Electric Vehicle Modeling in MATLAB and Simulink with SoC & SoE Estimation of a Lithium-ion Battery

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Abstract. To improve the energy storage management system of an electric vehicle, we monitored exact battery states. Here we created different models for BMS management, for thermal modelling, thermal characteristics and EV modelling. We used different drive cycles sources to get our results here, we simulated models for different set of time and got simulation results. The variation in graphs and display lead us to different conclusions that how different parameters affect the performance and efficiency of an electric vehicle. We have presented a simple integrated State of charge (SOC) and State of energy (SOE) estimation technique. By utilizing this technique, the battery SOC and SOE both can be assessed easily rather than processor computational difficulty in BMS.

Keywords: Electric, vehicle, simulation, lithium-ion battery, SOC, SOE, Battery Management system

1. Introduction
A BMS (Battery Management System) is a system i.e. totally electronic in battery pack linked with battery of a vehicle such as car. It operates battery within its safe operating areas, calculates and monitors battery’s data and simultaneously controls and authenticates it. We validated the connection between battery’s State of Charge - SOC and State of Estimation – SOE[¹] for lithium-ion battery under many working conditions. Experimental outcomes show that the proposed strategy can successfully appraise the SOC and SOE of the battery under various working conditions with high precision. So overall, this strategy of SOC and SOE estimation assists with diminishing the computational difficulty to the processor utilized in BMS (Battery Management System)[²] and hence it is appropriate for implementation in Electric Vehicle applications.
2. Simulation of Electric Vehicle with Simulink

Using FTP 75 as Drive Cycle Source – This drive cycle is used to perform the simulation with simulation time of 1874 seconds.

![Simulation using FTP 75 as drive cycle.](image1)

Using WOT (Wide open throttle) as Drive Cycle Source:

![Simulation using WOT as drive cycle source.](image2)

**Parameters:**

![Parameters of Simulation.](image3)
Our Simulink Model is basically having four parts:-

i. Vehicle Model
ii. Battery Model
iii. Motor and Motor Controller
iv. Longitudinal Driver

2.1 Vehicle Body

![Vehicle body model](image1)

**Figure 4.** Vehicle body model.

2.2 Motor and Motor Controller

![Motor and motor controller model](image2)

**Figure 5.** Motor and motor controller model.

3. Simulation Results

Simulation was done and we evaluated the Speed Comparison and SOC of Battery by both Drive Cycle Sources.

We simulated FTP Source for 1874 Seconds and got results as below:
3.1 Speed comparison

Here we observed that yellow curve and Blue Curve almost follow each other throughout 1874 seconds and We Observed that distance covered was around 16 Km in 1874 Seconds that Means Average Speed was around 30 km/ hr. In Display it travelled around 13 km and this variation happened due to difference in Instantaneous Velocity and exact Velocity.

3.2 SOC of Battery
SOC Scope tells us the Variation in SOC and at what Discharge Rate our Battery is Depleting.
From this Scope Operator we get to know that in about 1874 seconds the SOC reaches from 100% to 70-75% because there are several Acceleration and De-Acceleration Profiles in the Speed Comparison Profile.

We Simulated WOT (Wide Open Throttle) Drive Cycle Source for 60 sec
In WOT the vehicle accelerates up to 30 seconds and then decelerates after 30 Seconds the Distance Travelled in WOT is .8 km

![Figure 8. Acceleration Vs Time plot.](image)

3.3 State of Charge
During first 30 Seconds the Battery SOC drops from 100% to 98.2% and during next 30 Seconds the regenerative Power produced by Motor charges battery Pack from 98.2 to 98.8%.

![Figure 9. SOC percentage Vs Time plot.](image)

4. Simulation of BMS in SIMULINK
Battery Management System maintains the safe operation of Batteries and also it keeps track of:
- Voltage
- Temperature
- State of Charge
- Current
- State of Health
It also maintains Battery by preventing it from Over Current over Voltage over Temperature under Temperature\textsuperscript{[3]}. BMS also balances the cells

4.1 \textit{SIMULINK Model}:
Main Components are BMS ECU and BMS Plant

![BMS ECU & BMS Plant Model](image)

\textbf{Figure 10.} BMS ECU & BMS Plant Model.

BMS ECU performs major monitoring and Control Battery Pack\textsuperscript{[4]}. It is responsible for Monitoring, Balancing and estimation of SOC Pack

![BMS Monitoring](image)

\textbf{Figure 11.} BMS Monitoring.

5. \textbf{Four states in State Machine}
State Machine defines operating State of BMS. In State Machine there are four states
- First State – Stand by Driving, Fault and Charging
- Second State- When Something goes beyond Safe Limits
- Third State and fourth State- define ON/OFF State for Charger and Inverter Circuit.
5.1 **BMS Plant**
Plant Consists of Battery Pack with Charger and Inverter System. There are two types\(^5\) of Battery Pack Arrangement. A 1 module pack and 16 module pack. Each Module Consists of 6 cells connected in Series. Hence 16 module packs have total of 96 Cells which can be used if there is requirement of higher Power.

5.2 **Harness Dashboard**

![Figure 12. States of BMS.](image)

**Figure 12. States of BMS.**

![Figure 13. BMS Plant.](image)

**Figure 13. BMS Plant.**

![Figure 14. Harness Dashboard.](image)

**Figure 14. Harness Dashboard.**
6. Test Sequence
We ran Simulation for three Test Sequences and Configuration selected for Simulation is 1 module battery Pack (With 6 Cells in Series).
TEST SEQUENCE has Different Conditions like for Balancing Charging and Driving
TEST SEQUENCE 1 includes Driving Condition, Balancing Condition and Charging Conditions with Transition Occurring at Specific Time Intervals.
TEST SEQUENCE 2 includes Driving and Charging Condition
TEST SEQUENCE 3 includes only Charging

6.1 Test Sequence 1
Figure 15. Test Sequence Simulation 1.

To 3000 seconds BMS switches to driving Condition and from 3000-4000 seconds BMS comes to Standby Mode and from 4000-9000 BMS changes to Charging Condition. The SOC rises from 40% to 95% during Charging Condition and reached up to 100% at around 9000 second time, and remains same.

There was no Fault in this Test Sequence.

6.2 TEST SEQUENCE 2
Initially for First 10,000 Seconds BMS follows the Driving Condition followed By Charging. Fault Signal is there because at cell 6, Temperature Reaches value more than permissible Range because Current flows through battery for longer time.

6.3 Test Sequence 3
Figure 17. Test Sequence Simulation 3.

It has only one Charging Condition. Initially it has around 80% charge in it as shown in Figure. Charging for around 2000 seconds makes it Almost close to 100% SOC. Cell Voltage rises to 4.2V within 500 Seconds and eventually to 4 V after 2000 Seconds. There is No Fault Observed during this Sequence.

7. Configuration of generic battery model
A generic battery block and its criteria is changed keeping in mind the individual battery type and similarly the charge/discharge attributes. Here, we used PLOT option to plot parameter values with attributes of default battery model. EEMB’s Lir18650 battery is taken as a source reference. Positive (+) and Negative (-) terminals are conserving ports here and Multiple (m) vector signal\(^6\) is used as output port.

7.1 Configuration & Characteristics

Figure 18. Parameters of battery model.
The primary plot b/w Voltage and Time (hours) with value of current shown as 1.3 A indicates discharge characteristics when discharged at the same current value. Further the second plot displays battery discharge correlation at current rate of 0.25 C, 1C and so on. At 0.5C Discharge rate, time is 2 hours and similarly at 4C discharge rate, discharge time is 16 minutes. Therefore, we observe that battery range is declining remarkably on increasing current discharge rates.

7.2 Generic model discharge & charge with UDDS cycle

![Figure 19. Lithium-ion battery model.](image)

In configuration of a basic battery block (Lithium-ion battery) as indicated in above photo that includes a governed current source and a signal builder block. Working of a signal builder block is that it triggers signals by recording battery load where UDDS drive cycle data is considered reference for signal. Generation of equal current signals is done by governed current source w.r.t signal out of signal builder block. To simulate, on a change in UDDS drive cycle, a similar current signal is made and consecutively signal builder block, imports it.

![Figure 20. Current plot for Charge/Discharge with UDDS cycle.](image)
8. Simulation Outcomes
A 100% state of charge is initialized in battery. After a period of 22.8 minutes battery state of charge drops to 91.2% following simulation. The maximum drop is observed after 200 seconds which means high drop discharge to a certain percentage. Therefore, demand of power drop and power peak is analyzed. Thus, the simulation of generic battery model with UDDS drive cycle with Charge/Discharge attributes is understood.

Figure 21. Voltage plot for Charge/Discharge with UDDS cycle.

Figure 22. SOC Plot.
8.1 Thermal modeling of a Battery Pack
EV’s have more advantages than conventional IC Engine vehicles which mainly includes energy efficiency, instantaneous power, quite operation and much more. The Battery performance is mainly dependent upon the working ambient temperature. Meagre thermal management will negatively affect the charging and discharging power, cycle life, cell balancing and capacity of the battery pack. The simulation of thermal behaviors stated above shows the impact of a faulty cell on performance and cell temperatures. In order to achieve determined performance variation in temperature and cell capacity in the battery pack leads to change in thermal behavior which as a result leads to under-utilization, under charging or vice-versa deteriorating the battery pack life.

Figure 23. Thermal Modelling of battery pack

8.2 Electric Vehicle modeling using Lithium-ion battery
The electric vehicle model is a complete representation of an electric vehicle shown by using MATLAB/Simulink built using powertrain block sets. It includes vehicle dynamics and electrical system each containing sub systems that relates to the vehicle body and tyres; and motor and battery pack respectively. Here, the battery pack contains 30 numbers of cells in series and 2 numbers of cells in parallel each. The simulation is done taking the reference speed as Artemis Motorway (130 kmph), where the manual tuning of the PID controller tracks the reference speed. The power losses are less hence, increasing the efficiency of the electric vehicle as compared to normal IC vehicles or HEV. However, increase of public charging stations is required to use the EV at full capacity. Also, the material for the battery should have low cost.

Formula to calculate SOC

\[
SOC(t) = SOC(t-1) + \int \frac{I}{C_{Bat}} dt
\]

where
- SOC(t) = state of charge at time t
- SOC(t-1) = initial state of charge
- I = charge/discharge current(A)
- T = time(H)
$C_{\text{bat}} = \text{Battery Capacity (A)}$

**Figure 24.** EV System level configuration.

**Figure 25.** EV Electrical system.
8.3 State of charge estimation

Coulomb counting is a method to track the state of charge of a battery pack that functions by assimilating the active flowing current over time to derive the total sum of energy entering or leaving the battery pack.

Only using this method leads to some faulty estimation of SOC, hence both coulomb counting and voltage-based method is used together. In BMS, coulomb’s counting-based algorithm express SOC as the ratio of available capacity to the nominal one. There are three modes on which the algorithm works: charged mode, discharged mode, self-discharged mode. In charged mode, the coulomb counter \(Q_{\text{GAIN}}\) is represented by charge accumulation during the operating period. In discharged mode, the coulomb counter \(Q_{\text{LOST}}\) is represented by the number of charges lost. In self-discharged mode, the coulomb counter \(Q_{\text{OC}}\) is represented by the amount of charges lost per hour.

8.3.1 Charged mode

In a lithium-ion battery charging approach has constant current voltage, where \(Q_{\text{gain}}\) depicts coulomb counter.

8.3.2 Discharged mode

This mode persists when current is negative and \(Q_{\text{lost}}\) depicts coulomb counter.

The value of DOD (Depth of Discharge) is calculated as

\[
DOD(t+\tau) = DOD(t) + \Delta DOD(t+\tau)
\]

Where,

![Figure 26. Vehicle dynamics.](image)

![Figure 27. SOC estimation graph.](image)
\[ DOD(t+\tau) = Q_{\text{lost}}(t) + Q_{\text{rated}} \]

### 8.3.3 Self discharged mode
Also, \( Q_{\text{soc}}(h+1) = Q_{\text{soc}}(h) + q \) per hour
Where, \( h \) is an hour of storage
\[ Q_{\text{lost}} = Q_{\text{lost}} + Q_{\text{soc}} \]
\[ Q_{\text{tot}} = Q_{\text{tot}} - Q_{\text{soc}} \]

### 9. Conclusions
- In Figure 27 the Battery SOC shows a linear and a slow discharge Rate, and Charging Peak at 950 sec because of Regenerative Braking in Vehicle.
- Power Losses In EVs Are Very less than Conventional Because they use Complex gear System.
- Efficiency of EV is More Compared to HEV or IC Engines.

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