

Comparison of a Single Branch and a Double Branch R-C Models for the Li-ion Batteries Considering the Electric Vehicle Applications

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Abstract-This paper explores the idea of comparing the single and double branch R-C models for the Li-ion batteries considering the Electric Vehicle (EV) applications. The running range and the charging/discharging time are the utmost factors to be considered while designing the batteries for these applications. The Li-ion batteries are the common choice and the proven technology since many years for the EV and HEV applications and hence, to be modeled with the due consideration given to the Resistance (R), Capacitance (C), State of the Charge (SoC), Thermal Dependence of R and SoC. This paper covers all these parameters and their comparison for the single and double branch performance for the Li-ion batteries. The simulations are carried out in the MATLAB/Simulation[®] environment. The results showing comparison of the two models are also presented in the paper.

Index Terms-Li-ion Battery; Electric Vehicles (EVs); Modeling; R-C Branch

1. INTRODUCTION

The Hybrid Electric Vehicles (HEVs) started their journey in the late nineteenth century and that evolution process is still going on. With the growing concerns for the carbon footprints and issues of global warming, the scientists and researchers around the world are looking in depth for the technologies for transportation around the globe [1-3]. Their basic concentration is for the non-fossil fuel vehicles and the obvious choice is the Electric Vehicles (EVs) and the Hybrid Electric Vehicles (HEVs). There are few combinations like, (1) FHEV (Full Hybrid Electric Vehicle) – These vehicles have electric motors and internal combustion engines (ICE) working together and are suitable for the short distance when running on the electric power only. (2) BEV – known as the battery electric vehicles and powered by the energy stored in the battery. The batteries can be recharged from the grid. The main concentration of research in this area is the power density and the energy density enhancement and the longer distance to run for the BEVs. (3) FCEV

(fuel cell electric vehicle) – it typically uses hydrogen to generate electricity and powers an electric motor. (4) EREV – known as the extended range electric vehicle. It consists of an internal combustion engine, on-board charger and an electric motor. It has a longer range than a battery vehicle [4-6].

Now, for the above mentioned EVs and HEVs the primary component is the battery and the Lithium Ion (Li-ion) batteries are the established batteries in this technological segment. Therefore, a mathematical model that shows the performance of these batteries considering the thermal dependence is utmost necessary. Over the past few years, researchers have come up with the various models of Li-ion batteries and the single branch R-C and double branch R-C models are the two main models. Here, in this paper, an attempt is made to compare these models considering the thermal effects, the battery parameters and the load effects. The batteries for these models are tested in the Simulink[®] environment of MATLAB[®]. The results

proved are indicating the performance and the comparison of the models taken into consideration.

2. MODEL FORMULATION

As pointed out earlier, the basic models consist of either one RC or two RC branches. Both these models are shown in Figures 1 and 2 respectively. In both these R-C models, the voltage source is shown by E and there is a definite relation between an open circuit voltage E and the State of Charge (SoC) of a battery. This relation is considered in the form of a look-up table in the MATLAB/Simulink[®] environment. Figure 3 shows the theoretical model of the Li-ion battery. This model has 'n' numbers of the branches where 'n' is an integer and its choice depends upon the required information from the model and complexity of the model. The components R – Resistance and C – Capacitance show the internal opposition and a charge storage mechanism. In a single branch R-C model, the R-C effect is considered as the lumped parameters whereas, the two R-C branch model has two such lumped groups. These models show the dynamics of the battery pack. The further increment in the numbers of branches is always possible leading to the theoretical model of 'n' branches, where 'n' can be any integer but again as the numbers of branches are increased, the model complexity and the computational efforts are also increased. The State of Charge (SoC) has also a relation with the temperature T. This correlation is also established by a look-up table.

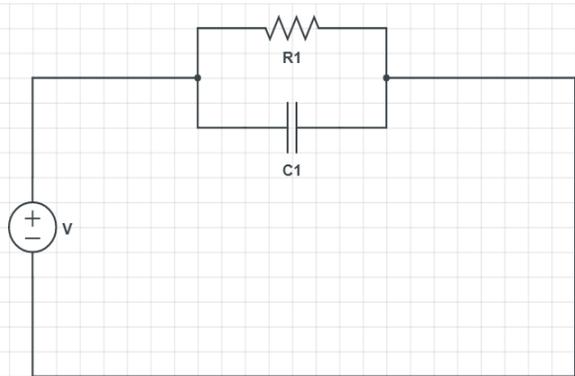


Figure 1. A Single Branch R-C Model of an Li-ion Battery

These all look-up tables are useful while plotting the charge/discharge characteristics, SoC and voltage profile for both the said models. For all the

standard equation related to these models refer [7-8]. Here, the focusing point is comparison of the said models and not the theory or the equations associated with these models. One more resistance, R_s , that works as the internal series resistance can be shown connected in the series after the voltage source but it is not shown in these models.

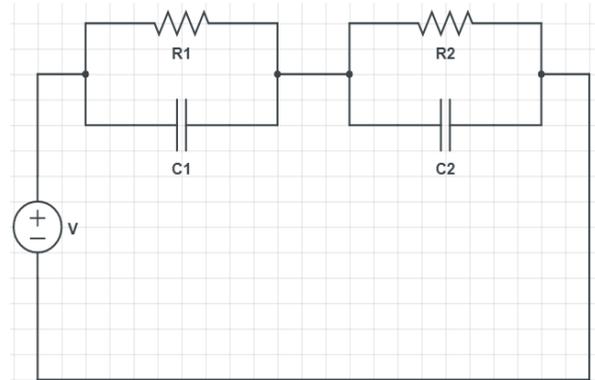


Figure 2. A Double Branch R-C Model of an Li-ion Battery

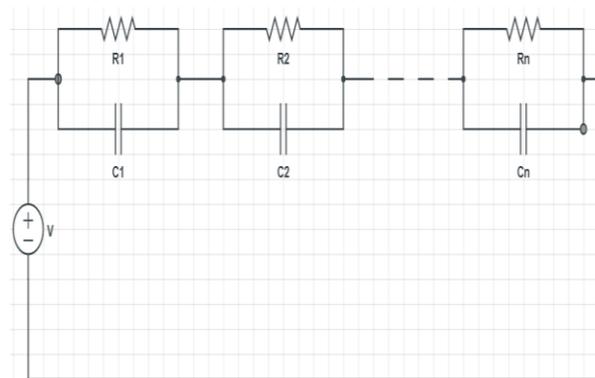


Figure 3. A Theoretical 'n' Branch R-C Model of an Li-ion Battery

3. RESULTS AND DISCUSSION

The single and double branch models of the Li-ion batteries were simulated in the Simulink[®] environment of MATLAB[®] and the results are presented below.

3.1 Single Branch R-C Model

Results for the single branch R-C model are shown in the figures 4 (a) to 4(d). Figure 4(a) shows the Charging/Load Current for the Single Branch R-C Model. Initially the charging current shoots up to value

nearly to 31 A and then the numbers of discharge pulses are marked at the regular intervals of 3600 seconds that equals to one hour. Figure 4(b) shows the voltage profile for the single branch R-C model. It is clear from the figure that in the initial current charging period, the voltage profile also goes high and at the discharging currents at the prescribed intervals, the voltage touches to 1.95 V from initial value of 3.6 V.

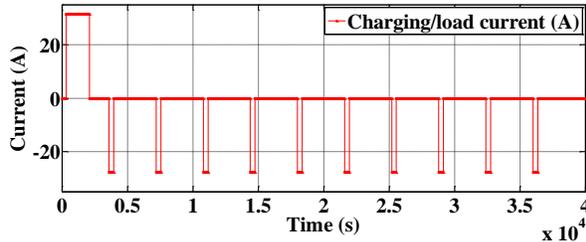


Figure 4(a) Charging/Load Current for the Single Branch R-C Model

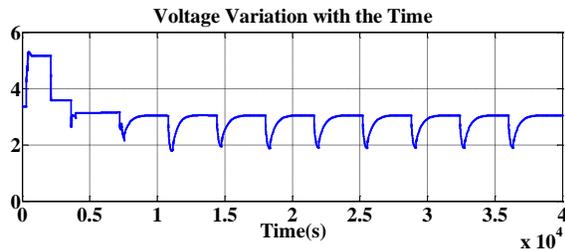


Figure 4(b) Voltage Profile for the Single Branch R-C Model

Figure 4 (c) presents the State of Charge (SoC) for the Single Branch R-C Model. From the initial SoC of the battery let say 100%, the SoC falls down by around 6% over the total simulation time of 36000 seconds or 10 hours. Again the pulses of SoC decrement are registered at the regular intervals correspond to the load current pulses. Figure 4(d) shows the temperature variation. Apart from the initial phase of charging, the temperature hovers between 20degree cen. to 37 degree cen. depending upon the successive load current pulses.

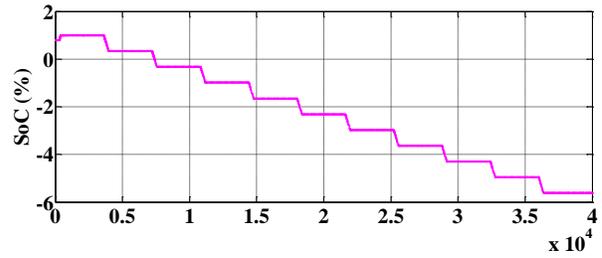


Figure 4 (c) State of Charge (SoC) for the Single Branch R-C Model

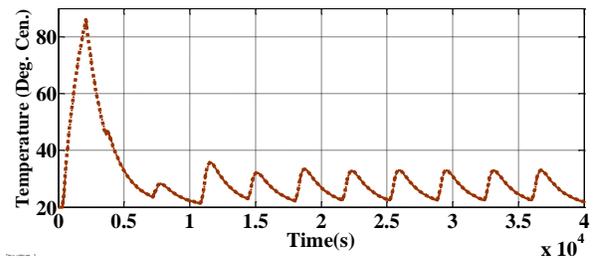


Figure 4 (d) Temperature Variation for the Single Branch R-C Model

3.2 Double Branch R-C Model

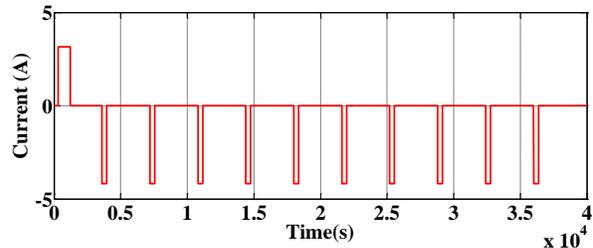


Figure 5(a) Charging/Load Current for the Double Branch R-C Model

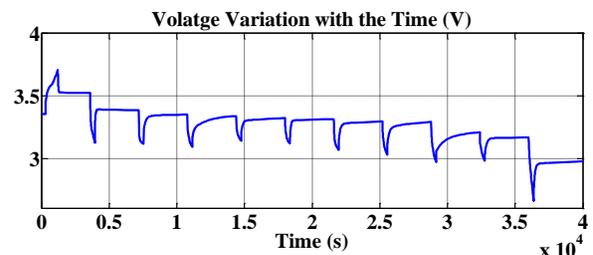


Figure 5(b) Voltage Profile for the Double Branch R-C Model

Similarly, Figures 5(a) to 5(d) shows the current variation, voltage variation, SoC variation and the temperature variation respectively for the Li-ion battery's double branch R-C model. Here, the discharging current was kept to 4A at the regular intervals of 3600 seconds or 1 hour. The voltage profile

has spikes from 3.4 V to 3.1 V in the discharging mode. In comparison to the single branch model, the spikes in the voltage profile are sharp basically due to fast charging process of the first branch and the charge redistribution process. The SoC variation is has nearly the same pattern as of the single branch R-C model but the temperature variation has many transients in comparison to the single branch R-C model.

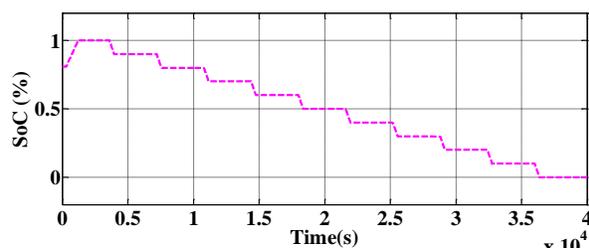


Figure 5(c) State of Charge (SoC) for the Double Branch R-C Model

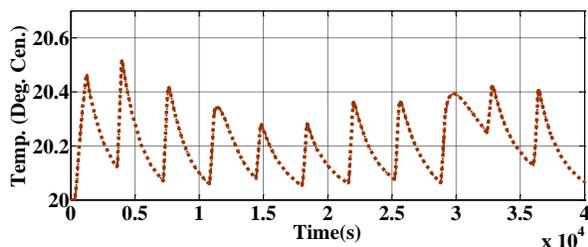


Figure 5(d) Temperature Variation for the Double Branch R-C Model

4. CONCLUSION

After formulating the single and the double branch model for the Li-ion battery, both these models were compared for the voltage profile variation, State of the Charge variation and the temperature variation. One of the important point to note is in the variation of the voltage profile. For the single branch R-C model, the voltage variation is without much of the spikes but the double branch R-C model has many transients. The simple reason behind this is for the second order circuit like the double branch model, the charge redistribution process and fast charging process of the first branch. The SoC variation for the both these models is almost same but again the temperature variation graph for the double branch model is with transients basically due to response of the second order R-C branch.

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