Voltage and loss estimation for Li-ion batteries during drive cycles with various parameter identification methods

Preferred Topic 1:	Topic 8 E-MOBILITY
Preferred Subtopic 1:	Subtopic 8f - Batteries: Management Systems (BMS), Monitoring and Life-Time Prediction
Preferred Topic 2:	Topic 6 - RENEWABLE ENERGY POWER SYSTEMSl
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Keywords

≪Batteries≫, ≪Energy storage≫, ≪Ohmic Losses≫, ≪Modelling≫.

Abstract

In this paper, the parameters in battery RC link models are extracted from a physics-based model using the pulse discharge method with different C-rates and fitting regions. A 2RC links model with parameters obtained from 1C pulse discharge test has a better performance on the voltage and loss prediction.

Introduction

There exist two fundamentally different kinds of battery cell models. One is based on the underlying physics of the operation of the Li-ion cell and capturing the cell dynamics (physics based modelling). Another method approximates the behaviour of the cell's voltage in response to different input currents (equivalent circuit modelling). Although not as accurate, the equivalent circuit modelling is preferred for applications in battery management systems (BMSs) due to its largely reduced computational complexity compared to the physics based models, which contains much more degrees of freedom [1]. The method to find the RC link parameters for Li-ion batteries from time domain data such as a pulse discharge test is presented in the following [2–5]

The contribution of this work is to quantify the battery RC link model accuracy with different parameter extraction methods. A comparative study is presented where four C-rates are used in the pulse discharge to characterize the cell. The model is validated under transient driving cycles and a physics based model is used as the reference. The comparison is performed on two aspects i.e. terminal voltage estimation as well as loss prediction.

Theory

The RC link modelling is a type of equivalent circuit model commonly used in BMSs which regulate the battery performance within operating boundaries and estimate internal cell states. A RC link model combines different equivalent circuit elements (resistors and capacitors) with the open circuit voltage (OCV) to accurately predict the terminal voltage of the battery cell under dynamic operating conditions. The model can accommodate an adequate number of RC pairs to model the slow and fast electrochemical processes in the cell. An example of the 2 RC link model is shown in Fig. 1.

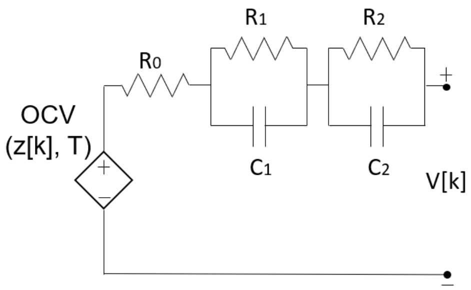

Fig. 1: An equivalent circuit model with 2 pairs of RC links.

Case setup

Reference model

A physics based pseudo-two-dimension (P2D) model is used as the reference model in this work. The model is implemented in COMSOL Multiphysics 5.5 and the geometry and electrochemical values are taken from [6]. This battery has NMC as the positive electrode and graphite as the negative electrode.

Parameter identification

In this paper, different approaches have been taken to obtain the parameters of RC link equivalent circuit models. Pulse discharge test simulations are performed on a physics based model, whose terminal voltage has been considered as ground truth values.

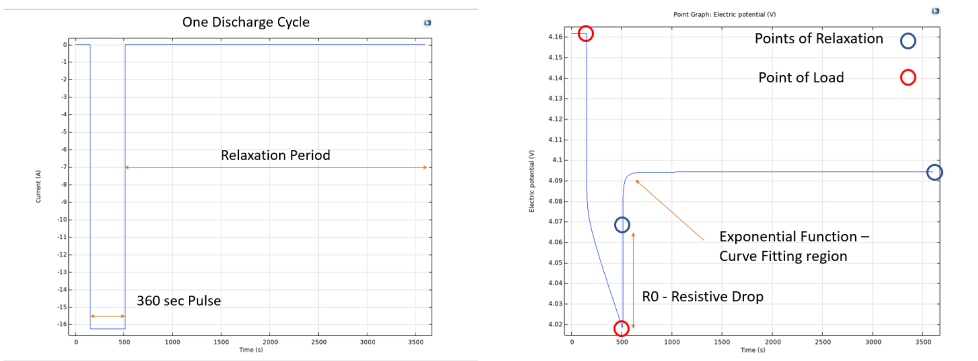

Fig. 2: 1C discharge pulse and voltage response. R_0 is obtained manually from the instance voltage drop and the relaxation part is used for the RC link fitting.

Traditionally, the relaxation part of the pulse is used to fit the equivalent circuit model as the SOC is constant during the relaxation, as shown in Fig. 2. In this work another approach has been attempted by using the entire pulse. Firstly, the nonlinear least squares method is used to fit the relaxation part of the terminal voltage with the parameters of an RC link model. Then, the values obtained from the relaxation curve fitting are used as the initial values in a convex optimization algorithm for the entire pulse and obtained a new set of values.

The process was repeated for different state of charge (SOC) values of the cell and different C-rates of the input current. For this study, 0.5C, 1C, 5C and 10C pulses are used to obtain the RC parameters at varying SOC levels.

Drive cycle

The drive cycle used for this work is the worldwide harmonized light-duty vehicles test cycle class 3 (WLTC). The new world harmonized light-duty vehicles test procedure (WLTP) uses this driving cycle to estimate the energy consumption by passenger vehicles as well as light commercial vehicles. This drive cycle simulates a urban, suburban, rural and highway scenario. A simple electric powertrain model is implemented in MATLAB using the QSS toolbox to simulate the dc current on the battery pack which will later be fed to the physics based model and the equivalent circuit model for the loss quantification.

The fidelity of the simulated voltage and loss from the RC link models have been quantified using cumulative root mean squared error (CMRSE) in comparisons with the simulation results from the physics based model.

Results and discussion

The parameters of a 2 RC link model extracted from different C-rates are presented in Fig. 3.

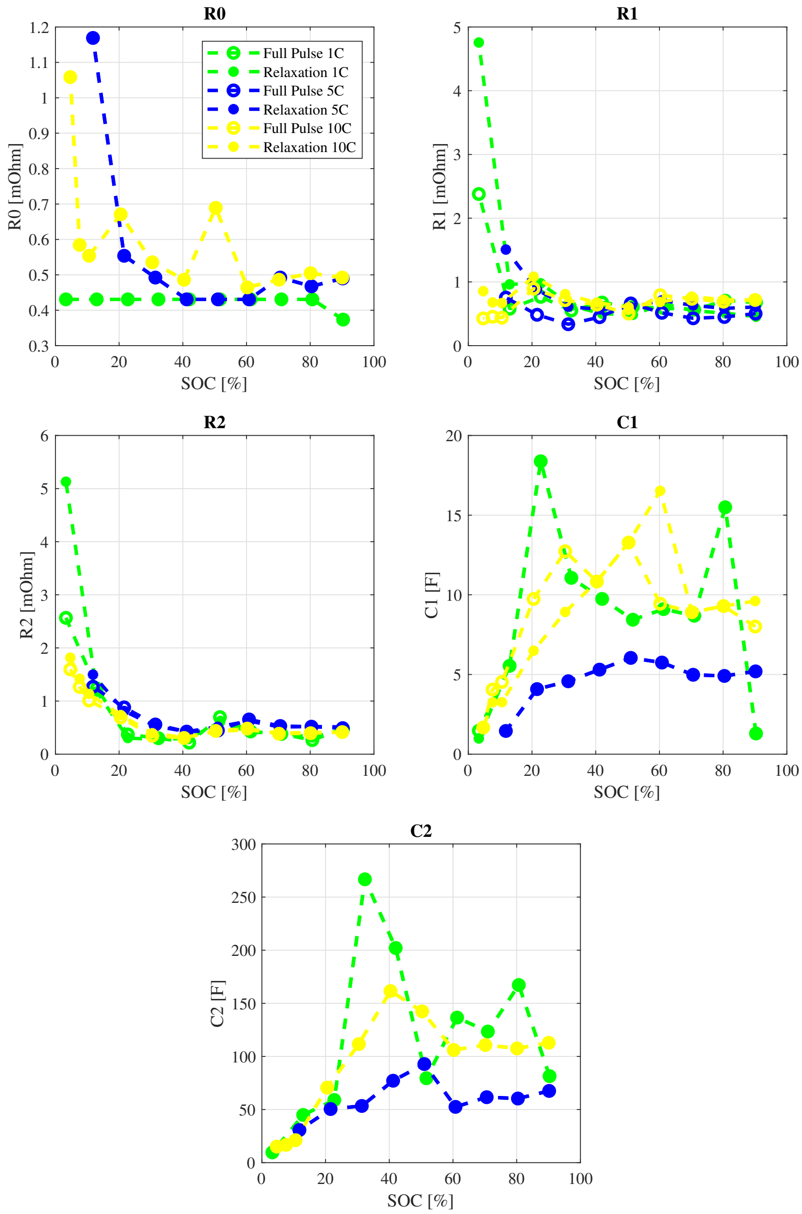

Fig. 3: RC link Parameters at different C-rates with different fits

It can be observed that there are minor variations in the resistances with a sharp increase at low SOC levels, which is the correct physical behaviour of a lithium ion battery cell. However, the capacitance values are of largely different magnitudes, with two peaks in the capacitance values at around 20% and 80% SOC. This can be attributed to the changing slope of the OCV curve at these SOC values, due to the phase shift phenomenon in the graphite electrode.

Fig. 4 and 5 show the terminal voltage and loss estimated simulated from the 2RC model under a WLTC drive cycle. The ground truth values from a physics-based model and the OCV have also been plotted. The OCV curve is obtained as the average voltage value from a C/20 charge discharge test.

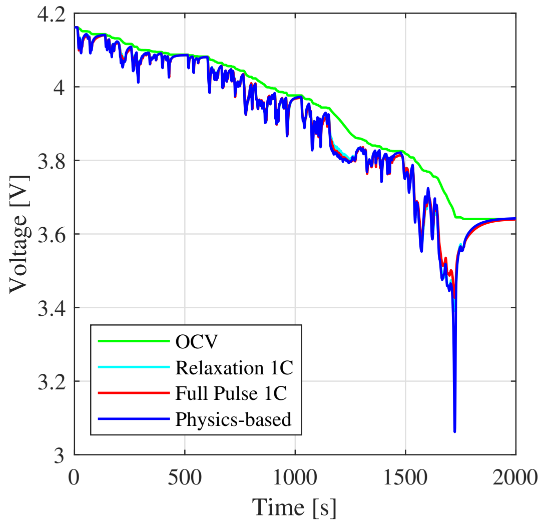

Fig. 4: The voltage profile of a single cell during a WLTC drive cycle simulated with a 2RC circuit model. The parameters are obtained from fitting the relaxation part and the whole pulse in 1C pulse discharge test.

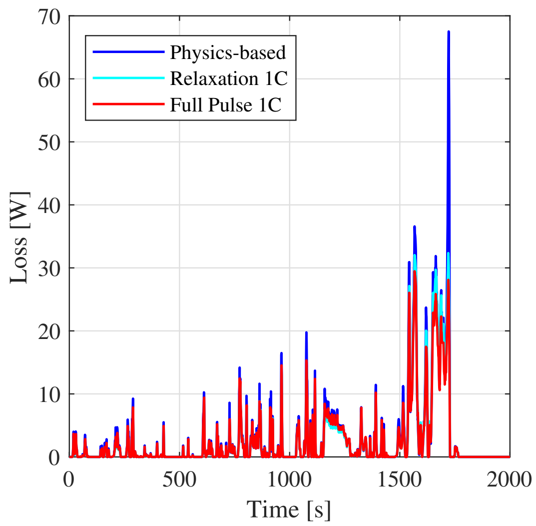

Fig. 5: The instance loss of a single cell during a WLTC drive cycle simulated with a 2RC circuit model. The parameters are obtained from fitting the relaxation part and the whole pulse in 1C pulse discharge test.

The CRMSE values obtained from the simulations have been presented in Tables I and II. The relaxation fit parameters obtained from 1C discharge characterization have the least error in comparison with other parameters

Table I: Comparison of the estimation errors with different C-rates used in the pulse discharge test. A 2 RC links model is used.

Pulse discharge C-rate	Voltage (mV)		Loss (mW)	
	Relaxation Fit	Full Pulse Fit	Relaxation Fit	Full Pulse Fit
0.5C	30.26	30.44	3022.08	3057.15
1C	**20.09**	23.09	**2014.72**	2375.71
5C	24.52	26.31	2339.52	2522.25
10C	24.77	26.25	2173.58	2323.13

Table II: Comparison of the estimation errors with different models. 1C current is used in the pulse discharge test.

Number of RC links	Voltage (mV)		Loss (mW)	
	Relaxation Fit	Full Pulse Fit	Relaxation Fit	Full Pulse Fit
2 RC links	20.088	23.094	2014.72	2375.71
3 RC links	22.021	23.255	2177.83	2288.70

Conclusion

The work uses the pulse discharge test technique to obtain the RC parameters for equivalent circuit models for Li-ion batteries. The pulse discharge tests were done at four different C-rating of the battery. As per the results it is observed that 1C rating is a better choice for characterizing the battery since it gives the least CMRSE. The relaxation fitting is more suitable to extract model parameters when the model is used for a driving cycle which has multiple transients. A comparison between an equivalent model with 2RC links and the one with 3RC links was performed. The result shows that 2RC link model has a better performance than the one with 3 RC links.

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