# Modeling of Battery management system for lithium-ion batteries

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ABSTRACT

The idea behind this paper is to study the battery management system of lithium-ion batteries for increasing the efficiency of the lithium-ion battery. Li-ion batteries have a high energy density, no memory effect (Other than LFP cells), and low self-discharge. the advantages of lithium-ion batteries make them in great demand. The research is to study the principal characteristic of lithium-ion batteries and model a cascade battery management system. The main objective of this paper is to study and develop the battery management system of Lithium ion battery for most effective use of the battery and to avoid damage to the battery.

INTRODUCTION

A battery management system (BMS) is an electronic system that manages a rechargeable battery (cell or battery pack), such as by protecting the battery from operating outside its safe operating area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and/or balancing it. The performance of the lithium-ion batteries is based on the chemical reaction inside the battery. With the use of the batteries, chemicals degrade with time hence affect the working and energy storing capacity of the battery. The battery depreciation process needs to be reduced by conditioning the battery in a suitable manner by controlling it is charging and discharging profile, even various load conditions. To increase the efficiency and performance of the battery two aspects are taken into consideration. Firstly, enhancing the battery capacity, and secondly is the battery management system (BMS).

A lithium-ion battery or Li-ion battery is a type of rechargeable battery in which lithium ions move from the negative electrode through an electrolyte to the positive electrode during discharge, and back when charging. Li-ion batteries use an intercalated lithium compound as the material at the positive electrode and typically graphite at the negative electrode. Li-ion batteries have a high energy density, no memory effect (Other than LFP cells) And low self-discharge. Due to these characteristics, the lithium-ion battery has come into people's attention more frequently. Table 1 are results that have been obtained [2] to compare the parameters and the characteristics of lithium-ion batteries to other 2 types of batteries. Thus, the parameters of a lithium-ion battery are greater compared to lead Acid battery and Nickel Metal Hydride battery.

| **category of battery** | **Energy density (Wh/kg)** | **Power density (W/kg)** | **Cycle life (time)** | **Cost ($)** |
|---|---|---|---|---|
| **Lead-acid** | 30~50 | 200~400 | 400~600 | 400~600 |
| **NiMH** | 50~70 | 50~70 | >800 | 150~200 |
| **Lithium** | 120~140 | 250~450 | 1200 | 150~180 |

TABLE 1- COMPARISON PARAMETERS OF THE DIFFERENT TYPE OF BATTERY

The construction of a lithium-ion battery includes a negative electrode, a positive electrode, the separator between the electrodes, and an electrolyte for submerging the electrodes. The negative electrodes are made of active materials including at least one lowly graphitized carbon material and at least one highly graphitized carbon material. The positive electrode is made of active materials including lithium-ion, transition metal ion and polyanion [3].

A **battery management system** (**BMS**) is any electronic system that manages a rechargeable battery (cell or battery pack), such as by protecting the battery from operating outside its safe operating area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and / or balancing it.

Battery management systems (BMS) are electronic control circuits that monitor and regulate the charging and discharge of batteries. The battery characteristics to be monitored include the detection of battery type, voltages, temperature, capacity, state of charge, power consumption, remaining operating time, charging cycles, and some more characteristics. Proper charging and discharging of a battery can significantly lengthen its life and produce more efficient use of the battery.

With the increased interest in electric vehicles and electronic devices, the Battery Management System has become one of the chief components. Battery monitoring is vital for electric vehicles and electronic devices because the safety, operation, and life span of the battery depending on the battery management system. Battery Management Systems (BMS) handle all monitoring, control and balancing, and safety circuitry of the battery packs and control systems. Battery Management Systems effectively monitors the cell voltage, balances the voltage between the cells to maintain a constant pack voltage, and manages its charging and discharging. Besides that, the other important feature of Battery Management System is to protect the system from overvoltage and over-current conditions for packs of cells in series. It also monitors the system's temperature, handles power saving, and interacts with external controllers to provide system feedbacks [4].

BATTERY MODELING

The performance of the lithium-ion batteries is based on the chemical reaction inside the battery. With the use of the batteries, chemicals degrade with time hence affect the working and energy storing capacity of the battery. The battery depreciation process needs to be reduced by conditioning the battery in a suitable manner by controlling it is charging and discharging profile, even various load conditions.

The research of this experiment is to study the characteristics of the lithium ion battery and model a battery management system. All the important attribute of the lithium battery should be recognized and the important criteria to differentiate the battery should be known. There are three types of battery models, namely, experimental, electrochemical, and electric circuit based. Experimental and electrochemical models are not well suited to represent cell dynamics for the purpose of state-of-charge (SOC) estimations of battery packs. However, electric circuit-based models can be useful to represent electrical characteristics of batteries. The simplest electric model consists of an ideal voltage source in series with an internal resistance [5]. This model, however, does not take into condition SOC. Another model is based on an open circuit voltage in series with resistance and parallel RC circuits with the so-called Warburg impedance [6]. The identification of all the parameters of this model is based on a complicated technique called impedance spectroscopy [7]. Shepherd developed an equation to describe the electrochemical behavior of a battery directly in terms of terminal voltage, open-circuit voltage, internal resistance, discharge current, and state-of-charge [8], and this model is applied for discharge as well as for charge. The Shepherd model is interesting but causes an algebraic loop problem in the closed-loop simulation of modular models [9]. Battery models with only SOC as a state variable are discussed in [10] [11]. These models are very similar to Shepherd's but don't produce an algebraic loop. In this paper, a model using only SOC as a state variable is chosen in order to accurately reproduce the manufacturer's curves for the four major types of battery chemistries. These four types are: Lead-Acid, Lithium-Ion (Li-Ion), Nickel-Cadmium (NiCd) and Nickel Metal-Hydride (NiMH). In this paper the charge and discharge curve are obtained by simulation or the different type of batteries with the manufacturer's datasheet.

To obtain a physical charging and discharging curve, a system needs to be created using the charging and discharging equation. The main aim of the project is to obtain correct equation which is determined by lithium-ion battery as the model of charging and discharging changes depending on the type of battery used. When all the estimation techniques have been distinguished, it should be converted into simulation blocks utilizing computational software of MATLAB to be joined.

Figure 1 shows the results of the battery output voltage with different cycle numbers for 250 C and figure 2 shows the results for the 500 C obtained by the proposed model for discharge condition, 0.9A and 1.8Ah lithium-ion battery. Where the figure 3 and figure 4 shows the results obtained by Ramadass[12] for the same condition. From the figure 1 and figure 2,

| cycle Number | Ramadass (Remaining capacity Ah) | Proposed model (remaining capacity Ah) |
|---|---|---|
| 10 | 1.2 | 1.2 |
| 100 | 1.5 | 1.5 |
| 400 | 1.6 | 1.6 |
| 800 | 1.78 | 1.78 |

can see that the proposed model and results acquired by Ramadass[12] are very comparable, as the capacity fading significantly increases with increment of temperature and cycle number. The summary of the results is shown in table III, for the different cycle numbers.

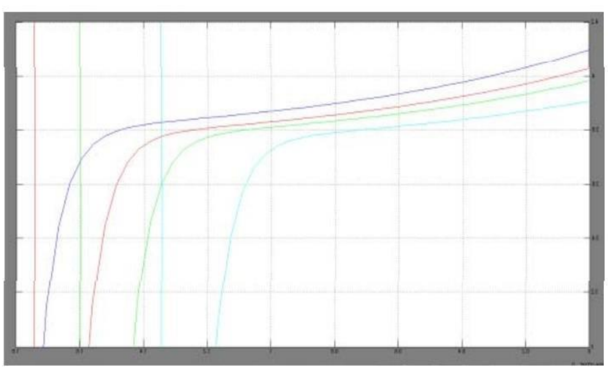


Fig. 1. Results obtained by proposal model (25°C)

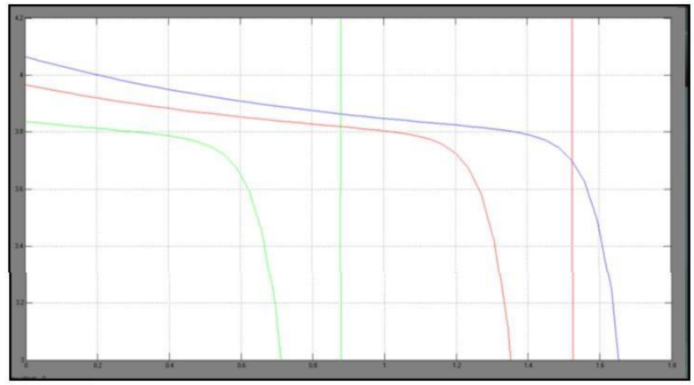


Fig. 2. Results obtained by proposal model.(50°C)

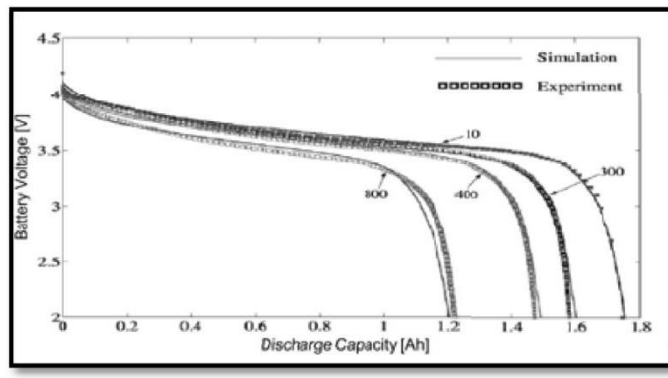



Fig. 3 Results obtained by Ramadass

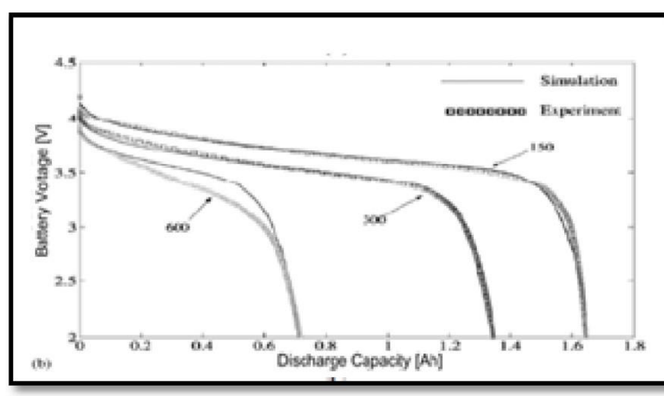



Fig 4 Results obtained by Ramadass

TABLE II. SUMMARY OF PROPOSED MODEL AND RAMADASS RESULT FOR 25°C

From the above results with increased cycle number and temperature, the battery usage time is reduced. It is also found that the ideal operating temperature of the battery is 25°C. Table III shows the summary results for the different cycle.

TABLE III. SUMMARY OF PROPOSED MODEL AND RAMADASS RESULT FOR 50°C

| cycle Number | Ramadass (Remaining capacity Ah) | Proposed model (remaining capacity Ah) |
|---|---|---|
| 150 | 1.65 | 1.65 |
| 300 | 1.28 | 1.28 |
| 600 | 0.7 | 0.7 |

## III.METHEDOLOGY

**A.** Battery Charging

Li-Ion batteries commonly require a constant current, constant voltage type of charging algorithm. In other words, a Li-Ion battery should be charged at a set current level (typically from 1 to 1.5 amperes) until it reaches its final voltage. For the charging process, it is constantly accepted that the battery will be charged to its 100% limit before its utilization. As the battery is directly connected to the charging adaptor, the charging time frame will not deliver any losses in voltage because of temperature, capacity fade, or from internal resistance. The main challenge in charging a Li-Ion battery is to realize the battery's full capacity without overcharging it, which could result in catastrophic failure. Nonetheless, every battery has its own life time. The chemical composite of the battery decides the internal losses of the battery. The battery’s life span depends on how frequently the battery being charged and discharged. The more times the battery being charged and discharge the shorter the life span of the battery. This is because research shows that, each time the battery is charged, the life expectancy of the battery will decrease by one cycle.

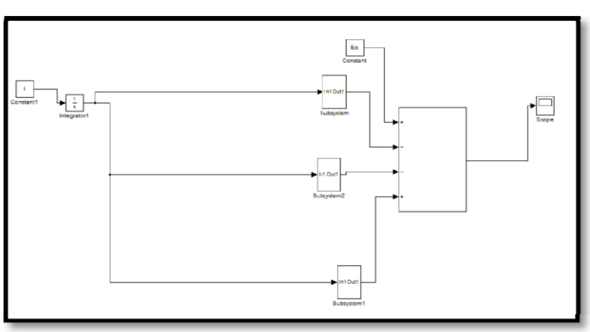


fig. 5. Lithium-Ion Charging Model

Following are the equations for the Subsystem 1, 2 and 3 in the charging model:

- Subsystem = □(□ / (□□+0.1)□)□
- Subsystem 1 = □(□ / (□−□□))□□

Subsystem 2 = □ * exp(−□ * i□)

**B.** BATTERY DISCHARGE

Important parameters needs to be identified before starting modeling the battery discharge curve

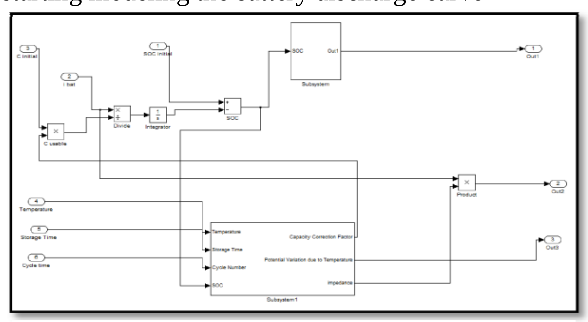


Fig 6 : Lithium-Ion Discharging model

Battery open circuit voltage can be determined due to the battery open circuit voltage drop result the battery equivalent internal impedance and the temperature correction of the battery potential. The battery output voltage expressed as

$\square_{\square\square\square} = \square_{0\square} - i_{\square\square\square} \times \square_{e\square} + \Delta\square(\square)$ (4)

**1) The battery open circuit voltage**

The difference of electrical potential between two terminals of a battery when there is no external load connected is known as battery open circuit voltage. The value of open circuit voltage can be calculated as below

$V\,OC(SOC) = -1.301 \times \exp(-35 \times SOC) + 3.685 + 0.1256 \times SOC - 0.1178 \times SOC^2 + 0.321 + SOC^3$

The battery SOC can be expressed as:

$\square\square\square = \square\square\square_{i\square\square} - \int( i_{\square\square\square} / \square_{\square\square\square\square\square e})\square\square$

**2) The effect of capacity fading**

Capacity fading is known as the irreversible loss in usable capacity of a battery due to temperature, cycle number and time. The capacity correction factor can be calculated as:

□□□ = 1 − (□□□e□□□□ □ife □o□□e□ + □□□□e □ife □o□□e□) (7)

Then the remaining usable battery capacity defined as

□□□□□□e = □i□i□i□□ × □□□ (8)

During the battery is not in use, the calendar life losses of a battery consist of storage losses. The percentage of storage losses are as per below

% □□o□□□e □o□□ = 1.544 × $10^7$ ×exp $\left(\frac{40498}{8.3143□□}\right)$ □ (9)

The rate of change in negative electrode SOC is dependent on cycle number and temperature can be represented as in equation

$\frac{□□□}{□□}$ = k1□ + □2 (10)

Where the coefficient $k_1$ accounts for capacity losses that increase rapidly during adverse conditions such as cycling at high temperature, and $k_2$ is a factor to account for capacitylosses under usual conditions of cycling [8]. The values of k1 and k2 can be referred to the Table 10below [13]. It is interesting to notice that k2 doesn't change much due to temperature. The variations of negative electrode SOC can be considered for simulating the cycle life losses [13].

TABLE IV. TABLE 10. VALUES OF THE COEFFICIENTS DEPENDENT CYCLING TEMPERATURE

| **Cycling temperature[°C]** | **$K_1$[$cycle^{-2}$]** | **$K_2$[$cycle^{-1}$]** | **$K_3$[$\Omega/cycle^{1/2}$]** |
|---|---|---|---|
| 25 | $8.5 \times 10^{-8}$ | $2.5 \times 10^{-4}$ | $1.5 \times 10^{-3}$ |
| 50 | $1.6 \times 10^{-6}$ | $2.9 \times 10^{-4}$ | $1.7 \times 10^{-3}$ |

**3) Variable equivalent internal impedance of battery**

The battery equivalent internal impedance consists of a series of resistor composed of □□e□ie□ and □□□□□e and two RC network composed of □□□□□□ie□□□ , □□□□□□ie□□□, □□□□□□ie□□_□, □□□ □□□□□□ie□□_□, □□e□ie□ is accountable for instantaneous voltage drop in battery terminal voltage [13]. Meanwhile, the other component of series resistor □□□□□e is meant to define the increase in the battery resistance with cycling. The components of RC networks are responsible for short and long-time transient's inn battery impedance . the □□□□□□ie□□_□, □□□□□□ie□□_□, □□□□□□ie□□□ □□□ □□□□□□ie□□□ [13] value is calculated, due to battery SOC as:

□□e□ie□ (□□□) = 1.562 × exp(−24.37 x SOC) + 0.07446 (11)

□□□□□□ie□□_□(□□□) = 0.3208 x exp(−29.14 x SOC) +0.04669 (12)

□□□□□□ie□□_□(□□□) = 752.9 x exp(−13.51 x SOC) + 703.6 (13)

□□□□□□ie□□□(□□□) = 6.603 x exp(−155.2 x SOC) + 0.04984 (14)

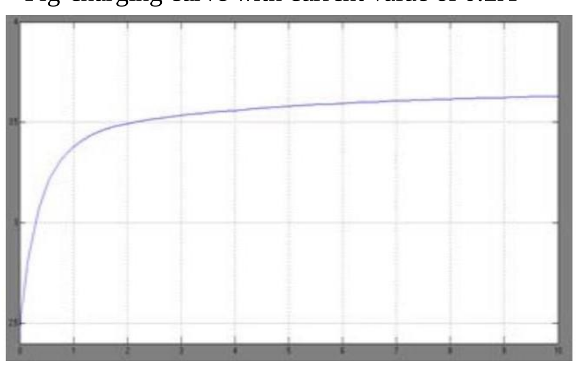
□□□□□□ie□□□(□□□) = −6056 x exp(−27.12 x SOC) + 4475 (15)

RESULTS

A. CHARGING

Figure 7 shows the battery is charged at the constant voltage of 3.7348V and current of 0.2A is being supplied to the simulation. The simulation process produces a smooth charging curve as per figure 6. The battery reaches its maximum charge voltage in its Q=10Ah. Therefore, the lithium-ion battery requires a short period to reach its maximum charge 3.8V.

Fig-charging curve with current value of 0.2A



B. DISCHARGE

Figure 8, shows the outcome from the discharging simulation of lithium ion battery. The battery is discharged at 4.2V and it discharging period completes at 1.7h. The model is being supplied with the current rate of 0.9A. At the time of Q=0.2Ah, the battery discharges quickly until it reaches 3.8V. Then the battery discharge at a constant value of 3.6V from Q=0.4Ah till it reaches Q=1.4Ah. Later if the battery wascontinuously discharged, the voltage of the battery will drop below the battery's voltage.

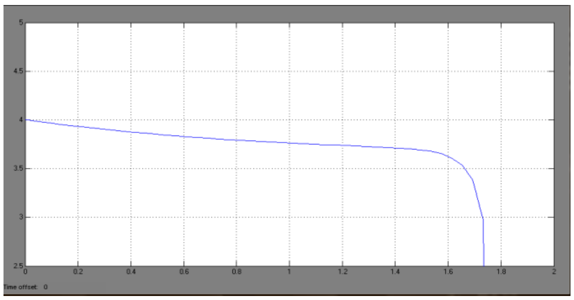


FIG 8 -Discharge Curve with SOC initial 0.89 (10 cycle time) & current value 0.9A

Figure 9, shows the overall comparison between discharged with different load. Table III shows the results obtain from the discharge period. It is summarized that the higher the load value (resistance), the lower its discharge capacity.

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TABLE V. COMPARISON OF DICHARGING CURVES USING VARIES LOADVALUE

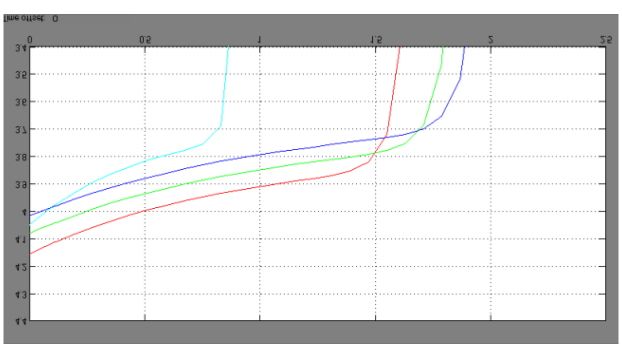
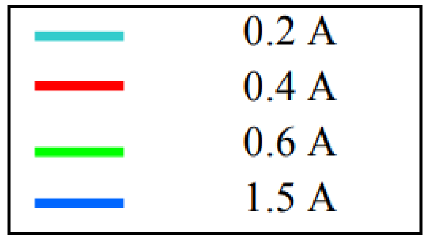


Fig. 9. Comparison of discharge curves with different loads

| LINE | CURRENT(A) | DISCHARGE CAPACITY (Ah) |
|---|---|---|
| 1 | 0.80 | 1.60 |
| 2 | 0.85 | 1.70 |
| 3 | 0.95 | 1.90 |
| 4 | 1.50 | 0.8 |




Line 4 in figure 9 shows the effect of over-discharge due to heavy current supply to the battery. The battery starts to discharge at 4.05V and its discharging period completes at Q=0.7Ah. This shows the battery has reached its malfunction level (damage) where it loses its storage capability

CONCLUSION

In nutshell, lithium battery is picked to be the best since Li-ion batteries have a high energy density, no memory effect (other than LFP cells) And low self-discharge. Cells can be manufactured to either prioritize energy or power density. They can however be a safety hazard since they contain flammable electrolytes and if damaged or incorrectly charged can lead to explosions and fires. The model picked would be non-straight battery model by which the model just uses condition of charge (SOC) as a state variable. This mode was selected because in order to accurately reproduce the charging and discharging curve with based on assumption that been identified. This project depends on the computation of the charging and discharging equation using the model chosen. the property of the battery changes when the battery is being charged or discharged with load. Thus it is essential o study optimal load a battery could support to avoid malfunctioning of the battery.

NOMENCLATURE

$V_{bat}$ = Battery output voltage [V]

$V_{oc}$ = Battery open-circuit voltage [V]
$Z_{eq}$ = Battery equivalent internal impedance [Ω]
$I_{bat}$ = Battery current [A]

$\Delta E(T)$ = Temperature correction of the potential [V]
$SOC$ = State of charge

$SOC_{init}$ = Initial state of charge

$C_{usable}$ = Usable battery capacity [Ah]

$T$ = Temperature [ºC-ºK]
$t$ Storage time [months]
$Q_n$ = Change in state of charge of battery negative electrode
$N$ = Cycle number

$k_1$ = Coefficient for the change in SOC of batterynegative electrode [cycle$^{-2}$]
$k_2$ = Coefficient for the change in SOC of batterynegative electrode [cycle$^{-1}$]
$k_3$ = Coefficient for the change in $R_{cycle}$ [Ω/cycle$^{1/2}$]
$CCF$ = Capacity correction factor $C_{init}$ = Initial battery capacity [Ah]$E_{Batt}$= Nonlinear voltage (V)
$E_0$ = Constant voltage (V)
Exp(s) = Exponential zone dynamics (V)
K = Polarization constant (Ah$^{-1}$) or Polarizationresistance (Ohms)
i* = Low frequency current dynamics (A)i = Battery current (A)
it = Extracted capacity (Ah)
Q = Maximum battery capacity (Ah)A = Exponential voltage (V)
B = Exponential capacity (Ah)$^{-1}$

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