Charging and Discharging for Lithium-ion Battery Based on Sliding Mode Observer method with Battery Status

Biniyam Zemene Taye

Abstract- Lithium-ion batteries provide rigorous state of charge (SOC) which popularly worn in electric vehicles and renewable energy. The new SOC design consists of self discharge with one R-C block. In this Sliding Mode Observer (SMO) used to estimate SOC. According to battery status SOC estimation divides into two stages that is charging and discharging. The R-C block battery model consists of series and parallel resistance which gives more SOC estimation for large discharge of current. For performing this method simulation to be done

Keywords: Lithium-ion battery, SOC estimation, Sliding Mode Observer, Battery Status.

1. Introduction

As compared with other batteries like nickel-cadmium (NiCd) and nickel-metal-hydride (NiMH) battery Lithium-ion battery has high energy, power densities and doesn’t bear memory issue [1].

The praxis on profitable Li-ion battery creation reveals significance of battery management system (BMS). A high operation of BMS enhances Li-ion battery functioning efficiency and increase lifespan. Ideal energy application one test BMS. The precision of SOC can affect battery at time of starting the charging, and stopping the discharging mainly in large powers like Evs. In case of engineering intensifies we require SOC estimate algorithm.

By combining open loops or closed loops methods to respective battery model we can esteem the SOC. In open-loop types coulomb counting method is generally used since it gives maximum precision of SOC with accurate current measurement. In this case we face two problems. First it’s difficult to find initial SOC. In order to find initial SOC, we need to ease battery for distinct hours, that’s unbearable since battery is on runtime. Second is that accrued error when integrating the calculated current with time. This can be rectified by regular recalibration. It refers the SOC estimate precision specifically for high current flow in and out battery [2].

Aside coulomb counting method, few more closed-loop methods are ripe. Plett scheduled Kalman filtering method to judge battery SOC. It optimally esteems battery SOC from noise in the environment. This process has complicated mathematical estimation and memory resources. What’s more partial modeling and the limitation of Gaussian distribution of the outside noises may reduce its enterprise. Another process is SMO to esteem the battery SOC. It can remove model error when system achieve predefined sliding surface. Even if overwhelming the deficiency in coulomb counting method, yet it doesn’t infer the battery inner resistance and self discharge, which decrease the total SOC precision [3]. Excepting for methods, Fuzzy logic methodology need the fuzzy theory to esteem SOC. It uses high previous intelligence when obtaining battery impedance model, which is trivial and annoying. Neural network process can esteem SOC yet ask difficult computation. Some electro-chemistry methods to obtain SOC. They furnish direct for manufacturing method of Li-ion battery still might not be suited in the condition whose controller is microcontroller.

Commonly many SOC computing methods don’t ponder battery status and parasitic parameters. This paper consists of charging and discharging based on SMO process and battery status. The new SOC equivalent circuit design with one R-C block. It is responsible for little estimation and memory assets and can be adjusted for real utilization with lower configuration. This process also divides the SOC esteem to two phases. Inner resistance is considering when battery is discharging. By using two phase SMO to evaluate the SOC.

The remaining paper is classified as follows: In segment 2, an identical circuit design is suggested to explain the battery behavior; in segment 3 and 4, the SMO for SOC esteem regarding the battery status is prepared. In segment 5, a MATLAB/SIMULINK simulation is run for showing the operation of suggested SOC esteem process. Finally, inferences are drawn in segment 6.
2. Battery Model

The corresponding circuit design of the Li-ion battery worn in this method shown above figure 1. The form can mock the explicit dynamic comportment of Li-ion battery. In this form, the open circuit voltage (OCV) is portrayed by restrained voltage source. Moreover an immediate terminal voltage difference due to battery current \( I_b \) is given by implant a series resistance mentioned by \( R_s \), which means Ohmic resistance. This layout energy and decrease SOC while the battery discharging. However RC block shows vigorous retort of battery voltage once step load current enforced. The total impotes capacitor \( Rsd \) is mentioned as \( C_n \) and soul execute energy decrease because of lengthy store. Even if Li-ion has less soul execute, It hush effect the precision of SOC especially high currents \( I_b \). whereas the molding errors, uneasiness and time changing elements in the type. This type is easy regarding the type errors can be redress by sturdy SMO.

Voltage through RC model given as

\[
V_f = \frac{1}{RfC_f} V_f + \frac{I_s}{C_f} + \Delta f_p
\]

Battery ultimate voltage described as

\[
V_s = V_x (V_{xc}) + I_s R_s + V_f + \Delta f_x
\]

Battery current explicit as

\[
I_s = \frac{V_s - V_x - V_f}{R_s}
\]

We have two certainties: first the imitative of ultimate voltage with reference to current is trivial. Because fast savor of real utilization time is realized; another is the OCV is piecewise straight \( V_{soc} \). Hence esteem of \( RsdCn \) is wide sufficient, \( V_{soc} \) limits from 0 to 1, SOC esteem could evaluate that item where battery won’t work. At last system’s state space was describe by

\[
\dot{x} = A x + B I_s + \Delta f
\]

\[
y = C x
\]

Where

\[
A = \begin{bmatrix}
-m_1 & m_1 k & 0 \\
0 & -m_2 & -m_3 \\
0 & 0 & -m_3
\end{bmatrix},
B = \begin{bmatrix}
0 \\
1 \\
0
\end{bmatrix},
C = \begin{bmatrix}
V_s \\
V_{soc}
\end{bmatrix}
\]

\[
\Delta f = \begin{bmatrix}
\Delta f_{soc} \\
\Delta f_{FE}
\end{bmatrix}
\]

3. Draft of SMO

For assessment of the SOC of Li-ion battery adopting SMO.

Observability matrix of system is

\[
\partial B = \begin{bmatrix}
C \\
Cd \\
Cd^2
\end{bmatrix} = \begin{bmatrix}
1 & 0 & 0 \\
-m_1 & m_1 k & 0 \\
a & b & c
\end{bmatrix}
\]

Where
Harmonize the row echelon matrix of eq. (10), we may get rank \((\text{obsv}) = 3\). Thus the state variables \(V_b, V_{soc}, V_f\)tin seen.

Second, the SMO is prepared by employing theory of SMO.

\[
\dot{V}_b = \left( m_1^2 + m_1 m_2 k \right) \dot{V}_{soc} - m_1 I_b + L_{soc} \text{sgn}(V_b - \hat{V}_b) \quad (10)
\]

This is esteem of \(V_{soc}\)

Scheming the SM surface \(s_b = e_b = V_b - \dot{V}_b\) the derivation of \(S_b\)

\[
s_b = -m_1 e_b + m_1 k \dot{V}_{soc} + \Delta f_{soc} - L_{soc} \text{sgn}(s_b) \quad (11)
\]

Where \(e_{soc} = V_{soc} - \dot{V}_{soc}\), thus obtain is

\[
s_e = -m_1 e_e + m_1 k \dot{e}_{soc} + \Delta f_{soc} - L_{soc} \text{sgn}(s_e) \quad (12)
\]

To secure the confluence of SMO, let \(s_e > 0\),

\[
\left| m_1 k \dot{e}_{soc} \right| - \left| \Delta f_{soc} e_e \right| - L_{soc} \text{sgn}(s_e) e_e < 0 \quad (13)
\]

We get

\[
L_b > \left| \Delta f_{soc} + m_1 k e_{soc} \right| \quad (14)
\]

Where \(|\cdot|\) is the total esteem work. Choosing the esteem of \(L\) fulfilling the condition (15), the SMO surface \(s\) can be come reached. Applying the proportional control technique for SMO to (13), the \(e_b\) and \(e_e\) could be zero and the model vulnerabilities \(s_{soc}\) can be repaid after some limited time. Then, one can acquire

\[
e_{soc} = \left\{ \frac{L_x}{m_1} \text{sgn}(e_x) \right\} \quad (15)
\]

From that point forward, the estimation work \(V^*\) given by

\[
\dot{V}_x = -(m_1 + m_2 k) \dot{V}_{soc} - m_2 V_f - m_1 \dot{V}_b + L_{soc} \text{sgn}(e_x) \quad (16)
\]

Planning the sliding-mode surface \(s_{soc} = e_{soc}\) one can get,

\[
s_{soc} \dot{s}_{soc} = -(m_1 + m_2 k) e_{soc}^2 - m_1 e_f e_{soc} - m_1 e_e e_{soc} + \Delta f_{soc} e_{soc} - L_{soc} \text{sgn}(e_{soc}) e_{soc} \quad (17)
\]

Where \(e_f = V_f - \dot{V}_f\). It is assumed that \(s_{soc} \dot{s}_{soc}\) is less than zero. estimator for \(V_b\) has been reached to the sliding-mode surface, \(eb = 0\), one can obtain

\[
\left| \Delta f_{soc} e_{soc} - L_{soc} \text{sgn}(e_{soc}) e_{soc} - m_1 e_f e_{soc} < 0 \right| \quad (18)
\]

Choosing \(L_{soc}\) satisfying the condition (19), the sliding-mode surface \(S_{soc}\) can be come to. As per the identical control technique for SMO, one can get

\[
e_f = \frac{L_{soc}}{m_1} \text{sgn}(e_{soc}) \quad (19)
\]

The observer exercise for \(V_f\)is given as

\[
\dot{V}_f = -(m_2 V_f + n_2 I_b + L_f \text{sgn}(e_f) \quad (20)
\]

Outlining the sliding-mode surface \(s_f = e_f\), the subsidiary of \(s_f\) can be given as \(s\)

\[
\dot{s}_f = -m_2 e_f + \Delta f_{soc} - L_f \text{sgn}(e_f) \quad (21)
\]

By choosing the \(L_f\) to fulfill \(s_f s_{dot} = 0\), the onlooker work \(\dot{V}^*\) can reach to sliding-mode surface.

To kill prattling of \(V^*\), the immersion work sat \((e)\) is embraced to supplant the \(\text{sgn}\) work

\[
s sat = e e^{0.15 e} - e^{0.5 e} \quad (23)
\]

To whole up, the structure of eyewitness conditions for state factors \(V_b, V_{soc}, V_f\) is indicated Fig. 2

4. SOC Esteem Considered Battery Status

Since the battery is a very nonlinear gadget, SMO is appropriate for tackling the nonlinear issue. It needs genuinely exact battery model to dispense with the model vulnerabilities and requires brief period for executing and this tackles the issues of coulomb tallying technique. The SOC can be evaluated by the SMO outlined in segment 3. Nonetheless, it worths taking note of that the SOC estimation is distinctive between battery charging and releasing.

The new SOC estimation technique in this paper makes a few upgrades to the normal SOC calculation. Initially, the new SOC estimation technique considers the impact of self-release resistor while charging and releasing the battery. It’s as yet essential for the Li-particle battery with low self-release. Furthermore, the new SOC estimation strategy ascertains the vitality utilization of \(Rs\) and \(Rf\) based on SMO when the battery is releasing. So the
The proposed SOC estimation in this paper is isolated into two sections. At the point when the battery is charging, the SOC estimation utilizes the SMO.

\[
SOC = \hat{V}_{soc}
\]  

(24)

At the point when the battery is releasing, the SOC estimation can be given as

\[
SOC = \hat{V}_{soc} - \frac{\int_{t_0}^{t_1} (I^2 R_s + \frac{\hat{V}^2}{R_f})dt}{\int_{t_0}^{t_1} V_x I_x dt}
\]  

(25)

Where \(t_0\) is beginning time, \(t_1\) is the finishing time.

The release tests are directed to get the parameters of the battery demonstrate in Fig.1. The test procedure is appeared in Fig.3. Right off the bat, energizing the battery to 100% and leave the battery for two hours. Besides, discharging the battery for 10 mins at 1C value current and later behind it vacant for 1hr. The SOC of battery reject 10%. The same steps repeat for 6 times till the SOC of battery achieve 0. Seeing this steps specification of battery process is well-known. Relation betwixt SOC and OCV is also achieving.

5. Simulation

To test the execution of suggested SOC esteem, a numeric simulation for 6000mAh Li-ion battery situated on MATLAB/Simulink R2013A is done.

![Image of a circuit diagram](image)

**Fig 2. The structure of sliding-mode observer**

Where

\[
L = \begin{bmatrix}
L_s & L_{sc} & L_f
\end{bmatrix} \Phi = \begin{bmatrix}
\text{sat}(V_x - V_s) \\
\text{sat}\left(\frac{I_x}{m_1}\text{sat}(V_x - V_s)\right) \\
\text{sat}\left(\frac{-I_{soc}}{m_2}\text{sat}(V_x - V_s)\right)
\end{bmatrix}
\]

**OCV = 1.4 * SOC + 2.8**  

(26)

The mould specification of Li-ion battery for simulation given above table 1. To interpret the relation betwixt SOC and OCV, gain of OCV vs SOC is \(k=1.4\). Hence voltage of battery limits from 2.8 to 4.2.

To affect the noises in actual utilization, the
Pseudorandom noise is added to Li-ion battery. Frequency of pseudorandom noise is 100Hz. The greatest esteem is 0.1V and the base esteem is 0.05V. The estimation of release current is 6A. The battery releases for 4 seconds and quit releasing for 1 second. Rehash this procedure till the voltage of battery drops to 2.75V. The piece of the releasing current is appeared in Fig.4. The underlying estimation of battery voltage is 4.2V and the SOC is 1.

The reproduction aftereffect of $V^*$ is appeared in Fig.5. What's more, the mistake between evaluated esteem and genuine esteem is appeared in Fig.6. As should be obvious from Fig.5 and Fig.6, the exactness of $V^*$ estimation utilizing sat capacity can be higher than sgn work.

The assessed SOC $V^*$ is appeared in Fig.7. Furthermore, the mistake between assessed esteem and genuine esteem is appeared in Fig.8. The underlying estimation of assessed $V^*$ is 0.8 and the blunder with genuine esteem is 0.2. Sees from the Fig.7, the assessed esteem can track the genuine esteem utilizing the proposed strategy. As should be obvious from the Fig.8, the maximum mistake between assessed SOC and genuine SOC utilizing sat work is 3%. It is lower than utilizing sgn work. It ought to be noticed that the meeting speed utilizing sat work is slower than sgn work.
The examination between the coulomb check strategy and the proposed technique is appeared in Fig.9. As should be obvious that there is no request of starting quality contrasted and coulomb check technique. The evaluated SOC can track the genuine esteem rapidly utilizing the proposed strategy.

The SOC evaluated mistake utilizing sgn work without adding pseudorandom clamor to Vb is appeared in Fig.10. There is high precision. Be that as it may, the evaluated mistake can be expanded when there is a model blunder. The maximum mistake of SOC estimation is 3% from the Fig.8 by utilizing the sat work.

6. Conclusion

This paper proposes another SOC esteem technique for Li-ion battery. Another proportionate circuit battery demonstrates self discharge in this technique. In addition, the utilization of SMO can repay the model blunders and tackles the issues of coulomb tallying strategy. Likewise, the SOC estimation technique in this paper considers the impact of internal obstruction of battery as per the battery status.

The immersion work is intended to decrease the babbling events. At last, the recreation results demonstrate that it's superior to the customary technique. In a word, the proposed SOC estimation strategy is significant in building practice since a lower equipment arrangement and programming plan.

References

