Modeling and Charge-Discharge control of Li-ion Battery using Simulink

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***Abstract*—Lithium-ion batteries have become increasingly popular in the recent days due to their high power/energy density, high nominal voltage, long life, fast charge rate etc. This had led to their increased usage in Electric vehicle (EV) applications as an energy storage system. The design of any efficient battery powered system requires accurate mathematical and simulation models of the battery which play an important role in predicting its electrical characteristics. The performance of a battery depends largely on the state-of-charge (SOC) which is an important parameter that is used to determine its charge/discharge characteristics. Thus, to prevent overcharging and discharging and protect the battery, an accurate estimation of the SOC is very much necessary. This paper demonstrates the development of an electrical battery simulation model in MATLAB/Simulink. A lithium-ion battery is considered to give a detailed explanation of the building of the battery model blocks and their interconnection. The battery model so developed is validated by comparing with a standard battery available in the MATLAB/Simulink library. The developed model could be used for other battery types as well. Further, the control of charge-discharge characteristics and battery voltage characteristics for different load powers of the modeled Li-ion battery is also presented.**

***Index Terms*—battery model, charge-discharge characteristics, lithium-ion battery, state of charge.**

I. INTRODUCTION

[Font: Times New Roman, Size:10] A rechargeable battery is an electrochemical device which converts electrical energy to chemical energy during charging and converts back to electrical energy during discharging. It plays a significant role in future technology since it is a potential choice as an energy storage element in green technology applications.

Batteries are an indispensable part of systems such as EVs, hybrid electric vehicles (HEVs), solar energy systems and smart-grid systems. A lithium-ion battery is highly preferred due to its chargeability and high energy to power ratio as compared to lead-acid and other nickel-metal-hydride batteries. To predict the performance and optimize energy dissipation, a designer needs to take battery behavior into account. Thus, information regarding charging and discharging of the Li-ion battery is an important factor for designing the circuit to attain high power performance and efficiency. Various parameters are associated with the behavior of a battery, of which the SOC is an important one. As, SOC information of the battery tells about its charge/discharge control, the correct indication of SOC is important in any battery based storage system.

A simulation model of a lithium ferro phosphate battery is developed using MATLAB/Simulink and the simulation results are compared with the experimental results to validate the model [1]. An electrical equivalent circuit model of lithium-ion cell is presented in [2] which shows the suitability of the model for successful monitoring of SOC and state of battery health. In [3], a Simulink model is developed based on first and second order Thevenin equivalent circuits with parameters expressed as functions of SOC and discharge current. Researchers have presented a simple technique for estimation of SOC and state of energy using which both parameters can be easily determined as in [4]. A lithium ferro phosphate battery has been modelled in Simulink and used to calculate the SOC for battery performance evaluation [5]. Robust techniques based on extended Kalman filter and unscented Kalman filter have been used to determine an accurate SOC [6]. A multi-temperature lithium cell Simulink model using a voltage source, a series resistor and a resistor capacitor block has been developed to account for thermal dependance as in [7]. A microcontroller based mathematical model is developed for evaluation of temperature, battery voltage, discharge current etc. and analysis of battery parameters such as SOC and State of health [8]. The charging discharging characteristics of lithium-ion battery has been analyzed considering different mathematical models in [9]. An accurate model for a commercial lithium-ion battery has been developed taking into account the effect of self-discharging and battery internal resistance variation in [10]. In this paper, an electrical battery simulation model is developed in MATLAB/Simulink from the mathematical model. The structure of the simulation model for a lithium-ion battery is presented and compared with a battery model available in Simulink library. The developed model could be used to model other battery types with slight modifications. The behavioral validation of the battery is done by plotting the charge-discharge characteristics and voltage characteristics for varied loads.

II. BATTERY MATHEMATICAL MODEL EQUATIONS

A MATLAB/Simulink model is built based on mathematical model equations of generic battery. Simulink model of Li-ion battery has been developed using Simulink blocks. Equations related to mathematical modelling of the battery are given below.

SOC equation:

$$SOC = SOC_0 - \frac{it}{Q} \quad (1)$$

Discharging equation ($i^* > 0$):

$$V_{bat} = f_1(it, i^*, i) = E_0 - \frac{KQ}{Q-it} i^* - \frac{KQ}{Q-it} it - Ri + A exp(-Bit) \quad (2)$$

Charging equation ($i^* < 0$):

$$V_{bat} = f_2(it, i^*, i) = E_0 - \frac{KQ}{it+0.1Q} i^* - \frac{KQ}{Q-it} it - Ri + A exp(-Bit) \quad (3)$$

where,

V_{bat}= battery voltage in volts.

i = battery current in amperes.

t = time in seconds.

E_0 = constant battery voltage in volts.

K= polarization constant in ampere/hour.

Q = maximum battery capacity in ampere-hour.

A = exponential voltage in volts.

B = exponential capacity in ampere/hour.

R = internal resistance of the battery.

SOC_0= initial state of charge of the battery.

SOC= realtime state of charge of the battery.

III. METHODOLOGY

In this model, the battery parameters are dependent on SOC and current. The state of charge is calculated using (1). It is determined using the subsystem shown in fig. 1. Here the initial state of charge is assumed to be equal to 100%.

The battery voltage signal is generated using (2) and (3). The various parameters required to determine the battery voltage are obtained as shown in fig. 2. Three subsystems are used to control the voltage value Vbat of battery model namely Vexp, Vpol and Rpol.

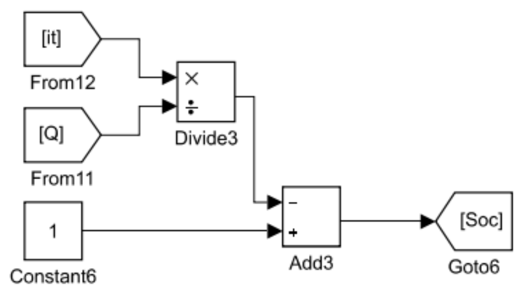

Figure 1:SOC Subsystem

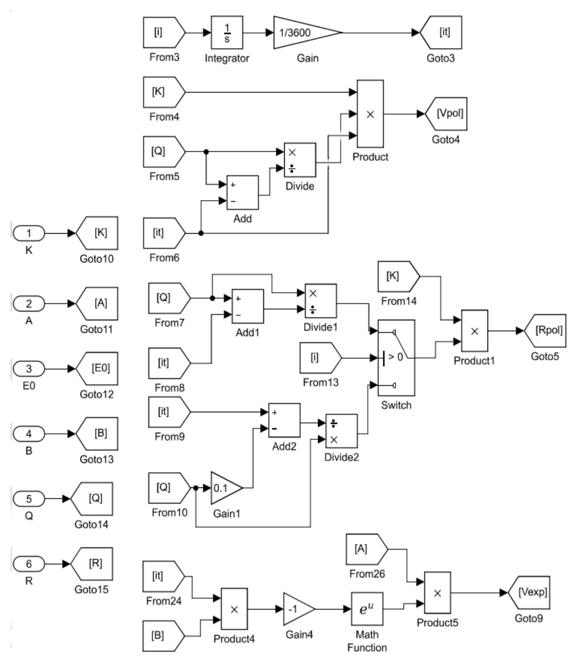

Figure 2: Subsystems for battery voltage

Fig. 3 shows the battery subsystem simulation model in MATLAB/Simulink. The percentage SOC, battery current and battery voltage are obtained as indicated in fig. 3. The battery terminal voltage is available at the output of a controlled voltage source between Conn 1 and Conn 2.

Here, a 7.2 volt, 5.4 A-h lithium-ion battery has been considered and suitable values for constant parameters K, A, E_0, B, Q and R are given as inputs. The SOC, battery voltage and battery current from the developed model are compared with those obtained from the standard battery model available in MATLAB/ Simulink as indicated in fig. 4. It is observed that the values match as shown in fig. 5a, fig. 5b and fig. 5c indicating the validity of the developed model.

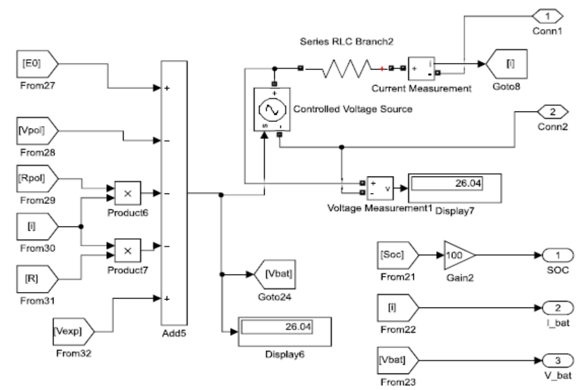

Figure 3: Battery subsystem Simulink model

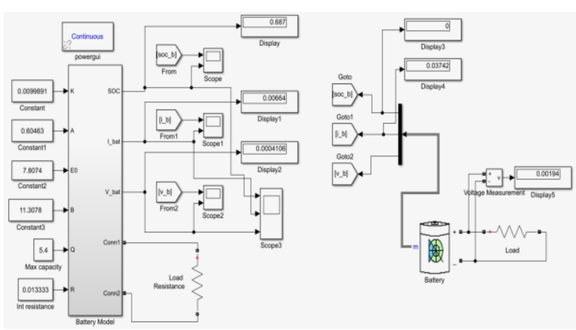

Figure 4: Simulink model for validation of modelled battery

Fig. 6 shows the Simulink model used to obtain the charge-discharge characteristics of the battery and to control the same. During discharging, the two vertical switches are closed thereby connecting the modeled battery to the load. The horizontal two switches are closed during charging of the modeled battery. A 15 V DC voltage source available in Simulink is used as a charging source.

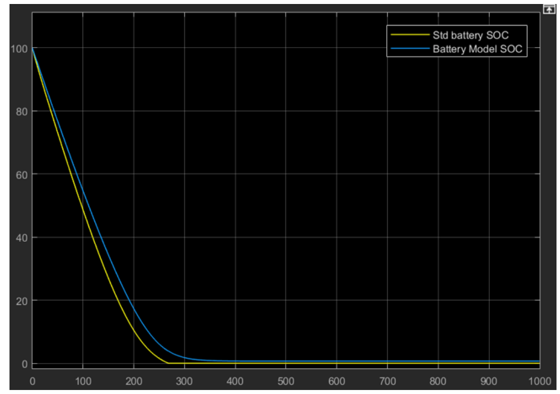

Figure 5a: Comparison between standard and modelled battery SOCs

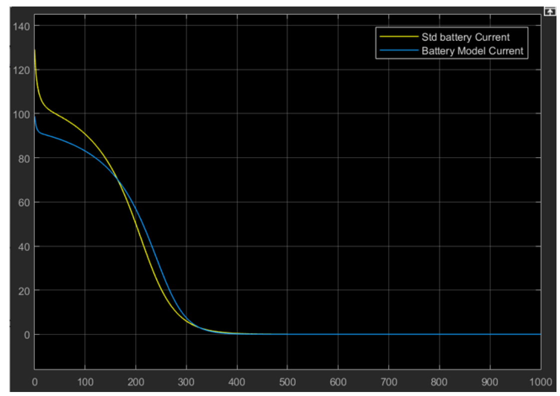

Figure 5b: Comparison between standard and modelled battery currents

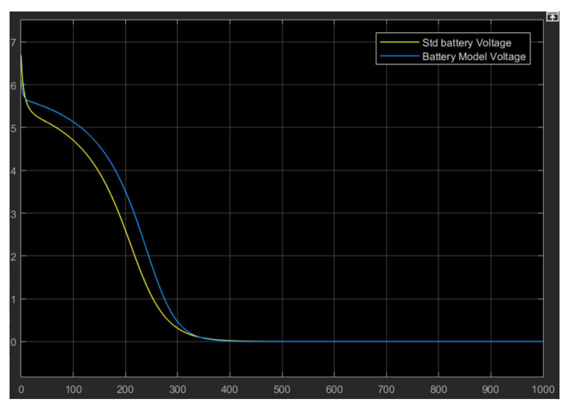

Figure 5c: Comparison between standard and modelled battery voltages

The Pulse control signal required to operate the switches is generated using a Matlab function block named CHART which takes the current battery SOC as the input and is programmed to function as per the required logic.

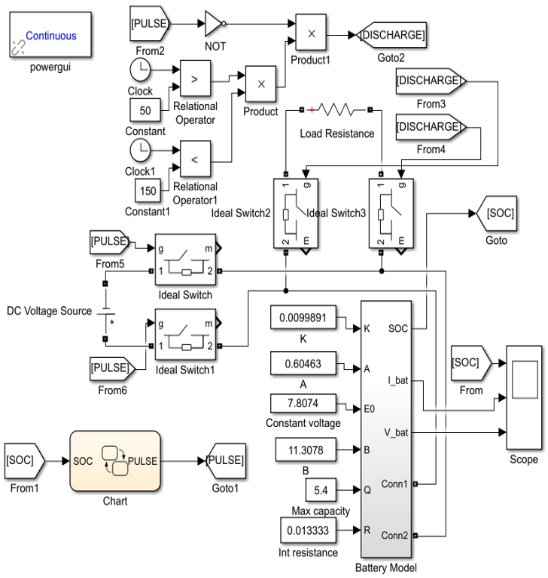

Figure 6: Simulink model for control of battery charge-discharge characteristics

The logic used to operate the switches is as explained below. It is assumed that initially, the battery SOC is 100 % and it is getting discharged into the connected load. When the SOC drops from 100 % to 40 %, the Pulse control signal becomes equal to zero i.e., the load is disconnected by the switches and the Pulse control signal becomes equal to one i.e., the DC charging voltage source gets connected to the modeled battery by the switches. Now the SOC starts rising due to charging. When the SOC reaches 80 %, the charging stops and the battery starts supplying power to the load and the charge-discharge cycle continues.

IV. RESULTS AND DISCUSSION

Fig. 7 shows the charge-discharge cycle of the modeled battery without any control over the discharge characteristics.

Fig. 8 indicates the controlled charge-discharge cycle of the modeled battery. Using the Clock Simulink block, suitable logic for controlling the battery discharge is realized as shown in fig. 6. It can be observed that the discharge takes place between 50 seconds and 400 seconds as designed.

Fig. 9 presents the discharge voltage characteristics of the modeled battery for three different load powers namely 0.9 W, 1kW and 1.1 kW. The characteristics show that the discharge time decreases for increased load power and increases for lower load power.

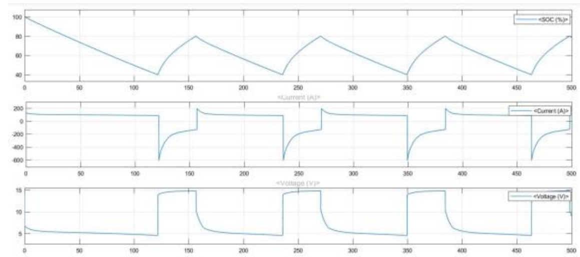

Figure 7: Charge-discharge characteristics without control

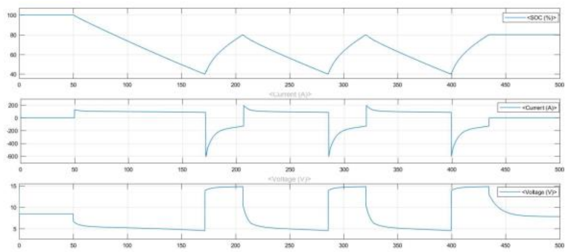

Figure 8: Charge-discharge characteristics with control

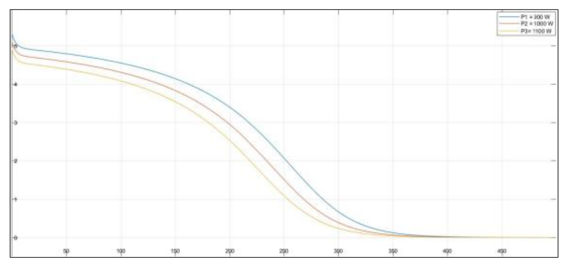

Figure 9: Discharge voltage characteristics for varying load powers

V. CONCLUSION

A MATLAB/Simulink model for a lithium-ion battery has been developed to study the characteristics of a battery. The structures of each subsystem of the developed model have been explained in detail. The accuracy of the developed model has been proven with standard battery results. It is expected that the developed battery model is applicable for other battery types with minor modifications thereby enabling circuit designers to easily build up their battery model since it does not involve complex computations. This simple and accurate battery simulation model will help in accelerating the development of energy storage systems in green technology applications. The paper also presents the successful control of charge-discharge characteristics and analysis of voltage discharge curves for varying loads on the battery represented by the developed Simulink model.

REFERENCES

[1] L. W. Yao, J. A. Aziz, P. Y. Kong, and N. R. N. Idris, - Modeling of lithium-ion battery using MATLAB/simulink,| in *IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society*, Vienna, Austria, 2013, pp. 1729-1734, doi: 10.1109/IECON.2013.6699393

[2] J. Kim, J. Kowal, - Development of a Matlab/Simulink Model for Monitoring Cell State-of-Health and State-of-Charge via Impedance of Lithium-Ion Battery Cells,| *Batteries*, vol. 8, no. 2: 8, 2022. https://doi.org/10.3390/batteries8020008

[3] G. Barletta, P. DiPrima, and D. Papurello, - Thévenin’s Battery Model Parameter Estimation Based on Simulink,| *Energies*, vol. 15, no. 17, 6207, 2022. https://doi.org/10.3390/en15176207

[4] L. Ma, C. Hu, and F. Cheng, - State of Charge and State of Energy Estimation for Lithium-Ion Batteries Based on a Long Short-Term Memory Neural Network,| *Journal of Energy Storage*, vol. 37, 102440, 2021, ISSN 2352152X, https://doi.org/10.1016/j.est.2021.102440

[5] R. Sakile, P. Kumar, U. Sinha, - Modelling of Lithium ion battery using MATLAB/ Simulink for Electric vehicle applications,| in *Recent advances in power electronics and drives*, 2021, pp. 291-299, doi:10.1007/978-981-15-8586-9 27

[6] R. P Priya, R. S. Sakile, - State of charge estimation of lithium-ion battery based on extended Kalman filter and unscented Kalman filter techniques,| *Energy Storage*, e408, 2022. doi:10.1002/est2.408

[7] T. Huria, M. Ceraolo, J. Gazzarri, and R. Jackey, - High fidelity electrical model with thermal dependence for characterization and simulation of high power lithium battery cells,| in *2012 IEEE International Electric Vehicle Conference*, Greenville, SC, USA, 2012, pp. 1-8, doi: 10.1109/IEVC.2012.6183271

[8] E. N. Malev, and T. H. Papanchev, - Simulation model development for evaluation of battery parameters,| in *2020 XI National Conference with International participation (ELECTRONICA)*, Sofia, Bulgaria, 2020, pp.1-4, doi: 10.1109/ELECTRONICA50406.2020.9305149

[9] O. Plakhtii, V. Nerubatskyi, A. Mashura, and D, Hordiienko, - The Analysis of Mathematical Models of Charge-Discharge Characteristics in Lithium-Ion Batteries,| in *2020 IEEE 40th International Conference on Electronics and nanotechnology*, pp. 635-640, doi: 10.1109/ELNANO50318.2020.9088827.

[10] K. S. Krishan, P. Pathiyil, and R. Sunitha, - Generic battery model covering self-discharge and internal resistance variation,| in *2016 IEEE 6th International Conference on Power Systems (ICPS)*, 4-6 March, 2016, pp. 1-5, doi: 10.1109/ICPES.2016.7584003