMENTAL SET UP

In this experiment, we used a LiFePO4 lithium battery which has capacity of 9.3 Ah. It has maximum voltage limit of 3.65 V and minimum voltage limit of 2.6 V while its operating voltage is 3.2 V. The battery was connected to Battery Analyzer BST8-10A30V of MTI Corporation that can be programmed to charge and discharge the battery. The specifications of BST8-10A30V are given in detail in Table 1. The set-up is shown in Fig. 9. The battery was just connected directly with the power cable and sensor cable so the battery analyzer could charge and discharge while it also simultaneously recorded the voltage and current flowing in or out of the battery. The power cable and sensor cable were separated so the effect of voltage dropped was avoided. In this experiment the temperature was maintained around 25°C so that the effect of temperature variations are neglible.

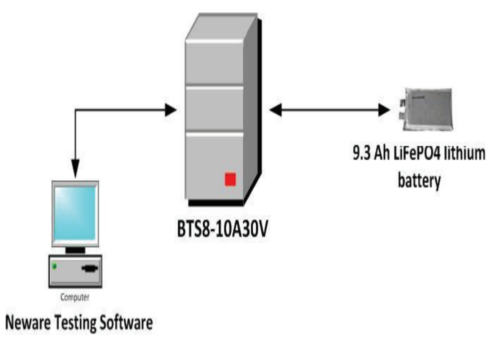


FIGURE 9. Experimental set up

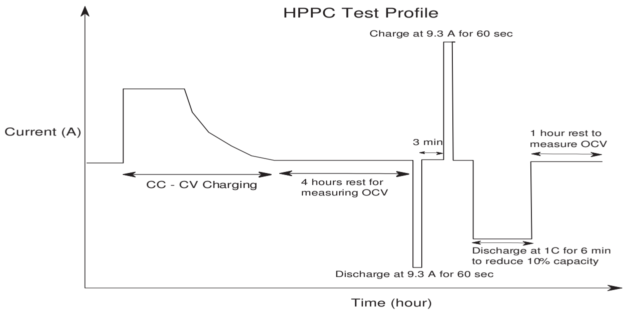
TABLE 1. BTS8 – 10A30V Specifications

Voltage measurement	• Range: 0.03 - 30 V • Accuracy: +/- (0.1% of reading + 0.05% of range)
Current measurement	• Range: 0.01 - 10 A • Accuracy: +/- (0.2% of reading + 0.1% of range)
Time Range	0 - 999 seconds
Cycle Measurement Range	1 - 9999 times
Input Impedance	≥ 10 m-ohm
Channels	8 Channels

PARAMETERS IDENTIFICATION PROCEDURE

In this research, HPPC test method which is described in detail in [10] was used to identify parameters of the battery. It is a current pulse technique to calculate the dynamic properties of the battery. The battery is charged and discharged under a controlled condition and the voltage, current, and temperature of the battery are measured. However, in our experiment, the temperature was kept constant.

Actually, the HPPC test requires that current pulse to be 3C either during charging or discharging however our battery charger/discharger, BTS8-10A30V, is only capable delivering or receiving 10 Ampere so we set our charging/discharging pulse at 9.3 Ampere or 1C. Moreover, the length of pulse required by HPPC test is 10 seconds but our device is only able to make the smallest length of pulse of 60 seconds. Therefore, HPPC profile test for our experiment is shown in Fig. 10. At the start of the experiment, the battery is charged until full 100%. After that it is rested for 4 hours for measuring OCV (Open circuit Voltage). Then 9.3 Ampere pulse discharge for 60 seconds is applied to the battery. It rests for 3 minutes before charge pulse with the same amplitude and length is applied to the battery. Then it rests again for 3 minutes. After that the battery is discharged with 1C pulse for 6 minutes so the SOC will be down by 10%. The battery is rested again for one hour to measure its OCV. The procedure is repeated for discharging process until the SOC reaches 0%. After that it continued the test with charging process until the SOC reached 100%. The result of the experiment is shown in Fig. 11.



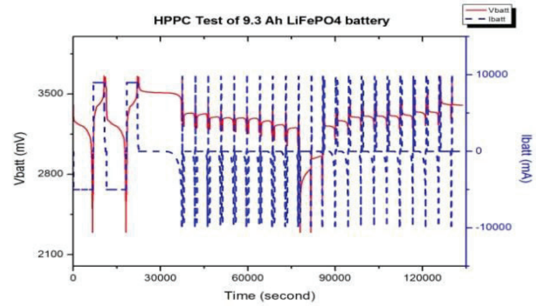
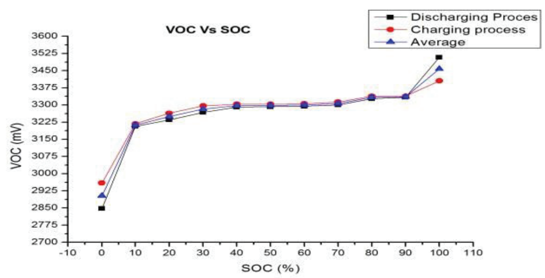


FIGURE 10. HPPC test profile

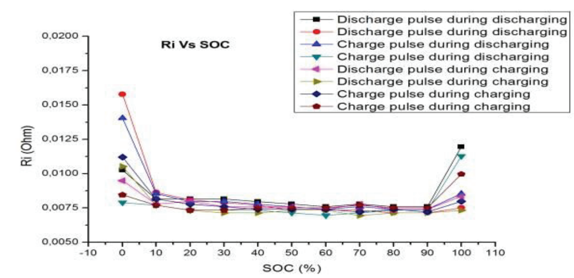
FIGURE 11. HPPC Test outputs

EXPERIMENTAL RESULTS AND VALIDATION

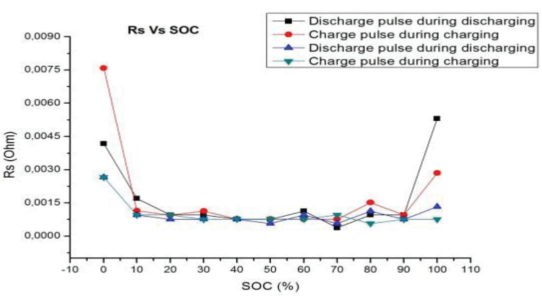
In this section, the resulted raw data from the experiment using HPPC test procedure were processed to derive parameters of the model using a method that mentioned in a paper by Thanagasundram et al [11]. The results are presented in Fig. 12.



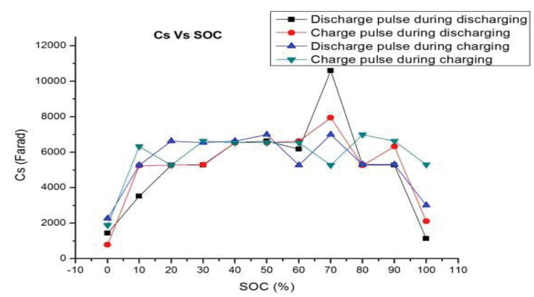
(a)



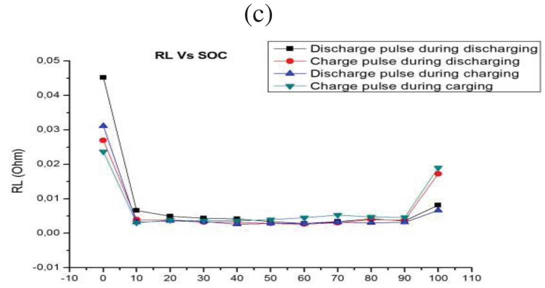
(b)



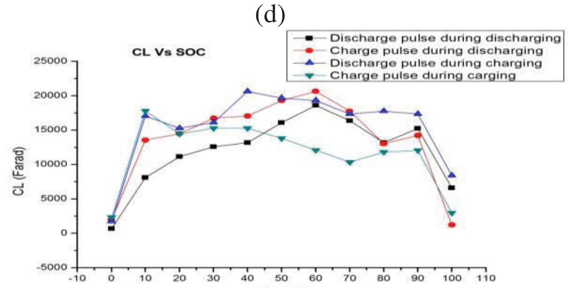
(c)



(d)



(e)



(f)

FIGURE 12. Parameters of the model

Figure 12 (a) shows the plot of relation between Voc and SOC while the rest of Fig.12 (b) – (f) show the graphs of values of model parameters related to SOC. From this data, we made curve fitting of the data so we got the polynomial functions that relates all parameters in model with SOC. Then, these polynomial functions were integrated into the lithium battery model that we developed in Scilab/Xcos to complete the model. Finally, the model was validated by comparing the simulation result with the experimental data as shown in Fig. 13. Figure 14 shows simple error analysis on the model.

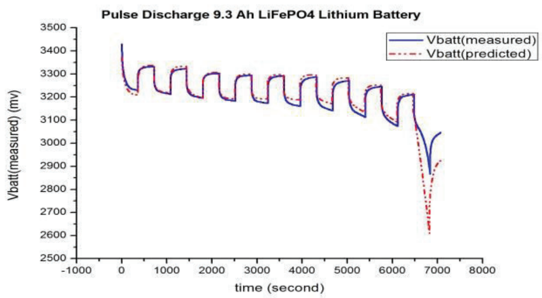


FIGURE 13. Comparison between simulated V_{batt} and measured V_{batt}

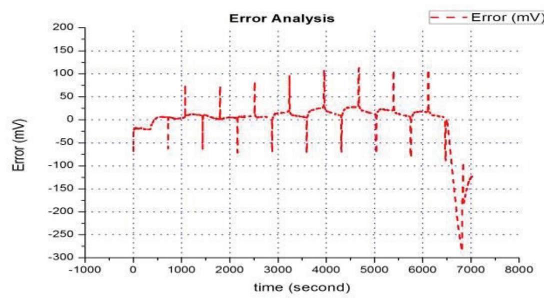


FIGURE 14. Simple error analysis of the two plots in Fig. 13

CONCLUSIONS

A lithium battery model in Scilab/Xcos environment was proposed to simulate the dynamic of lithium ion battery so that it could be used for system simulation that needs a lithium battery model in Scilab/Xcos environment. Moreover the model also could be used for estimating SOC that uses model-based algorithm such as Kalman filter, particle filter, etc. HPPC power test measurement was used to develop the model by identifying its parameters using pulse dynamic characterization. The model was validated by comparing the simulation results with the experimental data. The performance of the model is actually quite good since it has very small modeling errors except at low SOC the error increases about 0.275 V but it is still acceptable so we suggest that the model is mostly quite sufficient to capture the dynamics of the lithium ion battery.

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