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Model Based Battery Management System for Electric Vehicles

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Abstract

In this paper a model based battery management system for Lithium Ion batteries has been proposed. Power dissipated inside each cell due to variations of internal temperature of each cell of the battery is also considered. Entire modelling and simulation is done in MATLAB. The algorithm proposed in this paper has less mathematical complexity and easy to implement. The proposed battery management system balances both SOC and temperature variations of a Lithium Ion Batteries. Various drive cycles are used to demonstrate SOC variations of Lithium Ion battery.

Keywords

Lithium ion battery, battery management system, temperature variations, parallel electric hybrid vehicles, drives cycles, state of charge (SOC).

Introduction

With every passing year Lithium Ion battery based electric vehicles [1] [7] becoming popular. Currently it seems pure electric vehicles are the best possible solution of global problems like increasing fuel prices, climate change and air pollution. The main drawback in pure electric vehicles is the limitation of battery technology like usage of battery per charge and cost. With every passing year the battery technology is getting improved and cost also getting reduced. Similarly hybrid electric vehicles are also getting popular with every passing year, which also uses battery for their motion. Today Lithium ion [5] [6] based batteries are the most popular batteries among the various batteries available for electric vehicles. For electric vehicles $LiPFeO_4$ [2] [3] are the most popular. Lot of algorithms is presented in past literature for implementation of battery management system for electric vehicles using kalman filtering [4] [11] [14], artificial intelligence [9] but all these techniques suffers from mathematically complexity and computational burden. In this paper a model based battery management system has been proposed for lithium ion batteries. The proposed battery management system balances both SOC and temperature variations of a Lithium Ion Batteries.

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The proposed algorithm has very less mathematical complexity and its computational burden is quite low. The paper is organized as follows, in section II an electrical circuit of a cell of lithium ion battery is presented with battery parameters, in section III entire algorithm for SOC variation is presented including temperature variations, in section IV results are presented and in section V conclusions are drawn.

Electrical Circuit of Lithium Ion Cell:

This section describes the cell structure of Lithium Ion batteries and also presents values or parameters as shown in table I, used to calculate or estimated SOC of the battery under temperature variation of a cell.

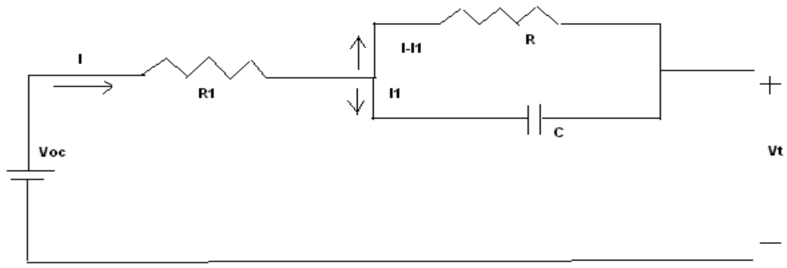

Figure 1: Single Cell Structure of $LiPFeO_4$ Batteries

TABLE 1: PARAMETERS USED FOR SOC ESTIMATION OF LI BATTERIES

Parameter	Value
[SOC_{min}, SOC_{max}]	[0.2, 0.8] p.u.
Battery type	Lithium-ion
Cell nominal voltage	3.30V
Cell nominal capacity	2.22 Ah
Energy capacity, ($E_{batt,\,nom}$)	4 kWh, 546 cells, 91 in series x 6 sets in parallel
E_{batt} (t_0)	3.0 kWh
η_{bat}	0.9 p.u.
V_{oc}	300 V
R_b	0.37 Ω
P_{ICE}	[0, 65] kW
η_{gen}	0.9 p.u.
C at 25^0C	4900 F
R (initial resistance) at 25^0C	3.17 mΩ
R_1 (initial resistance) at 25^0C	2.57 mΩ
Initial Temperature of Cell at the start	25^0C
Average Temperature of Cell during driving	40^0C

Mathematical Modelling of Lithium Ion Cell with Temperature Variations:

The electrical circuit of a cell of Lithium ion battery is shown in Fig 1. The resistance R_1 and R and capacitance C do not have fixed values and their values changes with temperature. The initial temperature of cell before driving start is 25^0C. The temperature

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of the cell increases linearly as battery discharges and again charges but to ease the calculation, it is assumed that average temperature of the cell during entire driving or drive cycle is 40^{0}C. The new values of R_1, R and C are calculated below.

$$R_1=1+\alpha_1(T_{final}-25^0C) \quad (1)$$
$$R=1+\alpha_2(T_{final}-25^0C) \quad (2)$$
$$\beta=(C-C_{25})\times 10^6/(C_{25}\times(T_{final}-25^0C)) \quad (3)$$

The value of α1, α2, and β temperature coefficients depends on the type of resistances and capacitance used in the Li battery.

The SOC estimation [1] of LiPFeO4 is as follows

Applying Kirchhoff law

$$Voc - I * R1 - (I - I1) * R - Vt = 0 \quad (4)$$

$$Voc - I * R1 - \frac{1}{c}\int I1 \; dt - Vt = 0 \quad (5)$$

Voc remains constant for LiPFeO4 and do not depend on SOC.

Value of V can be calculated by Power of the motor

$$V = P/I \quad (6)$$

Differentiating both sides with respect to time t

$$\frac{dv}{dt} = \left[\frac{\frac{dp}{dt}}{I}\right] - [(P * \frac{dI}{dt})/I^2] \quad (7)$$

Computing I1 in terms of I in (4)

$$I1 = -\big(Voc - V - I * (R + R1)\big)/R \quad (8)$$

Now using value of I1 from eq (8) and putting in (5)

$$Voc - I * R1 + \frac{1}{c}\int \left[\frac{(Voc-V-I*(R+R1))}{R}\right] dt - V = 0 \quad (9)$$

Differentiating equation (9) with respect to time

$$-R1\frac{dI}{dt} + \left[\frac{Voc*I-P-(R+R1)*I^2}{(I*R*C)}\right] - \left[\frac{\frac{dp}{dt}}{I}\right] - [\frac{(P*\frac{dI}{dt})}{I^2} = 0 \quad (10)$$

Solving the equation (10) and Integrating both sides for I (I to 0) and t (0 to t) (discharging condition) in equation (10), to integrate Trapezoidal integration rule is employed which is describe below. For a drive cycle usually dt = 1 sec and dp is the change in the power of the motor in 1 sec. All the values can be found in Table 1.

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$$\int_a^b f(x)dx = (b-a)\frac{f(a)+f(b)}{2} \quad (11)$$

$$V_{oc} - V - I \cdot R_1 + \frac{1}{RC}\int [Voc - V - \frac{P}{V}(R+R_1)]dt = 0 \quad (12)$$

$V_{oc,i}$: Voc in time instant t=*I*   *i – (i-1) = 1 second* (13)

$$V_{oci} - V_i - I_i R_1 + \frac{1}{RC} 1 \left[\frac{V_{oci}+V_{oci-1}}{2} - \frac{V_i+V_{i-1}}{2} - (R+R_1)\frac{P_i/V_i + P_{i-1}/V_{i-1}}{2} \right] \quad (14)$$

$$V_{oci} = \frac{1}{2RC+1}V_{oci-1} + V_i + \frac{1}{2RC+1}V_{i-1} - I_i \cdot R_1 + \frac{R+R_1}{2RC+1}(P_i/V_i + P_{i-1}/V_{i-1}) \quad (15)$$

After obtaining value of I we calculate the power of the battery

Voctotal = 3.3*91= 306.9 V **(16)**

Power of the batter supply Pbatt = Voctotal *6* I **(17)**

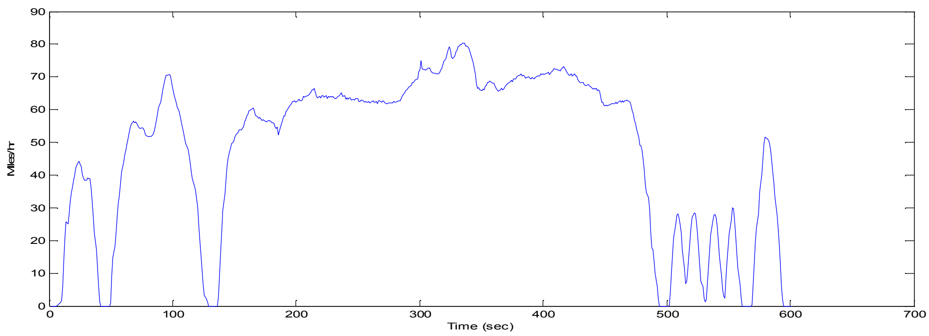
SOC calculated by below formula's (+/- depends whether it is charging or discharging)

$$E_{batt}(t) = E_{batt}(t_0) \pm \int P_{batt}(t)\,dt \quad (18)$$

SOC = Ebatt (t) /Ebatt, nom (19)

Results

The above mathematical model described in section III is applied on parallel hybrid electric vehicles for various driving cycles. The estimated SOC for Lithium ion batteries for various driving cycle are shown in figure 2, 3, 4.



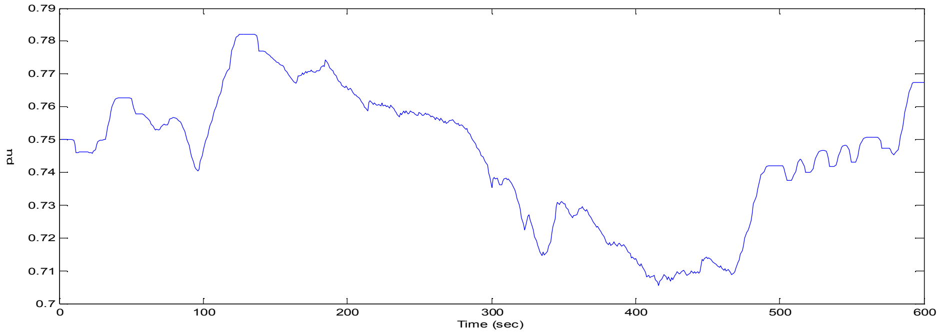


Figure 2: US06 supplemental FTP driving schedule and SOC calculated for Li Batteries

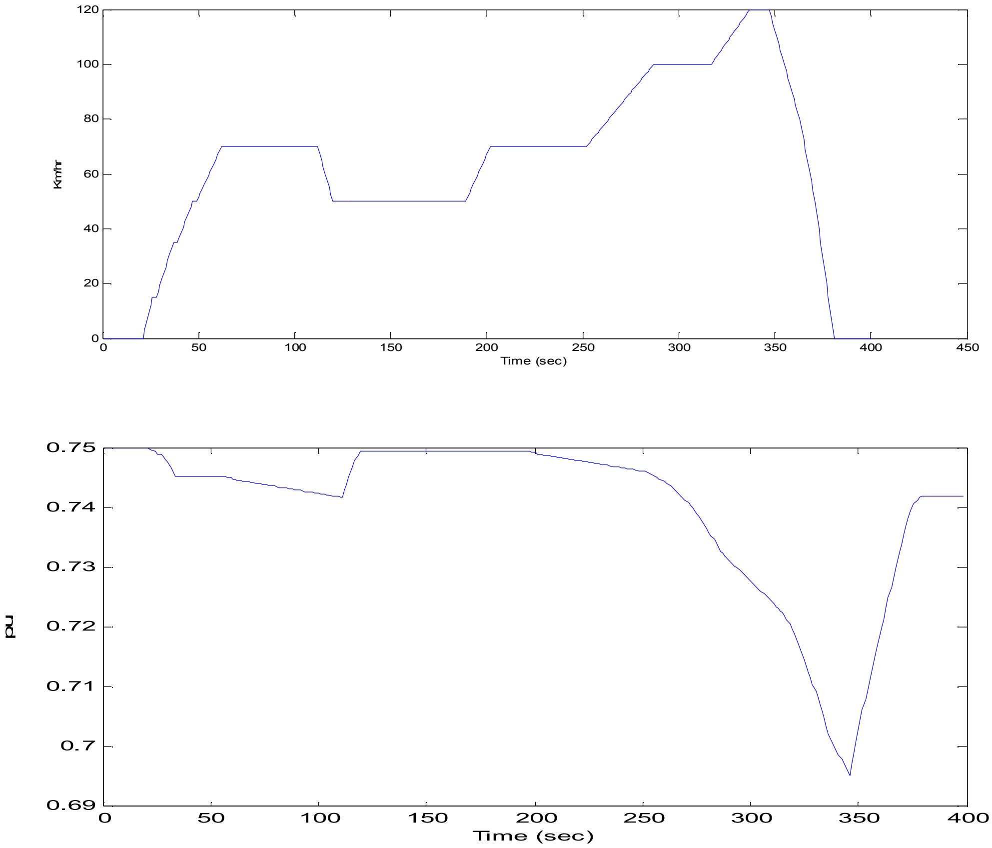
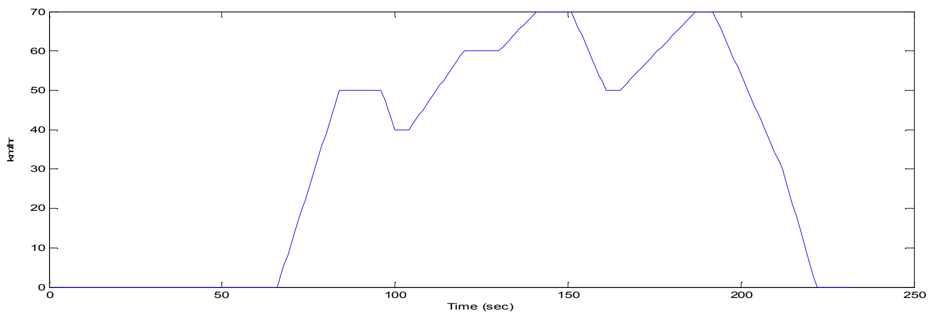


Figure 3: UN/ECE Extra-Urban driving cycle (part 2) and SOC calculated for Li Batteries



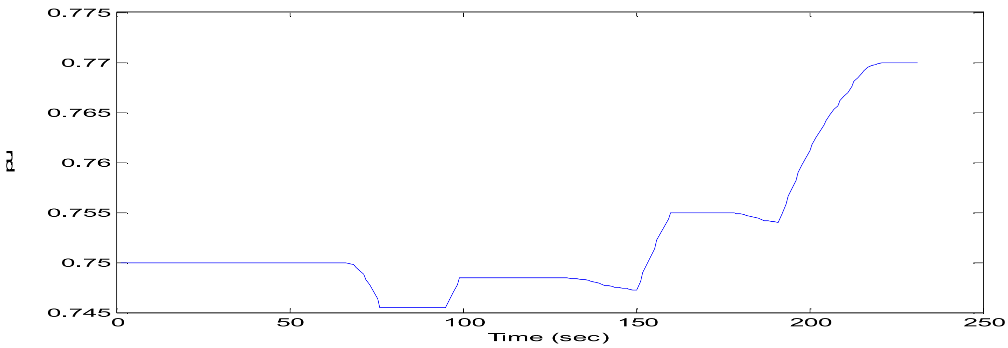


Figure 4: Japanese 15 mode driving cycle and SOC calculated for Li Batteries

Conclusion

In this paper a model based battery management system for Li batteries is presented. The main advantage of this battery management system that it offers very less mathematical complexity and computational burden is also quite low. The battery used is $LiPFeO_4$. The temperature variation is also considered due rise of internal temperature of cells of the battery due to heating, during charging and discharging of the battery. Various drive cycles are used to calculate and demonstrate SOC of Li batteries.

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