DYNAMIC MODEL OF USING POWERED LITHIUM-ION BATTERIES FOR EV / HEV APPLICATIONS

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Abstract: The work presents a simple and easy to use dynamic model for the work of the lithium-ion battery type LiFeYPO4. The dynamics model of charging and discharging of the battery is validated experimentally with a traction battery used in EV / HEV. An interesting feature of this model is the simplicity for extracting of the dynamic parameters of technical specifications of the battery. Only two points on the curve for the discharge of the battery in the steady state are required to obtain the necessary parameters. The model of the battery is included in the simulation using the LabJack U12 in the programming environment LabVIEW2012 for EV / HEV applications. The results show that the model can accurately represent the dynamic behavior of the battery during use of EV / HEV vehicles.

KEYWORDS: *Dynamic model of a lithium-ion battery; Electric vehicles – EV; Hybrid electric vehicles – HEV; State of charge of the battery - SOC .*

1. Introduction

The main element of the electric vehicles (EV), as well as most hybrid electric systems generally is the battery.This element stores a huge amount of energy that needs to be released when required. The battery allows for additional charging from regenerative braking in EV / HEV. .

Battery management system (BMS) has to ensure effective state of charge (SOC) of the battery. To achieve this, the designer of BMS must have a detailed simulation of the system control unit of EV / HEV, including a detailed model of the charge / discharge of the battery. The literature describes essentially three types of models of the battery , in particular: experimental , and the electrochemical reference circuit [2,3] . Experimental and electrochemical models are not well suited to represent the dynamics of the battery cells for the purpose of assessments of the state of charge. Based on the circuit patterns may be utilized to represent the electrical characteristics of the batteries. Developed is an equation for describing the electrochemical behavior of the battery in respect of direct voltage terminal, the voltage of the open circuit, the internal resistance, the current of the discharge and charge level [1]. This model is applied for dilution and charging. A modified version of this model was used in [4]. This modification is based on the use of the polarization of the voltage instead of the polarization of the impedance in order to eliminate the problem of the algebraic loop. This model uses only the SOC of the battery representing the behavior of the voltage as a state variable. This applies to steady state (constant current) this model produces inaccurate results when the state of the current range.

2. Purpose of work

The purpose of this work is to present a simple dynamic model of battery life, which can be applied to variable charge / discharge or changes to current, as in EV / HEV. The work is organized as follows: Section 3 shows a simplified model developed for high-power lithium ion batteries LiFeYPO4. Section 4 presents the model parameters and the procedure for their extraction from the graph of dilution manufacturers [5]. Section 5 presents the results of experimental validation of the model and 6 conclusions.

3. Dynamic model of a lithium-ion battery LiFeYPO4

3.1 Model of discharging

Fig. 1 shows a typical characteristic of the battery discharge. The proposed dynamic model is similar to the model [1], but can be presented in exactly the dynamics of the voltage when the current is different and account the open circuit voltage (OCV) as a function of SOC.

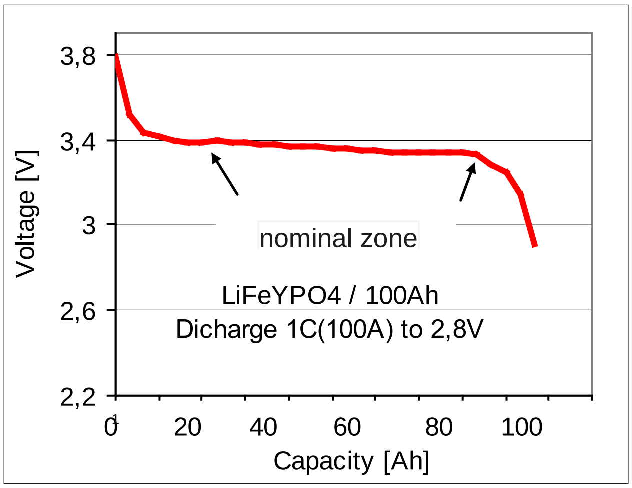


Figure 1. *Typical dilution curve of lithium-ion battery LiFeYPO4*

The term on the polarization voltage is added to represent better the behavior of OCV. In contrast to [1], where the formula for calculating the voltage to apply to all types of batteries, the battery voltage in this case is only calculated in the nominal area of the formula:

$$V_{batt} = E_0 - K\frac{C}{C-it}.it - Ri - K\frac{C}{C-it}.i^* \qquad (1)$$

where:

V_{batt} = battery voltage (V);
E0 = constant voltage of the battery (V);
K = polarization constant (V = (Ah)) or polarization resistance (Ω);
C = battery capacity (Ah);
it = $\int idt$ = actual battery charging(Ah);
R = internal resistance (Ω);
i = current of the battery (A);
i* = filtered curent (A).

Feature of this model is the use of filtered current (i *) passing through the polarization resistance [5]. In fact, experimental results show that the dynamic behavior slows down voltage for the reaction step of the current. This filtered current solves the problem of algebraic contour due simulation to electrical systems in Labview. Finally, OCV varies linearly with SOC.

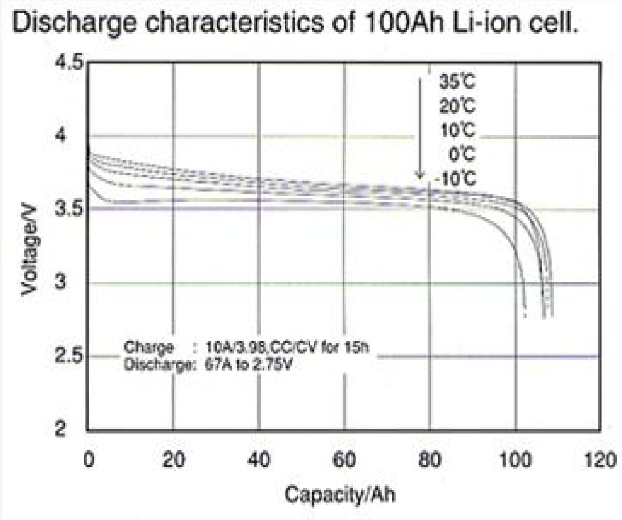


Fig.2. *Dilution curve at different temperatures lithium-ion battery LiFeYPO4*

The nominal area of the formula (1) is linear for lithium-ion batteries LiFeYPO4, as shown in the graph of Figure 2. discharge curves taken from the manufacturer. [5]

3.2 Model of charging

The charging voltage at nominal zone is calculated pa formula:

$$V_{batt} = E_0 - K \frac{C}{it - 0.1.C}.i^* - K\frac{C}{C - it}.it \qquad (2)$$

Generalized model of a lithium-ion battery from u-know (1) and (2) in nominal area will be:

$$Discharge: V_{batt} = E_0 - R.i - K\frac{Q}{Q - it}.it.(it + i^*)$$

$$Charge: V_{batt} = E_0 - R.i - K\frac{Q}{it - 0.1.Q}.i^* - K\frac{Q}{Q - it} \qquad (3)$$

3.3. Estimates of the model

The proposed model is based on specific assumptions and restrictions:

- The internal resistance is supposed to be constant during charge and discharge cycle, and do not varies depending on the current amplitude.
- The model only applies to batteries type LiFeYPO4.
- The parameters of the model are derived from discharge characteristics and shall be supposed to be the same when charging.
- Battery capacity does not change the amplitude of the current (no effect Phuket).
- The temperature no effect on behavior of the model.
- No self-discharge of the battery.
- The battery has no memory effect.

3.4. Limitations of the model

- The minimum unladen battery voltage is 0 V and the maximum battery voltage 2 E0.
- The minimum battery capacity is 0 Ah and the maximum capacity C. Therefore, the maximum SOC can not be greater than 100% if the battery is recharged.

4. Extraction (sample) of parameters

An important characteristic of the proposed model is the simplicity with which the derived dynamic model parameters. In fact, it is not necessary to take the experimental data of the battery, in order to extract the parameters, if the manufacturer is given the discharge curve. [5] Only two points of the nominal area of the dilution curve at steady state are necessary to obtain the parameters. The manufacturers of the battery provide specifications of the battery data, including "Specifications of the discharge curve" (Fig. 2), where it is possible to derive the fully charged voltage (Vfull) battery, the voltage at the beginning and end of the nominal area (Cnom, Vnom) (when the voltage begins to fall sharply exponent) and maximum capacity (C). Also, the internal resistance (R) is generally given.. Only two of these three points is possible solution using equations (1,2,3). The curve of the manufacturer is usually supplied with a constant current (equal to 0,2 C). Fully charged battery voltage, the extracted charge is 0 (it = 0) and the filtered current (i *) is 0, because the current step A has just begun:

$$V_{full} = E_0 - R.i + A \qquad (4)$$

In nominal rated voltage zone is given by:

$$Vnom = E_0 - K\frac{C}{C - Cnom}.(Cnom + i) - R.i \qquad (5)$$

When C = Cnom (when the cells of the battery are new).

$$Vnom = E_0 - R.i \qquad (6)$$

Therefore, in this type of battery nominal voltage Vnom depends on the internal resistance R and current flow i. The time constant of the filtered current (i *) is not given in the technical data from the manufacturer but only experimental data. The test can provide this information. However, the experimental data show a time constant of 30 seconds for this battery. Obviously, these parameters are approximations and the level of accuracy of the model depends on the accuracy of the points derived from the curve. Parameters of the model of cells of this type of lithium-ion batteries are shown in Table 1.

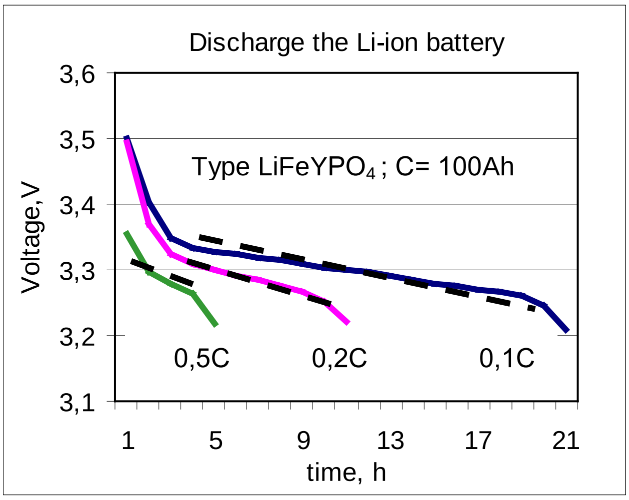
Table 1. *Parameters of lithium-ion cells*

Type Li-ion batteries / Parameters	$LiFeYPO_4$ 3,65V/100Ah
E_0(V)	3,659
R (W)	0.06
K (W from V/(Ah))	0.047
A (V)	0.33
B $(Ah)^{-1}$	26

5. Confirmation Model

5.1. Confirmation of steady state

The proposed model was tested at steady state to play "face area" in Figure 1. provided by the manufacturer of the "Typical discharge curves" (Fig. 2).



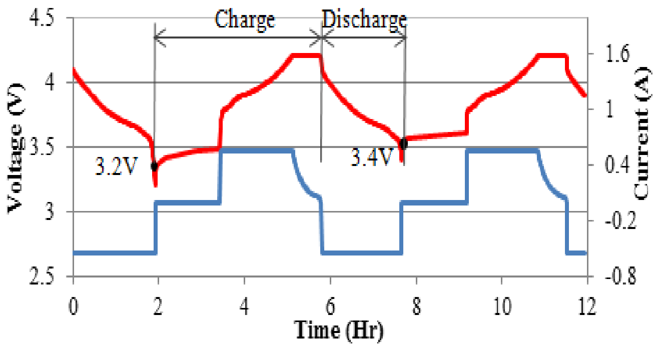


Figure 4. *Simulation of discharging the battery type LiFeYPO4 with discharge current of 0.5 C, 0.2 C and 0.1 C*

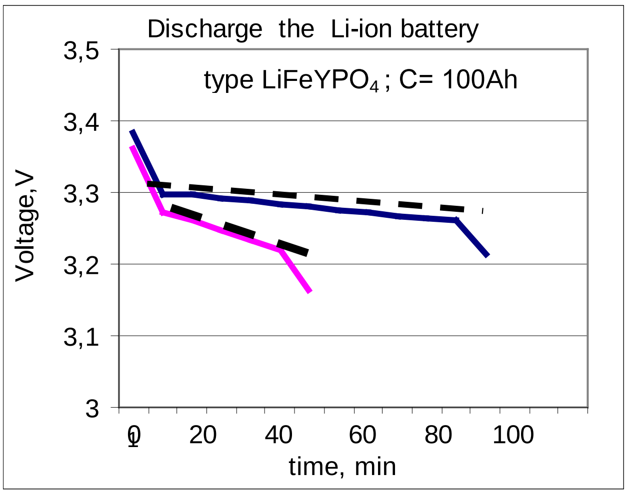


Fig.5. Simulation of discharging the battery type LiFeYPO4 from the data table of the discharging current 2C and C

Those contours do not represent the dynamic performance of the battery and discharging curves at constant current i of dilution capacity C. Experimental studies are carried out on cell battery pack in order to prove the validity of the model (Figs 4 and 5 and table 1) battery type LiFeYPO4. Fig. 4 shows the simulation results imposed into the the data from the experimental dilution curve. The first graph shows the voltage curve - time for 0,1 C discharge current, the second graph - current 0,2 C and the third - for 0,5 C discharge current. Fig. 5 shows the simulation results of (6) on the nominal area of the curve with 1C and 2C discharge current. With a black dotted line, the results of the simulation - it should be noted that the simulated sections coincide very well with the actual curves in almost 95% of the discharge, regardless of the amplitude of current discharge.
That is because this type of battery having a perfectly flat dilution curve in the nominal area. Cycles of charging and discharging of the battery should not leave the face area because the battery quickly damage from overcharging or over dilution.

5.2 Confirmation of the dynamic behavior

Fig. 6. Simulation of the dynamic behavior of the battery type LiFeYPO4

The dynamic behavior of a battery is tested by discharging and charging the cell at various levels. A fully charged cell battery 3,9 V to dilute / load to border tensions randomly to simulate real work . The experiments were made with a standard program LabVIEW2012 by a recording device and controlled charging current . Fig . 6 shows two cycles of discharge / charge the Li-Ion battery. Black lines are presented simulation results in formula (3) . The results show that the model is accurate to within 5 %.

6. Conclusion

This experimental validation of the model showed that, even if the model parameters are derived from the steady state of the discharge curve (current discharge is constant) taken from the manufacturer, it is possible to accurately simulate (error of 5%) the dynamic behavior of the voltage battery charge and discharge processes. The new simplified dynamic model of the battery type LiFeYPO4 allows adequate representation of the actual behavior of the battery based on the extraction of only two points of the discharge curve taken from the battery manufacturer. This model can be used in the development of algorithms and software for the evaluation of the state of charge (SOC) in the development of a system for battery management.

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