Estimation of SoC for $LiFePO_4$ and $Li_4Ti_5O_{12}$ battery cells

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Abstract

Lithium ion batteries do not self-discharge like lead acid batteries. The recharge and discharge is also faster. Open circuit voltage (OCV) tells the state of charge (SoC). State of charge is important to know when computing available energy left or required energy to recharge. The relaxation time constants of $LiFePO_4$ cells are equal to 2,8 h and 24,5 h. Therefore we must wait at least two days before OCV can be measured. Extended Kalman filter can be used to estimate OCV and SoC in real time. Internal resistance increases at low temperatures more with $LiFePO_4$ cells than with $Li_4Ti_5O_{12}$ cells. Internal resistance increases nine times when the LiFePO4 cell temperature drops from +23 ºC to -18 ºC. Therefore the cell temperature should be included in the estimation model.

Introduction

The $LiFePO_4$ cell recharging cutoff voltage is 3,65 V and discharge cutoff voltage is 2,65 V. The battery voltage relaxation time has been often underestimated (Xiong et al., 2013) and (Zheng et al., 2013). Nano lithium-titanate cells have lower nominal voltage and cutoff voltages equal to 2,8 V and 2,0 V. Voltage measurements have been made at four decimal resolution by Fluke 189 multimeter. The recommended discharge and recharge time of ordinary $LiFePO_4$ cell is 3 h. The nano-phosphate cell with same battery chemistry has 2 min discharge time and 15 min recharge time. The nano-titanate cells have 10 min time for discharge and recharge.

Results

90 Ah and 260 Ah $LiFePO_4$ cells have been discharged at three different temperatures namely -18 ºC , +6 ºC and +23 ºC . Internal resistance of the 90 Ah cell is 22,4 mohm at -18 ºC and 2,5 mohm at +23 ºC. Table 1 shows the OCV as a function of Ah from nominal. The measurement time from last recharge is also shown. Table 2 shows the OCV of a nano-titanate cell and the applied discharge. Figure 1 shows the battery model used in this study. The 90 Ah $LiFePO_4$ battery voltage relaxation can be modelled with two time constants namely 2,8 h and 24,5 h. Figure 2 shows the voltage response of a 90 Ah LiFePO4 cell during and after a 12 min long discharge pulse. Figure 3 shows the voltage response of a Lithium titanate cell.

Table 1. The open circuit voltage and the charge level of a 90 Ah LiFePO4 cell.

charge	5 %	15 %	25 %	40 %	55 %	65 %	75 %	85 %	95 %	105 %
OCV (V)	3,212	3,259	3,290	3,306	3,312	3,319	3,336	3,340	3,342	3,429
Rest (h)	43	30	65	46	52	65	71	47	74	113

Table 2. The open circuit voltage and the charge level of a 50 Ah nano-titanate cell.

charge	-10 %	-5 %	0 %	5 %	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	95 %	99 %
OCV (V)	1,920	2,025	2,072	2,110	2,138	2,202	2,282	2,331	2,341	2,349	2,375	2,414	2,463	2,494	2,574
Rest (h)	43	24	27	69	23	22	30	67	22	23	23	29	66	28	47

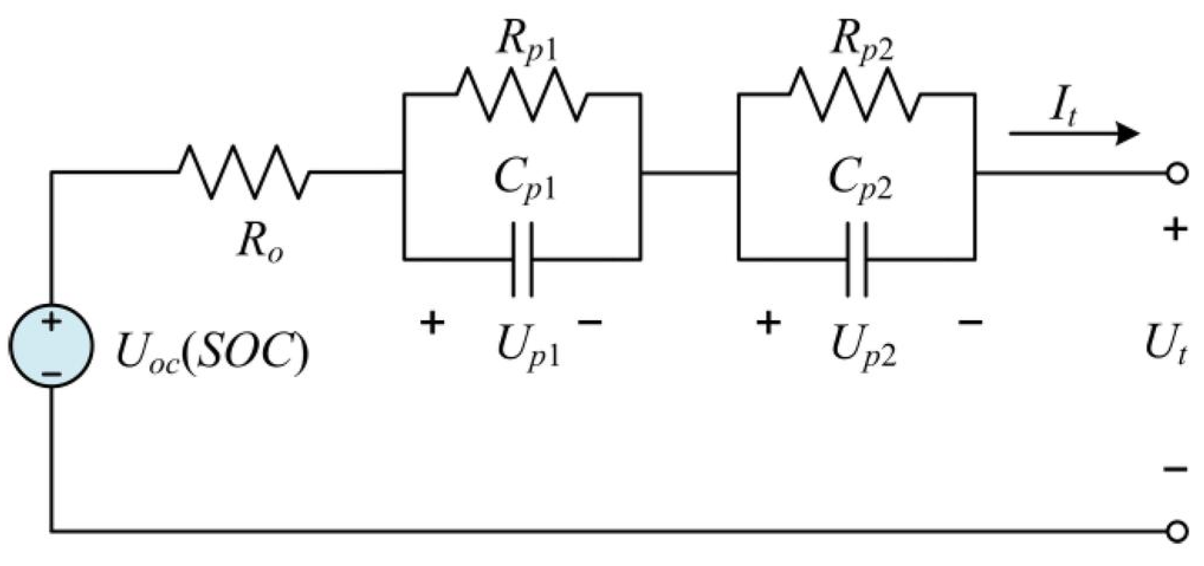

Figure 1. Second order battery model.

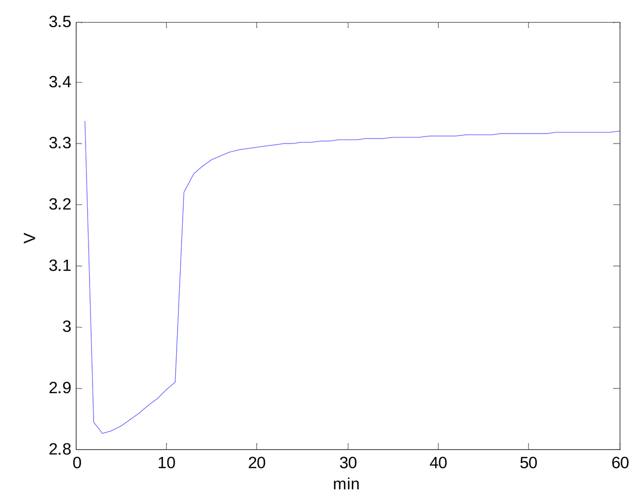

Figure 2. Discharge at 0,3 C, warming and relaxation of a $LiFePO_4$ cell at -18 ºC.

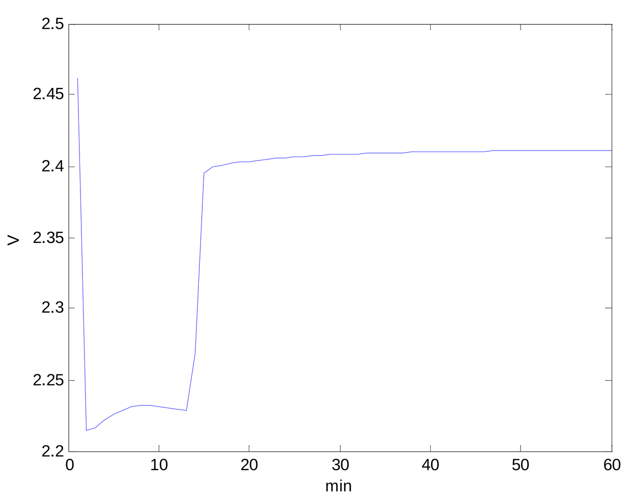

Figure 3. Discharge at 0,5 C and relaxation of a nano titanate cell at -18 ºC.

The Extended Kalman filter is based on the following battery model:

$$dx_1/dt=-(1/(R_1*C_1))*x_1+(1/C_1)*u+w_1$$

$$dx_2/dt=f_2(u)+w_2$$

$$dx_3/dt=-c_T*(x_3-T_0)+c_H*(R_0(x_3)+R_1)*u*u+w_3$$

where x_1 is the relaxation voltage, x_2 is the open circuit voltage and x_3 is the battery cell temperature. The cell current is marked by u. The R_1 and C_1 are relaxation resistance and capacitance. c_T , c_H and T_0 are thermal model parameters. R_0 () is the temperature dependent cell resistance. All model errors are modelled by random variables w_1, w_2 and w_3.

More accurate model should include at least two or three time constants. The best OCV observability is achieved by modeling only the longest time constant.
The measurement equations are as follows:

$$y_1=x_1-x_2-R_0(x_3)*u+v_1$$

$$y_2=h_2(x_2)+v_2$$

The variance of the measurement error v_2 is constant but the variance of v_1 is dependent on the cell current. This is the way how the faster time constants are modelled.

Conclusions

The Lithium ion battery cells do not require periodic recharging in standby applications like lead acid batteries. $LiFePO_4$ cell have long relaxation time and flat OCV curve. Extended Kalman filter makes possible to estimate state of charge in dynamic conditions. $Li_4Ti_5O_{12}$ battery cells operate better than $LiFePO_4$ cells at cold environment.

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References

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