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Analysis of the effects of temperature and RC pairs on Li-ion battery models

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ABSTRACT

Electric Vehicles have become the need of time to reduce the pollution from the transportation sector. Not only they reduce pollution but they are also excellent products of renewable energy. Two of the most eminent parts of any electrical vehicle are the Battery and Battery management systems(BMS). Modeling and testing of the systems using simulation is an effective method alternate to hardware testing since it reduces the cost and increases the efficiency of testing. The hardware testing of the battery also affects the safety of the system and any errors may lead to permanent damage to the components and sometimes affecting the people operating them. To model and simulate any component it is necessary to analyze the effects of the parameters which influence it. In this paper, the effect of temperature and the number of RC pairs taken to model the equivalent circuit of the battery is considered as the key factors. The results are used for the analysis of their effects in real-time using the simulation models.

Keywords— *Battery Management Systems, C-rating, Equivalent circuit, Open Circuit Voltage, Parameter Estimation, State of charge*

1. INTRODUCTION

Transportation is one of the largest sources of climate pollution in the world. To solve the climate crisis, we need to make the vehicles on our roads as clean as possible. To minimize all the major problems caused by transportation, Electric vehicles (Both pure and hybrid) are being promoted more into use since they cause comparatively less pollution when compared to diesel or gasoline-powered vehicles. Batteries are the most important part of any electric vehicle which provides the main source of power to them.

There are different types of batteries used like Li-ion, Ni-Mn, Lead-acid batteries, etc. Due to many higher advantages such as high energy density and specific energy, long life, higher voltage, and lower self-discharge rates, Li-ion batteries are more preferred. Li-ion batteries ' primary disadvantages are the need for proper management to guarantee safety and cost (of the cells, plus the supporting electronics) which are relatively high. However, since the advantages overweigh the disadvantages and also lithium-ion cells and electronics are becoming less expensive and over time we should see their price decrease significantly. Modeling of Battery and Battery Management Systems using software and simulating reduces the cost factor and safety factor in testing. It also helps in understanding the behavior of the system in real-time more efficiently, set up the limitations of the system, and helps in redesigning the circuits if required in case of any error in the circuits before implementing using hardware.

2. DESIGN METHODOLOGY

The design and analysis for this paper are split into two parts: Parameter Estimation and Parameter Validation. The general design flow is mentioned in Figure 2.1 . Parameter Estimation is the first step of the system design. The battery models based on equivalent circuits are preferred for system-level development and control applications due to their relative simplicity. Using equivalent circuits to model the thermo-electric behavior of batteries, parameterizing their nonlinear elements with correlation techniques that combine models and experimental measurements via optimization is the key objective. The key parameters for the modeling of the battery are the Open-Circuit Voltage, Internal resistance, and Resistor-Capacitor pairs. The equivalent circuit of a cell is mentioned in Figure 2.2.

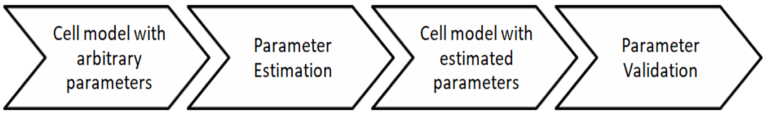

Fig 2.1. Design Methodology flow

The battery discharge circuit is used as an estimation model where the battery is imputed with arbitrary parameters and connected to the current load. The pulse data i.e., voltage, current, battery capacity, SOC measured at regular intervals are provided by the manufacturer. The important point to observe is all the parameter initial values fed are arbitrary values based on experience and they are taken as input in the form of look-up tables(Scalar matrix). The relationship between SOC and OCV is taken into consideration for the parameter estimation. The equivalent circuit of the cell consists of three important components:

- R0 is the internal resistance related to the ionic conductivity of the electrolyte
- Em is open-circuit voltage(OCV) and
- Parallel RC blocks are present which represent dynamic properties(for non-linearity).

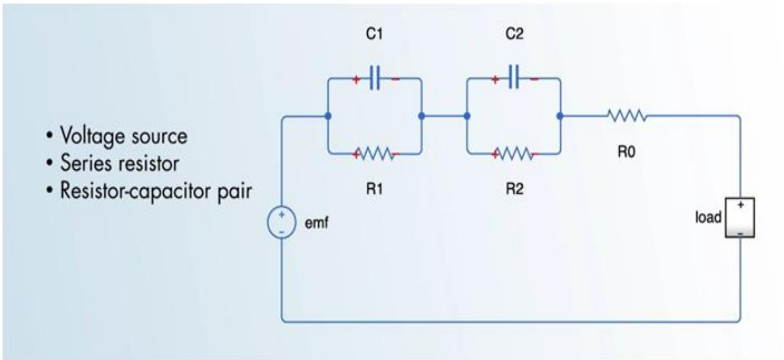

Fig 2.2. Equivalent circuit model of a Cell

2.1 Parameter Estimation and Validation

Parameter estimation corresponds to the estimation of the values for these components which interpret the behavior of the cell at different temperatures. The parameters for the battery which are fed to build the equivalent circuit of the cell model can be input in the form LUTs(lookup tables) which makes the design easy and efficient. Battery models based on equivalent circuits are preferred for system-level development and control applications due to their relative simplicity. Using equivalent circuits to model the thermo-electric behavior of batteries, parameterizing their nonlinear elements with correlation techniques that combine models and experimental measurements via optimization is the primary objective.

For higher efficiency, more than one set of parameters are taken which increases the iterations which further increases the similarity between the real-time component and the model. The flow of the parameter estimation of data is given in Figure 2.3.

Once the parameters are estimated they are fed as input in the validation model, which then is subjected to a load, and the actual voltage, temperature, and currents are measured. These values are then validated using the Battery Charge and Discharge data and are plotted for detailed analysis .

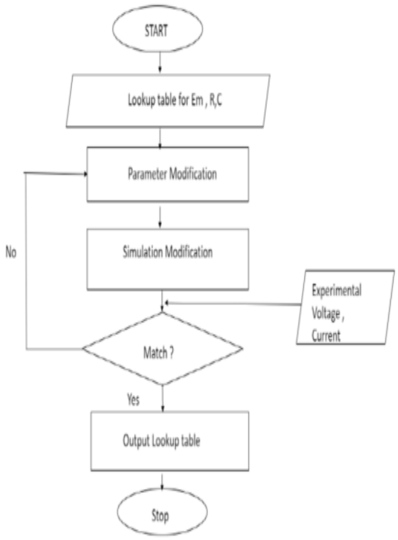

Fig 2.3. Parameter Estimation Flow

3. IMPLEMENTATION AND SIMULATION

As discussed, the implementation is split into two parts, Parameter estimation, and Validation. For parameter estimation, a cell discharge model is considered where the cell is subjected to constant current load to discharge. The parameters for cell are initially fed with arbitrary values and simulated. Using the pulse data obtained from the manufacturer and the MATLAB optimization function parameter estimation is performed.

The main focus of this paper is the effect of temperature change and the change in the number of RC pairs considered in the equivalent circuit of the cell on the system. To analyze this, the LUTs fed into the estimation are considered for different temperatures ranging from -200 C to 600 C. For each of the temperature scales, the number of RC pairs in the equivalent cell circuit is varied from one to three and simulated for all three conditions. The estimation model used is shown Figure 3.1

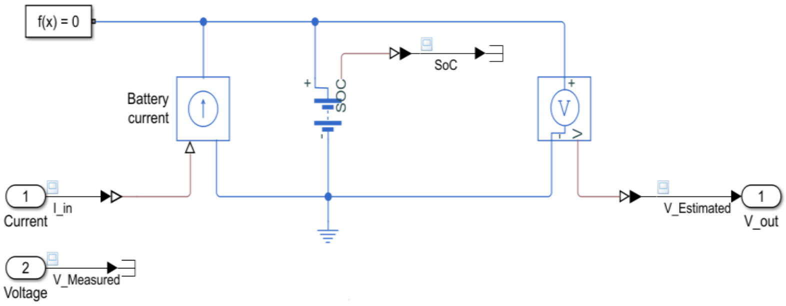

Fig 3.1. Parameter Estimation Model

The SOC and the voltage are measured and plotted with initial parameters than, using the parameter estimation toolbox and the relationship between SOC and OCV the actual parameters are estimated. These parameters are OCV(Em), Internal resistance (R0), and depending upon the number of RC pairs the value of the resistance and capacitors used(R1, C1, R2, C2, etc). They are stored and are fed into validation parameters for verification.

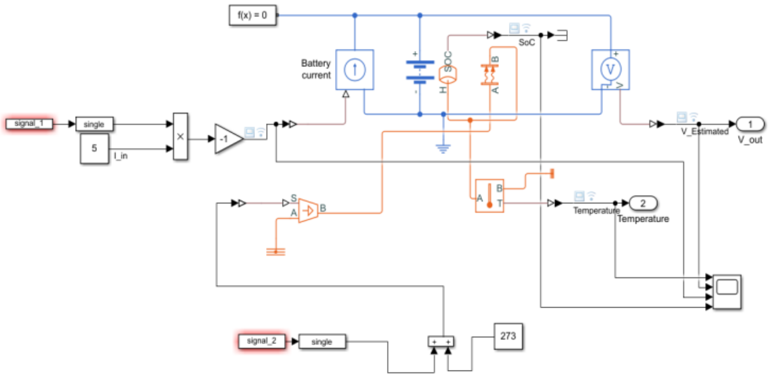

Fig 3.2. Parameter Validation Model

The validation model as in Figure 3.2 uses the estimated parameters fed into the cell and simulated. The voltage and temperature for each set of temperature and the number of RC pairs are noted and stored separately. Further, the noted voltages and cell storage data obtained from the manufacturers are compared and validated using the plots. For validation purposes at each temperature value, the model is subjected to different load currents and the values are stored and validated. This helps in understanding the behavior of the cell under different temperatures as well as analyzing the effect of the number of RC pairs more precisely

4. RESULTS AND INFERENCES

Both the estimation model and the validation model are simulated for all the temperatures and with the different number of RC pairs in the equivalent circuit.

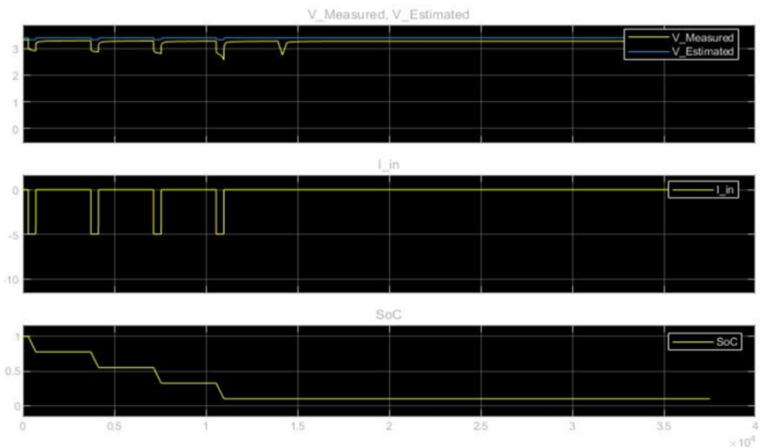

Fig 4.1. Output of Estimation Model using Arbitrary Cell parameters

4.1 Effect of number of RC pairs

Fig 4.1 shows the output plot of the estimation model where the cell parameters fed are arbitrary values based on the experience.

The first plot shows the measured voltage(manufacturer data) and estimated voltage, the second plot shows the discharge current and the third plot shows the SOC (State of Charge) of the cell. The dip in voltage is caused when the load is connected which shows that the current is discharging and the SOC also decreases due to the same.

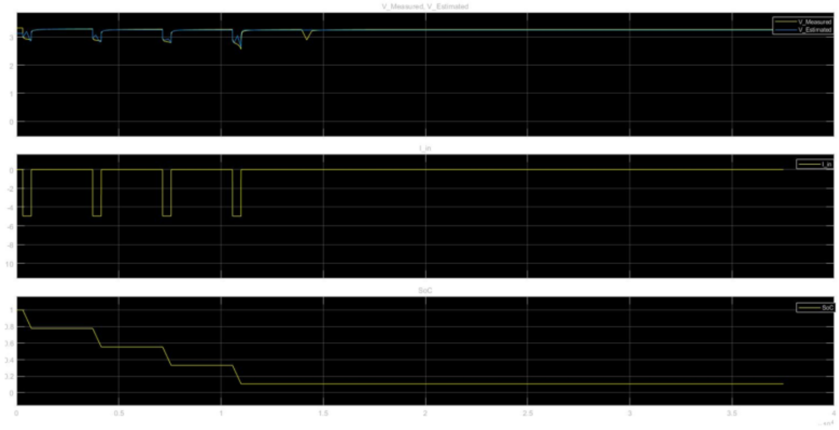

Fig 4.2. Output of Estimation Model using estimated cell parameters(1RC)

From Figure 4.2 we can see that although the estimated voltage is matching with the measured voltage there is a large difference when there is a dip in voltage when the load is connected. This infers that the delay model to interpret the battery requires more than one RC pairs.

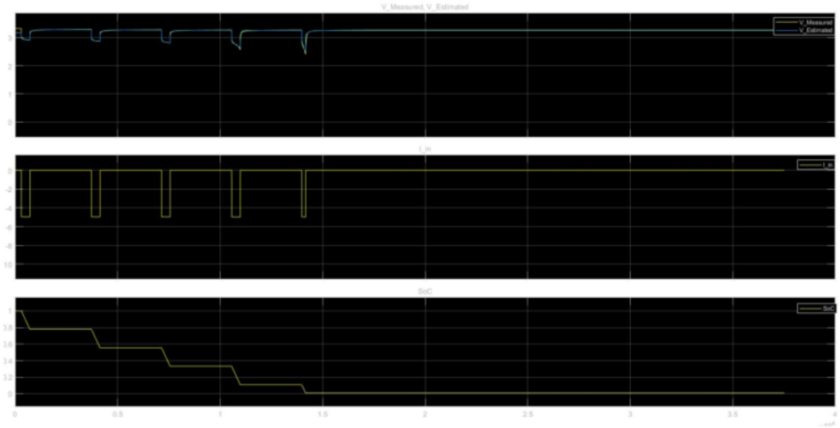

Fig 4.3. Output of Estimation Model using estimated cell parameters(2RC)

From Fig 4.3 and Fig 4.4 we can observe that the measured voltage and estimated voltages are precisely similar. The dip in the voltages is also nearly the same which infers that the cell with more than two RC pairs is able to exhibit the cell characteristics more accurately. From all the simulation plots, we can observe that the estimated voltage and measured voltage were different completely before estimation due to the arbitrary parameter values. When the parameters were estimated using the estimation toolbox, we can observe that the voltages are relatable to each other which satisfies that the parameters are nearly accurate.

One of the main objectives was to analyze how the number of RC pairs in the equivalent circuit affects the battery model. If we closely observe the voltage plots for different RC pairs, we can observe that when there is a dip in the voltage, the 1RC equivalent circuit is unable to match whereas the 2RC and 3RC equivalent circuits are able to match. This infers that an increase in the number of RC pairs helps in modeling the delay more accurately. But increase in the number of RC pairs may lead to more power consumption and heating of the circuit. Through these plots, we can observe that an equivalent circuit with 2 RC pairs represents the model much accurately and we can rule out that there is no need for another pair which may affect the model negatively.

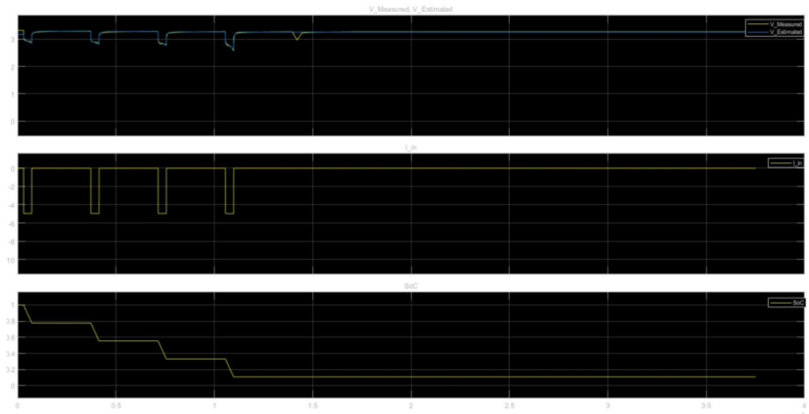

Fig 4.4. Output of Estimation Model using estimated cell parameters(3RC)

4.2 Effect of Temperature

The plots obtained after performing validation using the measured data and the cell discharge data are mentioned below.

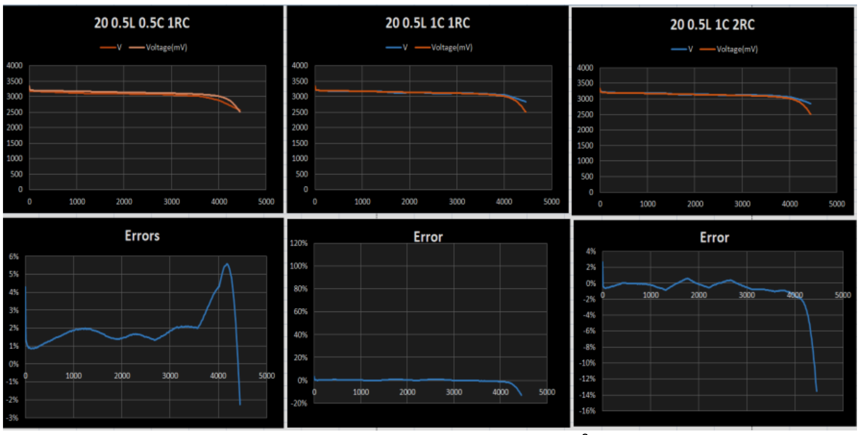

Fig 4.5. Validation plots at 20^0 C

In the validation model, the load current is varied and for each load current and temperature, the voltage is measured and noted. V represents validation model output and Voltage represents the measured voltage (manufacturer data).In the title of plots, 20 represents the temperature, 0.5L means the load current used is 0.5C where C is the C rating of the cell and 1RC represents the number of RC pairs. From all the plots we can observe that the error percentage is too high at the beginning and end. This is because when the voltages are measured, sometimes the initial and final state of the real-time cell may vary from that of the simulated cell.

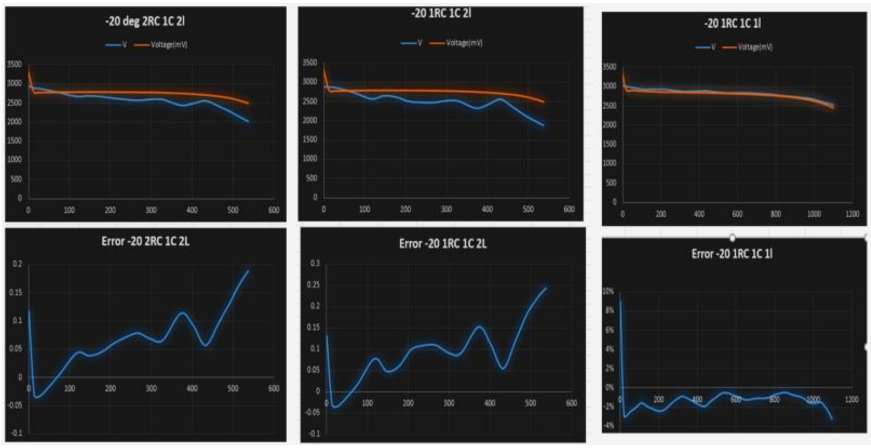

Fig 4.6. Validation plots at -20^0 C

From Fig 4.5 we can observe that both the V and Voltage are nearly similar which infers that the parameters estimated are accurate since even when the load is varied still the cell behavior is nearly the same. From Fig 4.6 we can observe that there is more deviation in V and Voltage which is also shown in errors. This infers that when the temperature is extremely low or high when compared to the optimal environment the cell behavior varies.

Comparing all the validation plots obtained, we can infer that the model gets severely affected when the temperature is too low such as less than 0^0 C, or too high such as greater than 45^0 C which deviates highly from the optimal working temperature of the battery. This also infers that the cell may get damaged when it is subjected to very high or very low temperatures which are more deviated from the optimal working environment of the cell.

5. CONCLUSION

It can be inferred from the results that the change in the number of RC pairs in the equivalent circuit of the cell affects the delay model of the battery which helps in modeling the battery more accurately in real-time. Although increasing the number of RC pairs improves the accuracy of the delay model, it also increases the noise and the power consumption which affects the lifetime of the battery. Depending on the requirement, the number of RC pairs can be varied. It is also observed the battery behavior is more affected when there is too much deviation from the optimum working temperature of the battery. It can be inferred that a battery model can be optimized by varying its thermal properties and the delay properties to interprets the characteristics of a real-time battery using simulation models more efficiently.

6. REFERENCES

[1] A. Berrueta, V. Irigaray, P. Sanchis, and A. Urs_ua, \Lithium-ion battery model and experimental validation," in 2015 17th European Conference on Power Electronics and Applications (EPE'15 ECCE-Europe), 2015, pp. 1{8. doi: 10.1109/EPE.2015. 7309337.

[2] Z. Gao, C. Chin, W. L. Woo, J. Jia, and W. D. Toh, \Lithium-ion battery modeling and validation for smart power system," 2015 International Conference on Computer, Communications, and Control Technology (I4CT), pp. 269{274, 2015.

[3] Y. Mazzi, H. B. Sassi, F. Errahimi, and N. Es-Sbai, \State of charge estimation using extended kalman filter" 2019 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS), pp. 1{6, 2019.
[4] H. Ren, Y. Zhao, S. Chen, and T. Wang, \Design and implementation of a battery management system with active charge balance based on the soc and soh online estimation," Energy, vol. 166, Oct. 2018. DOI: 10.1016/j.energy.2018.10.133.
[5] M. Chen and G. Rincon-Mora, \Accurate electrical battery model capable of predicting runtime and i-v performance," IEEE Transactions on Energy Conversion,vol. 21, no. 2, pp. 504{511, 2006. DOI: 10.1109/TEC.2006.874229.
[6] C. Piao, Z.Wang, J. Cao, W. Zhang, and S. Lu, \Lithium-ion battery cell-balancing algorithm for battery management system based on real-time outlier detection,"Mathematical Problems in Engineering, vol. 2015, p. 168 529, Oct. 2015.
[7] S. Yarlagadda, T. Hartley, and I. Husain, \A battery management system using an active charge equalization technique based on a dc/dc converter topology," 2011 IEEE Energy Conversion Congress and Exposition, pp. 1188{1195, 2011.
[8] M. Seo, T. Goh, M. Park, G. Koo, and S. W. Kim, \Detection of internal short circuit in lithium ion battery using model-based switching model method," Energies, vol. 10, no. 1, 2017, ISSN: 1996-1073.

