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Battery Models Parameter Estimation based on Matlab/Simulink®

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Abstract – Battery characteristics and performances at different operating conditions are crucial in its applications especially in Electrical Vehicles (EVs). With an accurate and efficient battery model it can be predict and optimize battery performance especially under practical runtime usage such as Battery Management Systems (BMS). An accurate method for estimating the battery parameters is needed before constructing the reliable battery model. Three famous battery models; the Partnership for a New Generation of Vehicles (PNGV), Thevenin and second order Battery model, are commonly used for battery modelling.

This paper proposes a new method of parameters estimation using Matlab/Simulink® parameter estimation tool for the premonition three battery models. A Lithium Polymer (Li-Po) 12Ah 3.7V battery is tested by specific standard tests at different State of Charge (SoC), temperature and current rate and the three models parameters are estimated according to these conditions. The comparison between PNGV battery parameter estimation spreadsheet method and Matlab/Simulink method for parameter estimation is presented. *Copyright Form of EVS25.*

Keywords – Parameters estimation methods, Matlab/Simulink, Thevenin battery model, PNGV, FreedomCAR battery model.

1. Introduction

Lithium-Ion (Li-Ion)/Lithium-Polymer (Li-Po) batteries are considered as high-capacity batteries, which can be designed for either high energy or high power applications. While there is a need for a model capable to describes the battery behavior, with a variation of battery conditions such as SoC, temperature, current rates, loading conditions static or dynamic loading and its applications. Three battery models, the Partnership for a New Generation of Vehicles (PNGV), Thevenin and Second order Battery model are commonly used for battery modelling [1-5]. Before selecting the battery model there are two steps that must be done carefully for achieving the best performance from the battery model; the first step applying a standards tests for estimating the battery parameters, the second step is using an accurate method for battery parameters estimation with minimal errors. In recent years, some approaches were proposed with different parameters estimation methods, these methods different according to the processing time for estimating the parameters, its degrees of complexity or using a simple battery model [1], [6] & [7]. The method used in [1] using PHGV battery parameters estimation spreadsheet has a limitation that it is used for only the PNGV battery model. The parameter estimation presented in [6] is complicated by using Extended Kalman Filtering (EKF), the method presented in [7] has a lot of mathematical expressions for extracting the battery parameters which is relatively complex and leads to a long estimation time.

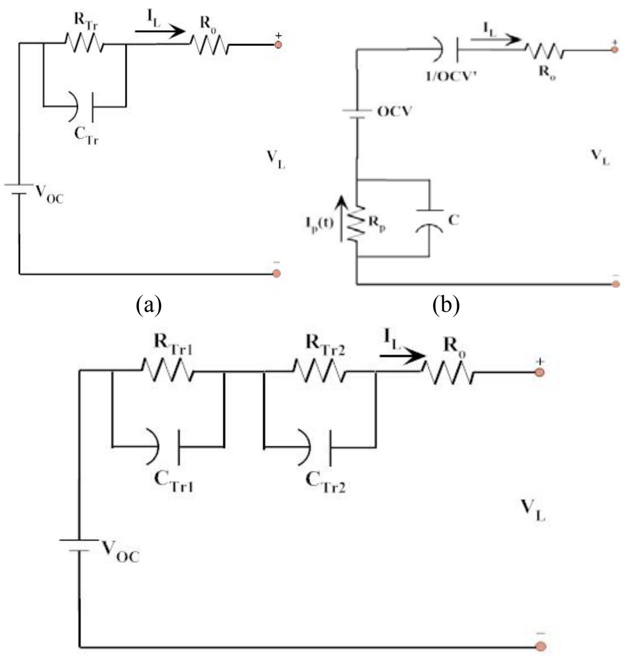
This paper presents new parameter estimation method using Matlab/Simulink® parameter estimation tool, which is easy, fast processing time, useful, powerful tool. The main advantage of this method that it can be used for any battery model, as the user builds, with a full control for estimation progresses. In addition this paper presents a comparison between the three common battery models Thevenin, PNGV, and second order battery model according their battery models parameters estimations. Also simulation the three battery models for their parameters validation with different load current profiles.

The paper is organized as follows. Section 2. Battery models and parameter estimation methods. Section 3. Comparison between parameters errors with different parameter estimation methods for the three models. Section 4. Illustrates Battery models parameters estimation using Simulink with the estimated parameters results. Section 5. Models parameters validation. Section 6. Paper conclusion.

2. Battery Models and Parameter Estimation Methods

2.1. Battery Model

The three common used equivalent circuits for describing the battery models are Thevenin, which describes the battery with an ideal battery voltage source (V_{OC}), internal resistance (R_o), and a parallel capacitance (C_{Tr}), and an over-voltage resistance (R_{Tr}), PNGV, which describes the battery with an Open Circuit Voltage source (OCV), internal resistance (R_o), open circuit voltage capacitance (1/OCV') and a Polarization circuit of shunted capacitance (C), and resistance (R_p), and second order battery model, which describes the battery with an battery voltage source (V_{OC}), internal resistance (R_o), and two parallel polarization circuits (C_{Tr1}-R_{Tr1} and C_{Tr2}-R_{Tr2}), as shown in Figure 1. The parameters of these battery models are estimated and validated with the aid of them Simulink modeling.



(a) (b)

(c)

Figure 1: Battery Models (a) Thevenin model (b) PNGV model (c) Second order battery model

Standard tests were done into the battery for extracting its different models parameters such as Capacity test, Dynamic Discharge Performance (DDP) test and a Hybrid Pulse Power Characterization (HPPC) test [1]. These tests were done at different SoC, temperature and C-rates.

2.2. PNGV Battery Parameter Estimation Spreadsheet Method:

From the premonition tests specially the HPPC test, the PNGV battery model parameters can be estimated using the PNGV battery parameters estimation spreadsheet method, as shown in figure 2.

The drawback of this method is the residual values (r^2) must exceed 0.995, in some cases it can't be reachable according to the tested battery and the testing process. In addition, the main drawback in this method it's valid only for PNGV battery model parameters.

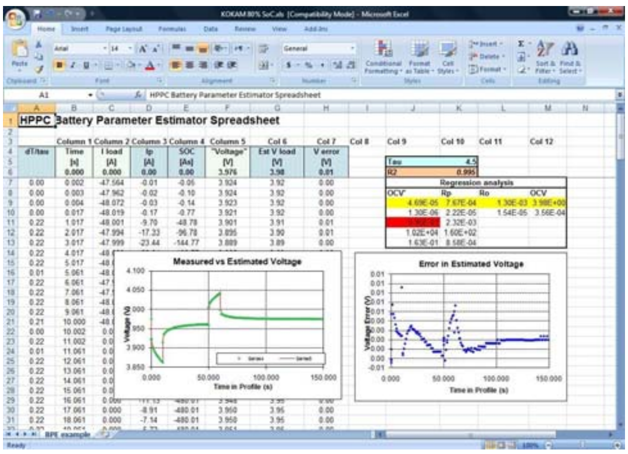


Figure 2: PNGV battery parameters estimation spreadsheet

2.3. Simulink Parameter Estimation Method:

A new method for estimating the battery parameters using Matlab/Simulink parameter estimation tool [8], under the Simulink environment, is proposed. Any suggested battery model can be built using Simulink simple mathematical blocks as shown in figure 3-a, or using SimPowerSystems blockset as shown in figure 3-b. The battery models build in Simulink shown in figures 3.a and 3.b are based on equations 1 and 2 [1].

$$V_L = OCV - OCV'[\int I_L dt] - R_O[I_L] - R_p[I_p] \qquad (1)$$

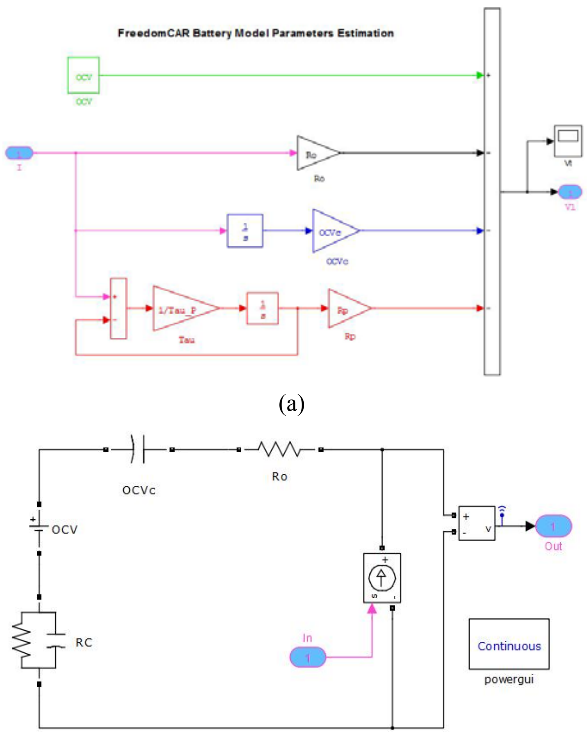
Where the polarization current I_p is the solution of the differential equation

$$\frac{dI_p}{dt} = \frac{(I_L - I_p)}{\tau} \qquad (2)$$

With a specified initial condition, e.g., $I_p = 0$ at $t = 0$.

Where:

OCV	An ideal voltage source that represents "open circuit" battery voltage
R_o	Battery internal "ohmic" resistance
R_P	Battery internal "polarization" resistance
C	Shunt capacitance around R_P
τ	Polarization time constant, $\tau = C.R_P$
I_L	Battery load current
I_p	Current through polarization resistance
V_L	Battery terminal voltage
1/OCV'	A capacitance that accounts for the variation in open circuit voltage with the time integral of load current I_L.



(a)

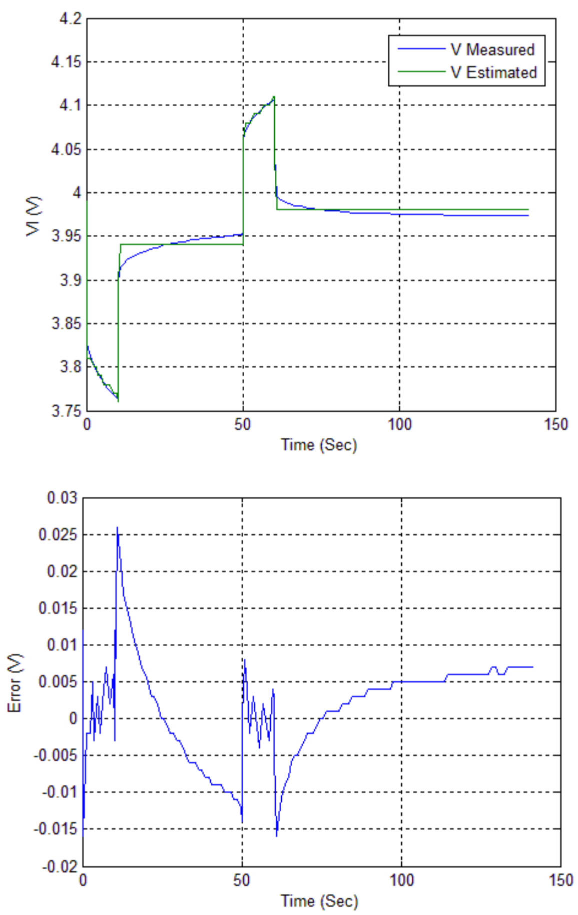
(b)

Figure 3: Simulink model for parameters estimation: a-Simulink mathematic blocks, b-SimPowerSystems Blockset

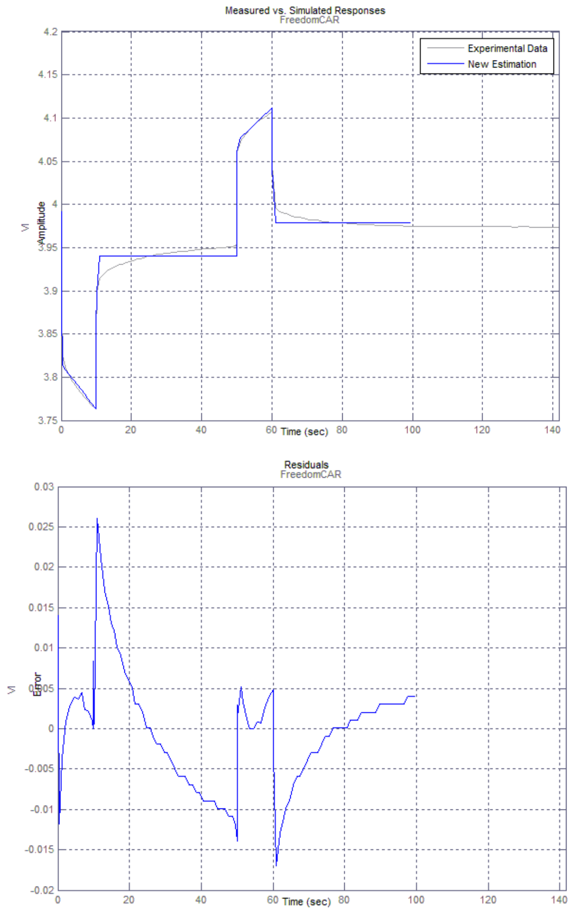
By using the premonition tests data, such as current and voltage function of time, where the current-time vector used as an input and the voltage-time vector as an output of the model. Also any initial values of the parameters to be estimated and them range which are the inputs of the Simulink model shown above in figure 3, the parameters estimation process can be done, and controlling the estimated parameters such as step time, solver type, which parameters will estimated and which will keep constant, parameters range … etc. The program will find the suitable parameters for fitting the input data with a minimal error between the measured values and the estimated ones.

3. Parameters Errors with Different Parameter Estimation Methods for the Three Models.

The battery models parameters were estimated using PNGV parameters estimation spreadsheet (only for PNGV battery model) and using Matlab/Simulink for the three battery models. One study case for the PNGV battery model parameters are estimated by PNGV Spreadsheets and Simulink methods shown in figure 4; the measured and estimated voltage comparison and corresponding errors between the measured and estimated voltage this case was done at 80% SoC and 25 ºC.



(a)

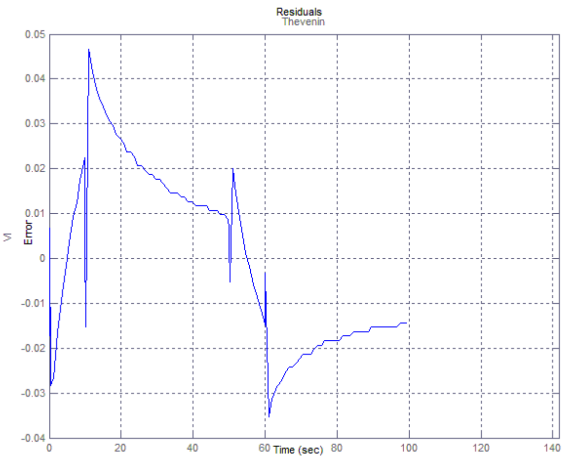


(b)

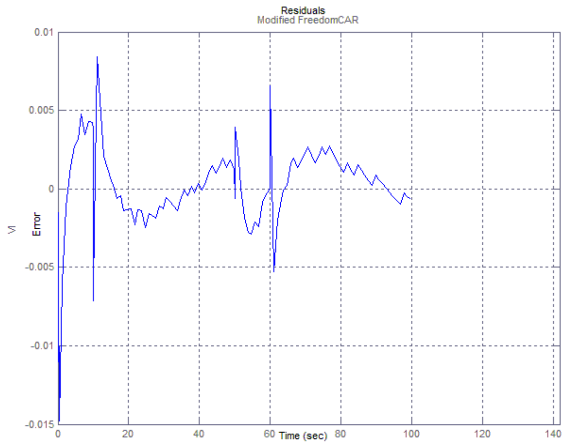
Figure 4: Example of voltage Error (a) PNGV Spreadsheet, (b) Simulink Parameter Estimation tool.

As shown in the figure 4, for the PNGV battery model the two parameters estimation methods nearly have the same error in estimated voltage, but the Simulink method is simpler, more accurate due to controlling the estimation step and faster with a fully control of the estimation process as mention before. In addition, *the Simulink method is valid for any model, which makes the Simulink a great tool in parameter estimation and model modification.*

Also for the other two battery models; Thevenin and Second-order parameters were also estimated using Simulink parameter estimation tool. The results for one study case, the two models estimated parameters error between measured and estimated voltage at 80% SoC and 25 ºC shown in figure 5.



(a)



(b)

Figure 5: Measured and estimated voltage error using Simulink (a) Thevenin (b) Second-order battery model.

As shown in figures 4 and 5; the parameters estimation at 80% SoC and 25 ºC for Thevenin battery Model gives a maximum error of 0.045 V (1.2 %), PNGV battery Model gives a maximum error of 0.025 V (0.68 %) and the Second-order battery Model gives a maximum error of 0.01 V (0.27 %).

The Second-order battery model gives less error than the PNGV and Thevenin models, that is according to increase in the number of parallel RC networks it increases the accuracy of the predicted battery response [5]. As a result, it can be expected that this model will have the best response during the validation process.

4. Models Estimated Parameters Using Simulink Parameter Estimation:

The estimated parameters for the three battery models using Simulink parameter estimation tool shown in figures 5-7. They are function of SoC and Temperature.

Another estimated parameters for the Second-order battery model as function of SoC and C-rates at 25 ºC is shown in figure 8.

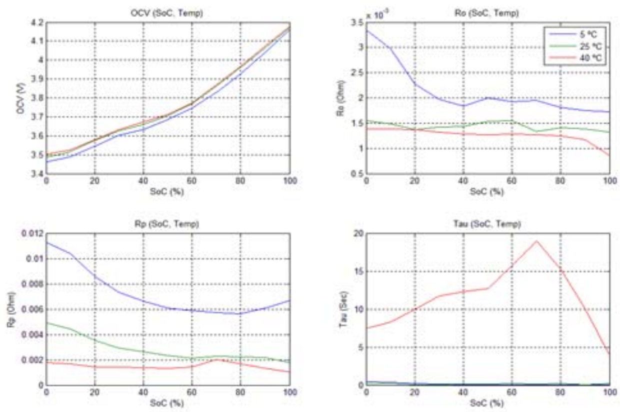


Figure 5: Thevenin battery model estimated parameters.

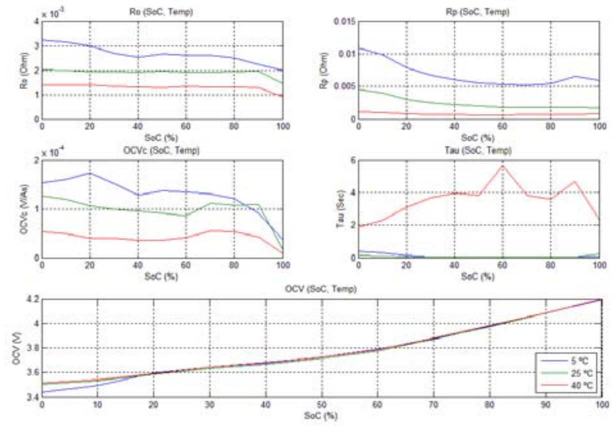


Figure 6: PNGV battery model estimated parameters

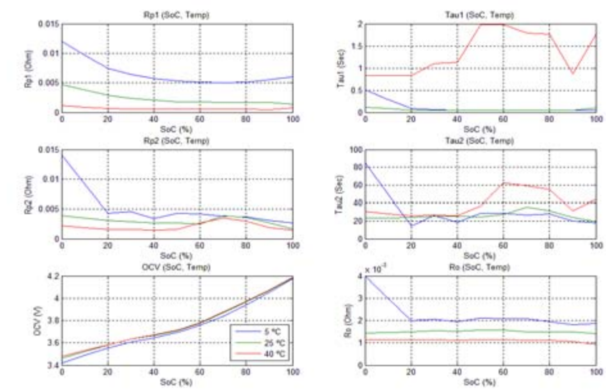


Figure 7: Second-order battery model estimated parameters function of SoC and Temperature

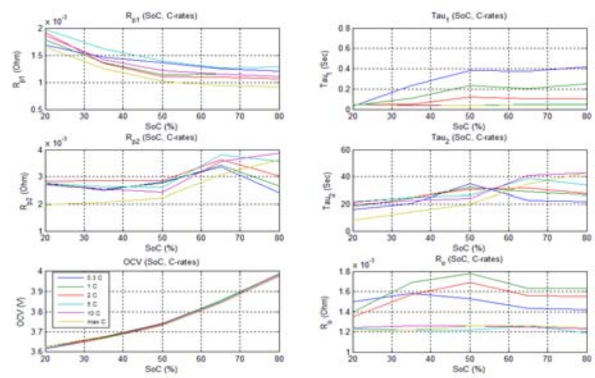


Figure 8: Second-order battery model estimated parameters function of SoC and C-rates

5. Models parameters validation.

The three models were simulated using Simulink for validating their estimated parameters, the validation done using two current profiles the first using HPPC test profile and the second using constant current 12A. Figure 9; shows the error between the measured and estimated voltage for the three models under the two loading conditions.

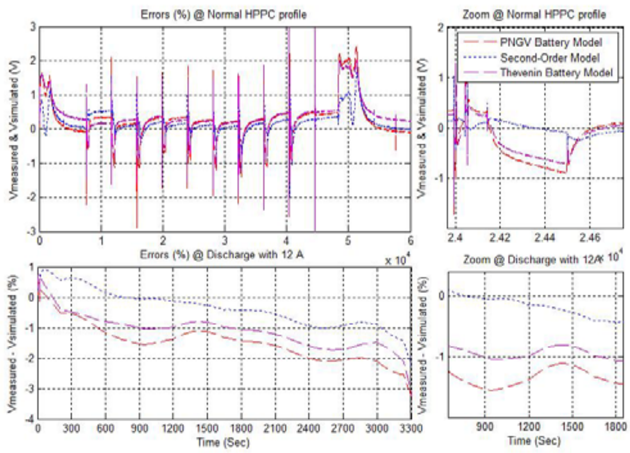


Figure 9: Validation profiles voltage errors for the three battery models with the estimated parameters.

6. Conclusion

The standard battery tests for parameters estimation were represented with different battery models parameters estimation methods. A new method for parameter estimation is proposed for any battery model using Matlab/Simulink. This method is based on Matlab/Simulink parameter estimation tool. Its advantages are low processing time, easy, powerful tool. It also gives accurate results. The main advantage of this method that; it can be used for any battery model as the user need with a full control for estimation progresses. It's applied for estimating the battery model parameters for three different battery models; Thevenin, PNGV and Second-order battery models.

The parameters of the three models are estimated and compared at different SoC, temperature and C-rates. The Second-order battery model gives the best result than the compared battery models, where for the parameters estimation process the Thevenin battery Model gives a maximum voltage error of 0.045 V (1.2%), PNGV battery model gives a maximum error of 0.025 V (0.68 %) and Second-order battery Model gives a maximum error of 0.01 V (0.27 %), which gives the best response into the battery simulation modeling. Also it gives the best response during the validation simulations. The validation profile proof that the Simulink parameter estimation method is accurate and valid for any battery model parameter estimation.

7. Acknowledgments

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