International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 6 Issue 2, January-February 2022 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Electric Vehicles Battery Charging by Estimating SOC using Modified Coulomb Counting

A. Srilatha[1], A. Pandian[2]

[1]Research Scholar, [2]Professor,
[1,2]Electrical & Electronics Engineering, Koneru Lakshmaiah
Educational Foundation (Deemed to be University), Andhra Pradesh, India

ABSTRACT

Quick and effective battery charging is critical for battery-powered vehicles. This paper describes a multilevel charging technique for Li-ion batteries used in electric vehicle applications. Instead of a single constant current level, five constant current levels are used to quickly charge the battery. A DC-DC converter is used as a current source in the charging circuit for safe and efficient charging. The precise calculation of state of charge (SoC) is used as an input to enforce the above optimal battery charging technique. The SoC is calculated using a hybrid method that incorporates both the Open Circuit Voltage (OCV) and Coulomb integral methods. To estimate battery parameters, the Simulink Design Optimization (SDO) tool is used. The simulations are performed using MATLAB. The difference between the inbuilt battery SoC estimation method and the updated coulomb counting system in terms of SoC estimation is less than 2%. A 3.7 V, 1.1 Ah Li-ion battery was used for all of the tests.

KEYWORDS: *Battery Parameters, Constant Current Constant Voltage (CC-CV) Charging, Fast Battery Charging, Li-ion Battery, Modified Coulomb Counting, Multilevel Constant Current Charging, State of Charge (SoC)*

How to cite this paper: A. Srilatha | A. Pandian "Electric Vehicles Battery Charging by Estimating SOC using Modified Coulomb Counting" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-6 | Issue-2, February 2022, pp.60-65, URL: www.ijtsrd.com/papers/ijtsrd49153.pdf

IJTSRD49153

I. INTRODUCTION

The exponential growth of the human population has resulted in the depletion of traditional energy sources. Automobile use of petroleum and its derivatives has increased dramatically in recent decades [1], [2]. The over-exploitation of conventional fuel sources may lead to their extinction in the near future. Furthermore, the burning of fossil fuels contributes significantly to deforestation and global warming. Battery-powered electric vehicles (EVs) have become very common as a solution to these problems [1]. Since batteries are reliable and environmentally friendly sources of energy storage [1], [3], [4], electric vehicles have emerged as a viable alternative to fossil-fuel vehicles [1], [3], [4]. EVs have a number of benefits, including the absence of toxic gases such as CO2, CO, NOx, and others [1] and lower operating costs than their counterparts [3], [4]. However, EVs face numerous challenges, including higher initial costs, restricted charging access, and limited energy and power delivery [1]. The battery for an EV application must be chosen in such a way that it overcomes the aforementioned challenges while also increasing the efficiency of the vehicle. Pb-acid, Ni-Cd, Li-ion, Ni-MH, Redox flow, and other battery chemistries are only a few examples. Slow charge, low energy density, short lifespan, high self-discharge, and low voltage per cell are all limitations of Pb-acid, Ni-Cd, and Ni-MH batteries [3]–[5]. The redox flow battery is a new technology that is still being studied [5]. Li-ion is thought to be the best battery for EVs because of its high energy density, which results in its small size and light weight, relatively long-life cycle, high power, and low self-discharge [4]–[6]. Because of their quick charging capability and wide operating temperature range, these batteries are common. The state of charge (SoC) of a battery plays an important role in battery charging performance. It represents the total amount of charge in a battery at any given time. An incorrect SoC calculation can cause a battery to be undercharged or overcharged, potentially damaging it. Various techniques for SoC estimation include the

Open Circuit Voltage (OCV) method, Coulomb Counting, Least Mean Square (LMS), Kalman filter, UnscentedKalman filter, and Extended Kalman filter [12]–[16]. Fast and optimal battery charging is aided by accurate SoC estimation combined with proper charging technique. Constant Current Constant Voltage (CC-CV), Pulse Charging, Multilevel Constant Current Charging, Boost Charging, and other battery charging methods exist [19], [20], [24]. For quick charging of Li-ion batteries, a multilevel charging scheme has been suggested [3], [19], [20]. However, there are a number of inconsistencies in studies related to its application. Paper [19], for example, focuses solely on the magnitude of charging currents involved in the multistage charging process. However, it falls short of providing a practical plan for putting the scheme into action. Multilevel charging technology is used in one example, while fuzzy logic is used in another. However, there is no study of reliable SoC estimation or battery modelling [20]. Another study [3] that explains this charging technique has flaws such as initial SoC estimation in the coulomb counting process, battery modelling, and parameter estimation. Many of the above limitations are attempted to be solved in this article. This section covers the full implementation of charging topology, parameter, and SoC estimation. As described in section II, battery simulation is performed to fit the battery equivalent circuit model and real battery characteristics. This section also shows how to get an accurate OCV-SoC curve using a hybrid SoC estimation technique and a pulsed charging test. The Taguchi method [19] is used to quantify several constant current levels in this paper. The multilevel charging technique and charging model schematic are highlighted in Section III. In section IV, simulation results are used to compare and contrast the multilevel constant current charging system and the CC-CV method. In section V, the hardware results are presented. In section VI, the findings are used to draw important conclusions.

II. SYSTEM MODELLING

To charge a Li-ion battery using a multilevel charging system, one must first understand the battery's internal model and state of charge estimate, as discussed here. On the MATLAB/Simulink 2018a platform, battery parameters are estimated for a 3.7 V, 1.1 Ah batteries. When it comes to battery charging and discharging, the word C_{rate} refers to the rate at which the battery is charged or discharged.

A. Battery Modeling

There are various existing analogous circuit models, such as the Rint model, The venin model, Dual Polarization (DP) model, which involves first and second order RC circuits, and so on [7]–[9].

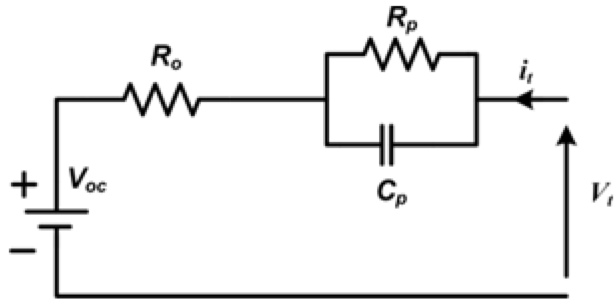

Figure 1 Circuit Model of Battery

Since it is relatively easy to build, the first order RC model is often used. As shown in Fig. 1, it is made up of a DC voltage source (Voc) in series with an ohmic resistance Ro and a parallel combination of polarisation parameters, Rp and Cp.Ro denotes the battery's experience with abrupt shifts in terminal voltage during charging and discharging processes [7], [9]. The parameters Rp and Cp comment on the battery's transient characteristics [7], [9]–[11]. These characteristics are due to a variety of transition effects that occur within the battery, each of which has a different time constant depending on the type and span of the transition effect [7]. Design Optimization (SDO) tool embedded in MAT- LAB is used to estimate the battery parameters. This instrument is used to determine the internal resistance of a device.

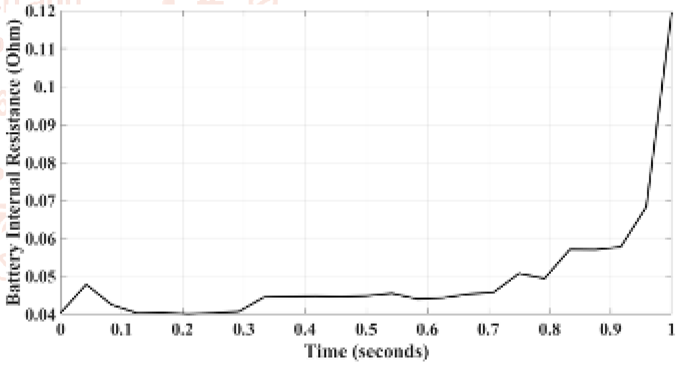

Figure2. Battery Internal resistance

B. Initial SoC estimation

To charge a battery using a multilevel charging scheme, an initial SoC estimate is required. Each battery has its own OCV–SoC curve [14–16]. The charging method or the battery equivalent circuit model has no effect on this curve [15]. The OCV-SoC curve is obtained using the pulsed charging technique in this study. The battery is charged with a pulsed current and then left at rest until the charge equilibrium point is reached in this test. The battery is charged for 5 minutes with a 0.25Crate (i.e., 0.275 A) pulse from a programmable DC source, then rested for 45 minutes. After time constant τ in the resting period, the terminal voltage equals OCV.

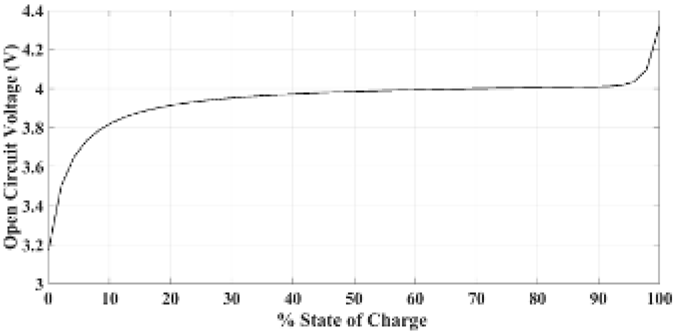

Figure 3 OCV-SoC Curve

The pulsed charging test is a negative approach because it takes a long time to charge the battery. Nonetheless, since it is a very accurate method for precisely predicting the relationship between OCV and SoC of a random battery [15], [16], this method is widely used. Figure 3 depicts the OCV-SoC curve for the battery under test. This curve is used to estimate a battery's initial SoC, which is required for subsequent SoC estimation using Modified Coulomb Counting, which is discussed in the next subsection.

C. SoC estimation using Modified Coulomb Counting

As compared to the conventional CC-CV system, the multilevel charging scheme terminates with a higher constant current stage. As a result, the multilevel charging approach necessitates precise SoC estimation. The OCV of a battery will tell you a lot about its SoC. The OCV-SoC properties in a Li-ion battery are non-linear in the pulsed test (Fig. 3), making it difficult to estimate SoC accurately. Modified Coulomb Counting is used to estimate SoC by combining OCV and Coulomb integral methods. Since the battery is initially at rest, the open circuit voltage is the terminal voltage. The initial OCV is mapped to its corresponding SoCinitial by curve fitting using the OCV-SoC curve obtained by pulsed charging (see Fig. 3). The charging/discharging current is continuously sensed using a highly accurate current sensor. As shown by equation, integration of the sensed current yields the modified SoC dependent on the charge added/subtracted during charging/discharging (1).

$$SoC = SoC_{intial} \pm \frac{\eta}{C_{bat}} \int i_t.dt \qquad (1)$$

Describes the efficiency with which charge is transferred into and out of the battery. For charging, the value of is 0.98, and for discharging it is 1 [14]. C_{bat} is the total power of the battery. Charging and discharging of the battery are defined by the positive and negative signs, respectively.

III. MULTI LEVEL CHARGING TECHNIQUE

As previously mentioned, the multilevel charging method is a quick battery charging technique that is inspired by the Taguchi approach. This method elucidates the magnitudes of optimal current levels needed for multilevel battery charging. It charges the battery with five constant current levels: 1:5Crate, 1:2Crate, 0:9Crate, 0:6Crate, and 0:4Crate [19]. These current levels have been estimated to improve battery performance and lifespan [19]. The constant current sections of this charging topology replace the constant voltage sections of the CC-CV system. One of the most critical characteristics of Li-ion batteries is that theirinternal resistance increases non-linearly as the SoC increases [3]. As a result, at lower SoC prices, current levels are held higher to minimise internal losses caused by lithium plating and internal heating. For healthy battery charging, current levels are reduced as the SoC increases.

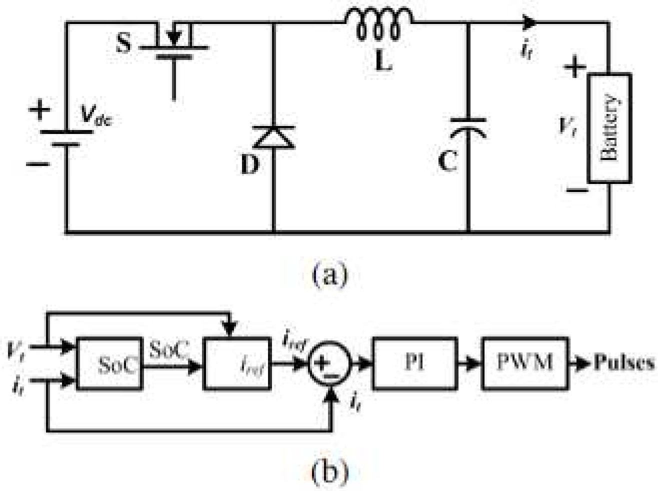

Figure 4 Battery Charger circuit with (a) power circuit (b) control circuit

The diagram of the power circuit used to charge the battery is shown in Fig. 4(a). In order to integrate several constant current levels in a closed loop, the buck converter operates in a current operated mode. It also allows for a close voltage tolerance, as Li-ion batteries cannot withstand voltages outside of their prescribed range [24]. They are prone to injury, and their cycle life is significantly reduced. By operating the converter at a high switching frequency, the size of the filter components used is reduced, resulting in a more compact circuit. The battery's SoC estimate has also improved as a result of the reduced ripple current.

As shown in Fig. 4(b), the control circuit is designed to predict the battery SoC during charging and produce a five-level reference current. SoC is calculated using modified coulomb counting with battery terminal voltage and charging current as inputs. On the basis of terminal voltage and SoC, the reference current controller generates the reference current. The proportional-integral controller has been fine-tuned to reduce the error in the charging current.

The pulse width modulation technique is used to produce high frequency pulses for the buck converter. The following segment goes over the simulation of the whole setup.

IV. SIMULATION RESULTS

In the MATLAB/Simulink platform, the five-level charging method and the CC-CV charging method are both simulated. Both methods are used to charge a 3.7 V, 1.1 Ah Li-ion battery. Both schemes are implemented using a simple buck converter, as shown in Fig. 4(a). A 5 V DC power supply powers the buck converter. Table I lists the buck converter's specifications

TABLE I: Buck Converter Specifications

Sl. No	Circuit Parameters	
	Parameters	Parameter Values
1	Input Voltage (Vin)	5V
2	Output Voltage (Vin)	4.2V
3	Switching Frequency (fs)	20KHZ
4	Inductor (L)	2mH
5	Capacitor(C)	1 micro Farad

A. Constant Current Constant Voltage Charging Method

As shown in Fig. 5, the battery is charged with 1Crate (i.e., 1.1 A) before the battery's terminal voltage exceeds its upper threshold value (i.e., maximum charge voltage of 4.3 V).The Constant Current (CC) charging mode is used in this section. As seen in the same red-colored figure, the corresponding SoC increases with charging time. The changing mode is switched to Constant Voltage (CV) mode once the battery's terminal voltage exceeds its upper threshold value, as shown in Fig. 5. The terminal voltage is held at its full charge value in CV mode. The battery draws an exponentially decreasing current during this portion before it is fully charged, which is indicated by a charging current of 0:02Crate (i.e., 0.022 A) [3], [17], [18], [24]. It is noted that by this time, the SoC has nearly reached 100%. As a result, in this charging process, SoC measurement is not needed to indicate the end of charging.

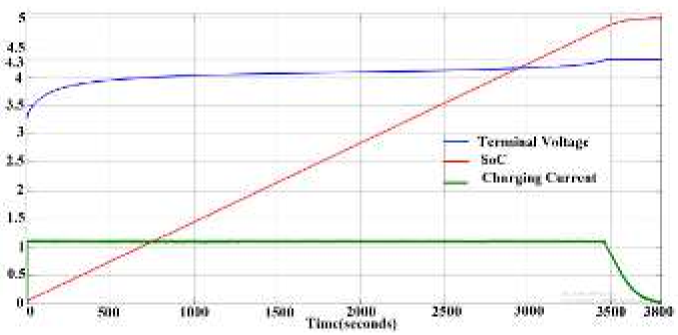

Figure 5 CC-CV Method Battery Charging Characteristics

The CC mode takes 3400 seconds, while the CV mode takes 400 seconds. The total charging time for the CC-CV is 3800 seconds (i.e., 1.055 hours).

B. Five-Level Charging Method

As previously stated, the battery is charged with five different currents in this charging process. As shown in Fig. 6, the corresponding constant current levels for the 1.1 Ah battery are 1.65 A, 1.32 A, 0.99 A, 0.66 A, and 0.44 A, respectively. In the same diagram, the corresponding voltage and SoC are also plotted.

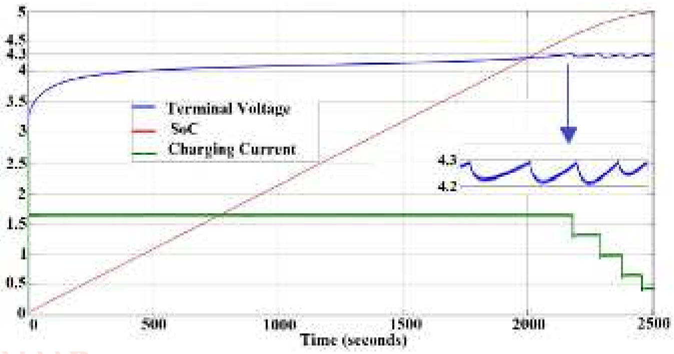

Figure 6 Five Level Charging Method Battery Charging Characteristics

The battery's initial SoC value is measured at the start of five-level charging by mapping the battery's OCV (i.e., terminal voltage of the battery at rest) using the OCV-SoC curve obtained earlier using the pulsed charging technique (see Fig. 3). In this case, the battery's initial SoC is zero percent with a terminal voltage of 3.2 V at start-up, as shown in Fig. 6. The battery will now begin to charge at 1.5Crate (i.e., current of 1.65 A). Following that, the terminal voltage and SoC begin to rise. During this time, the SoC is calculated using the Coulomb Counting method. The charging current moves to the next lower stage as soon as the terminal voltage reaches its upper threshold value (4.3 V) (1.2Crate or 1.32 A). As shown in Fig. 6, the change in current is followed by a drop in the battery's terminal voltage. With charge injection, the terminal voltage begins to rise and reaches 4.3 V once more, followed by a change in current level and so on. The battery chemistry determines the extent of the voltage drop. The spectrum of voltage variance is 4.2 V- 4.3 V, as depicted in the zoomed portion of Fig. 6. During charging, the terminal voltage of the battery reaches its full value five times. For a 100 percent battery charge, the five-level charging method takes 2500 seconds (0.69 hours).

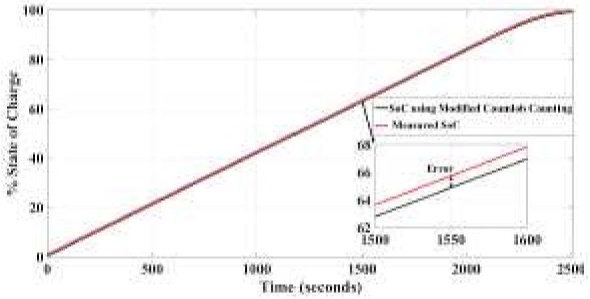

Figure 7 Modified Coulomb Counting Method to Estimate SOC

Figure 7 shows a plot of estimated battery SoC versus measured battery SoC . It can be seen in Fig. 7 that a 2 percent error is retained during the charging process. The slope of the SoC is observed to change with time due to various charging current levels. However, this feature is visible only after the battery has reached 90% SoC.

Table 2: Simulation Result Based Comparison Between Multilevel charging And Cc-Cv Charging

Comparison parameters	Charging Method	
	Multilevel Charging	CC-CV Charging
Constant Voltage Period	0 sec	400 sec
Total Charging Time	2500 sec	3800 sec

The multilevel charging system is compared to the traditional CC-CV method in Table II. By comparing the CC-CV system to the multilevel charging method, it reveals that the battery takes 34.21 percent longer to reach 100% power.

V. CONCLUSION

The current work proposes a multilevel constant current charging scheme for quick Li-ion battery charging in order to accelerate the transition from internal combustion engines to electric vehicles. Taguchi's method is used to determine optimal charging current values. The current CC-CV charging system is simulated and compared to this quick charging technique. It has been discovered that the CC-CV system takes 3800 seconds and the five-level charging method takes 2500 seconds to charge the entire battery. Energising the charging time has been reduced by 34.21 percent. Multilevel charging is preferable to the traditional charging scheme. The difference between the SoC estimated using modified coulomb counting and the battery model used in MATLAB is less than 2%.

REFERENCES

[1] Boulanger, Albert G., et al. "Vehicle electrification: Status and issues."Proceedings of the IEEE 99.6 (2011): 1116-1138.

[2] Carlson, D. E. "Fossil fuels, the greenhouse effect and photo-voltaics."IEEE Aerospace and Electronic Systems Magazine 4.12 (1989): 3-7.

[3] Kodali Samuel Prajwal, and Soumitra Das. "Implementation of five level charging schemes in lithium ion batteries for enabling fast charging in plug-in hybrid electric vehicles." 2017 National Power Electronics Conference (NPEC). IEEE, 2017.

[4] Chen, Xiaopeng, et al. "An overview of lithium-ion batteries for electric vehicles." 2012 10th International Power & Energy Conference (IPEC).IEEE, 2012.

[5] Chen, Aoxia, and Pankaj K. Sen. "Advancement in battery technology: A state-of-the-art review." 2016 IEEE Industry Applications Society Annual Meeting. IEEE, 2016.

[6] Ranjbar, Amir Hossein, et al. "Online estimation of state of charge in Li-ion batteries using impulse response concept." IEEE Transactions on Smart Grid 3.1 (2011): 360-367.

[7] Sun, Kai, and Qifang Shu. "Overview of the types of battery models."Proceedings of the 30th Chinese Control Conference. IEEE, 2011.

[8] He, Hongwen, Rui Xiong, and Jinxin Fan. "Evaluation of lithium-ion battery equivalent circuit models for state of charge estimation by an experimental approach." energies 4.4 (2011): 582-598.

[9] Jiang, Shugang. "A parameter identification method for a battery equivalent circuit model." No. 2011-01-1367. SAE Technical Paper, 2011.

[10] Kim, N., A. Rousseau, and E. Rask. "Parameter estimation for a Lithium-ion battery from chassis dynamometer tests." IEEE Transactions on Vehicular Technology 65.6 (2015): 4393-4400.

[11] Kumar, KS Ravi, et al. "Design and fabrication of coulomb counter for estimation of SOC of battery." 2016 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES). IEEE, 2016.

[12] Chang, Wen-Yeau. "The state of charge estimating methods for battery: A review." ISRN Applied Mathematics 2013 (2013).

[13] Xiong, Rui, et al. "Critical review on the battery state of charge estimation methods for electric vehicles." IEEE Access 6 (2017): 1832-1843.

[14] Yu, Zhihao, RuituoHuai, and Linjing Xiao. "State-of-charge estimation for lithium-ion batteries using a kalman filter based on local linearization."Energies 8.8 (2015): 7854-7873.

[15] Chen, Zheng, Yuhong Fu, and Chunting Chris Mi. "State of charge estimation of lithium-ion batteries in electric drive vehicles using extended Kalman filtering." IEEE Transactions on Vehicular Technology62.3 (2012): 1020-1030.

[16] Gao, Yizhao, et al. "Classification and review of the charging strategies for commercial lithium-ion batteries." IEEE Access 7 (2019): 43511-43524.

[17] Serhan, Hany A., and Emad M. Ahmed. "Effect of the different charging techniques on battery life-time." 2018 International Conference on Innovative Trends in Computer Engineering (ITCE). IEEE, 2018.

[18] Liu, Yi-Hwa, and Yi-Feng Luo. "Search for an optimal rapid-charging pattern for Li-ion batteries using the Taguchi approach." IEEE transactions on industrial electronics 57.12 (2009): 3963-3971.

[19] Liu, Chun-Liang, et al. "Optimization of a fuzzy-logic-control-based five-stage battery charger using a fuzzy-based taguchi method." Energies6.7 (2013): 3528-3547.

[20] Yang, Shichun, et al. "State of charge estimation for lithium-ion battery with a temperature-compensated model." Energies 10.10 (2017): 1560.

[21] Chuang, Ying-Chun, and Yu-Lung Ke. "A novel high-efficiency battery charger with a buck zero-voltage-switching resonant converter." IEEE Transactions on Energy Conversion 22.4 (2007): 848-854.