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Study on Battery Fast Charge and Discharge Model and its Parameters

Lun-qiong Chen[1,*], Lu-lu Du[2] and Bei Li[1]

[1]*School of Electronic Information and Electrical Engineering, Changzhou Institute of Technology, Changzhou, 213002, China*

[2]*School of Electronic Information, Wuwei Occupational College, Wuwei, 733000, China*

Abstract: In order to study the battery performance, putting forward a kind of two order RC equivalent circuit model, measuring static and transient data by HPPC test, fitting the relationship between open circuit voltage and state of charge (SOC), analyzing system identification of the dynamic parameters with MATLAB tool. Finally, by comparing the simulation data with the test data, the model is correct and feasible.

Keywords: Battery, dynamic model, open circuit voltage, state of charge (SOC), system identification.

1. INTRODUCTION

Because of environmental pollution needs, electric vehicles aroused more attention for energy saving and environmental protection. With the popularization of electric vehicles, the battery charging and discharging technology is especially important. The battery model is the key factor of charge and discharge of the battery. After defining model parameters through system identification, it can simulater charge-discharge and reflect the real performance status of battery, so as to study the battery capacity, circulation service life, self discharge rate and (SOC) etc [1, 2].

2. SELECTING MODEL

Modeling of the battery system mainly includes electrochemical model, artificial intelligence model and equivalent circuit model [3]. Establishment of model required high accuracy, little calculation work and achieving easily parameters. Therefore, an intuitive and accurate equivalent mathematical model was presented on the basis of the two order RC equivalent circuit model [4], as shown in Fig. (**1**).

In Fig. (**1**), left side of the circuit was on behalf of battery capacity, state of charge (SOC) and the operation time of battery; right side of it was transient state. The controlled voltage source was characterized with the nonlinear relationship between the SOC and the open circuit voltage. U_{soc} was the open circuit voltage. R_s was the ohmic resistance, standing for loss energy for long time, and could consider to infinity because of little impact by self discharge. C_{cap} was capacity of the battery. i_{cell} was charge or discharge current.

Based on circuit diagram, ordinary differential equation of the mathematical model were built:

$$\begin{cases} \begin{bmatrix} \dot{U}_{OC} \\ \dot{U}_{ts} \\ \dot{U}_{t1} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & -(R_{ts}C_{ts})^{-1} & 0 \\ 0 & 0 & -(R_{t1}C_{t1})^{-1} \end{bmatrix} \\ \begin{bmatrix} U_{OC} \\ U_{ts} \\ U_{t1} \end{bmatrix} + \begin{bmatrix} -C_{cap}^{-1} \\ -C_{ts}^{-1} \\ -C_{t1}^{-1} \end{bmatrix} i_{cell} U_{cell} = \begin{bmatrix} 1 & -1 & -1 \end{bmatrix} \\ \begin{bmatrix} U_{OC} \\ U_{ts} \\ U_{t1} \end{bmatrix} - R_s \times i_{cell} \end{cases} \tag{1}$$

In equation 1, state variables of this mathematical model were U_{oc} representing the open circuit voltage of the battery, U_{ts} representing voltage of R_{ts} and U_{t1} resprsenting voltage of R_{t1}, the battery charge or discharge current as input, the voltage as output.

3. THE EXPERIMENT

The experiments were processed on fixed temperature (25 ±2°C) for several days. Selecting three lead-acid batteries 6-MQ-7D (12V7AH), BTS-M 300A/12V and BTS-M30 A/48V testing device.

The Hybrid Pulse in Power Characterization (HPPC) of "Freedom CAD battery test manual" was used to complete charge and discharge test [5]. The HPPC can test dynamic power by pulse charge and discharge test system.

The discharge test system adopted in the experiment:

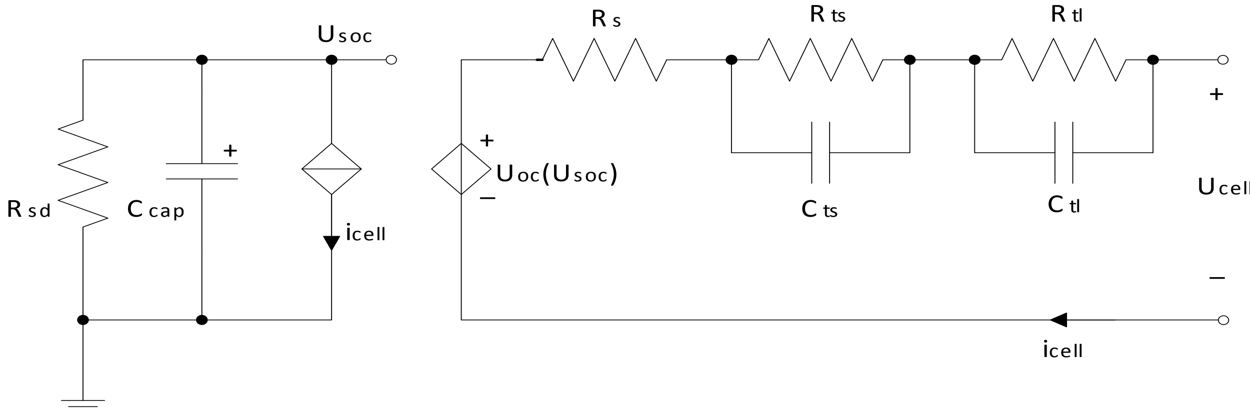

Fig. (1). Equivalent mathematical model of the battery.

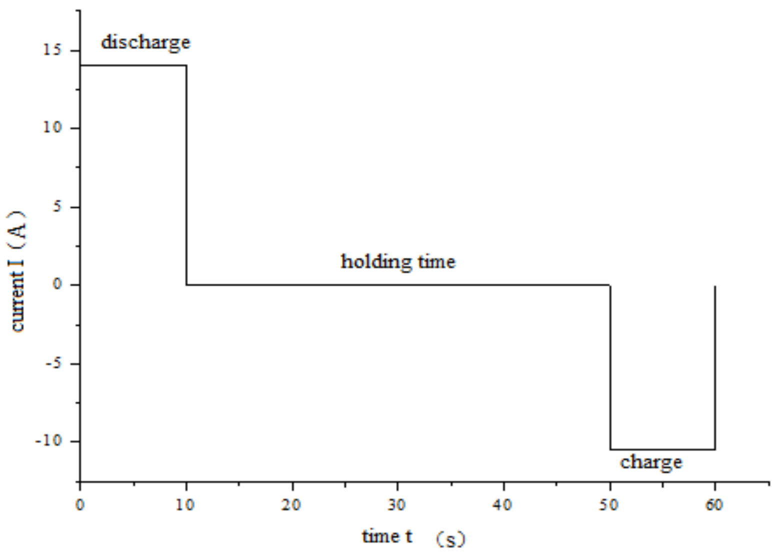

Fig. (2). The single cycle pulse discharge.

First, charging to full SOC using three stage constant current-constant voltage method and then holding for one hour at 25°C temperatures.

Second, discharging 10% (0.7Ah) of battery capacity by 1C(7A) and then holding for one hour, SOC was 0.9.

Third, discharging for 10 seconds by 2C(14A) and then holding for 40 seconds, charging for 10 seconds by 1.5C(10.5A) and then holding for 10 seconds. This process is shown in Fig. (**2**).

Fourth, repeating the steps second and third, each process released 10% battery capacity and respectively SOC was 0.8, 0.7,... 0.1 to the end of the test.

The HPPC charging process was similar to the discharging process. Beginning Charging process after discharging to the cut-off voltage and holding four one hour, then replace ‘discharging’ to ‘charging’ in the second. The following study would revolve mainly around the discharge process.

4. SYSTEM PARAMETERS IDENTIFICATION

Some unknown parameters of dynamic mathematical model in Fig. (**1**) were not certain because of SOC, the temperature of the environment and the cycle life of the battery. But considering the influence of SOC in a stable environment temperature and for several days.

4.1. The Relationship Between the Open Circuit Voltage and SOC

When there is no current through the battery, the potential difference between two poles is the open circuit voltage (OCV).

After the HPPC test, the battery was in holding state for one hour and the current was zero, then the polarization voltage would be gradually eliminated and the terminal voltage continued to rise. Fig. (**3**) showed the voltage curve after holding for one hour.

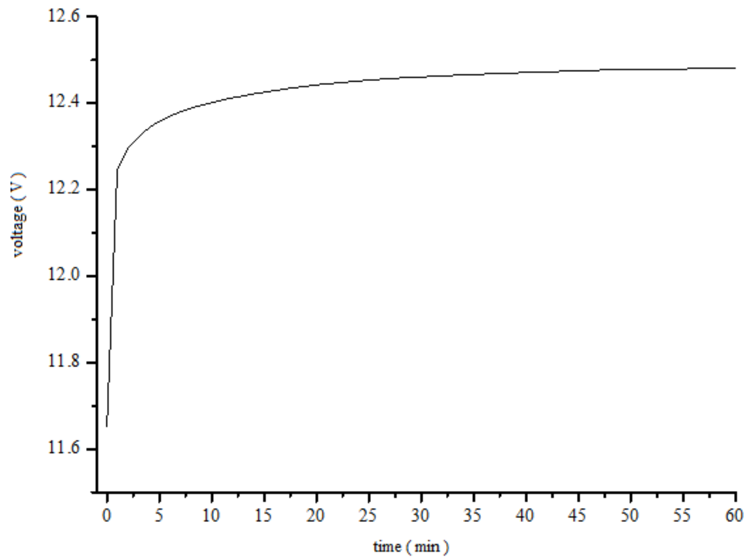

Fig. (3). The voltage curve after holding for one hour.

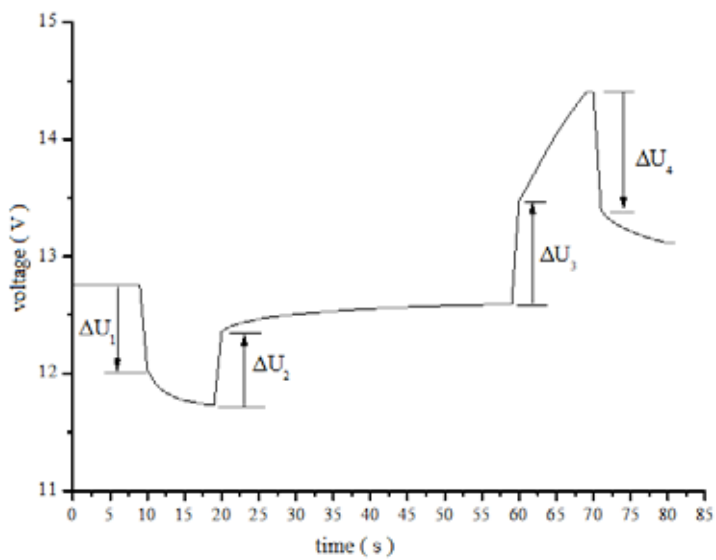

Fig. (4). Voltage response curve of HPPC.

In Fig. (**3**), after discharging, the terminal voltage rised rapidly to 80% of stable voltage in a short time, then the rate of rising decreased gradually and it kept stable at the end. So selecting the holding voltage for one hour as open circuit voltage.

The measured datas showed the curve between the open circuit voltage and SOC was relatively fixed. Averaging the measured datas of three battery and using the least squares fitting to derive equation 2:

$$U_{oc} = 0.684SOC^3 + 0.018SOC^2 + 0.519SOC + 11.825 \quad (2)$$

4.2. Identification of the Dynamic Parameters

In Fig. (**1**), resistance and capacitance were related to SOC. So, searching the response voltage curve according to SOC, then fitting the curve by fitting toolbox in the MATLAB software and combining with the model equation to get the unknown parameter values in the model.

As shown in Fig. (**4**), voltage response curve was under HPPC cycle pulse discharge charge when SOC was 0.8. There were holding state during 0 to 10 seconds, 20 to 60 seconds and 70 to 80 seconds. There were pulse current discharge during 10 to 20 seconds and pulse current charging. As an example to illustrate the identification process of all kinds of parameters [6].

The circuit in Fig. (**1**) showed capacitor terminal voltage wouldn't change at start moment during changing or discharging and current only flowed through resistance Rs. So in Fig. (**4**), the voltage ΔU_1 was caused by resistance

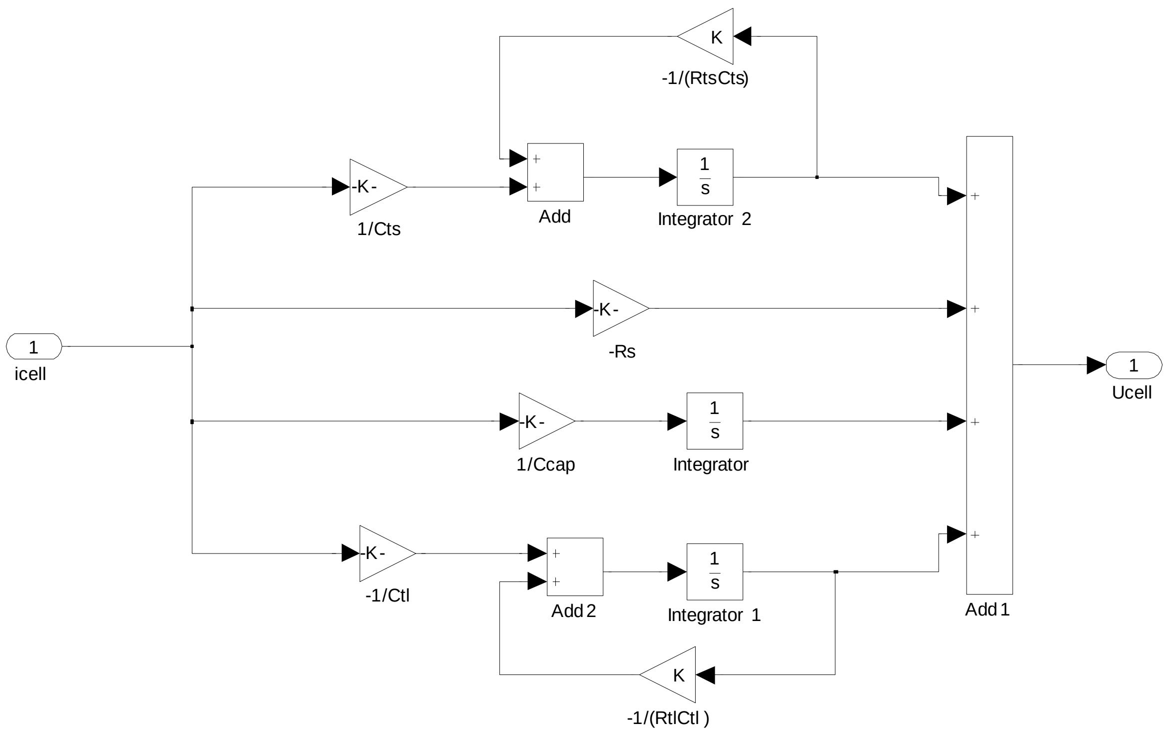

Fig. (5). Simulation circuit of the battery model.

Rs when pulse current began discharging at ten seconds. Similarly the voltage ΔU_2 was also caused by resistance Rs when pulse current discharge completed. Due to the impact of discharge process, the values of ΔU_1 and ΔU_2 were not same.

$$R_s = \frac{\Delta U_1 + \Delta U_2}{2I} \tag{3}$$

In Fig. (**4**), there was holding stage after pulse discharging for 20 to 60 seconds and the current in the circuit is zero. $R_{ts}C_{ts}$ and $R_{t1}C_{t1}$ circuits were zero input. We had

$$U_{cell1} = U_{oc} - U_{ts}(0)e^{-\frac{t}{\tau_{ts}}} - U_{t1}(0)e^{-\frac{t}{\tau_{t1}}} \tag{4}$$

In equation 4, $U_{ts}(0)$ and $U_{t1}(0)$ were voltages when discharging instantly. $\tau_{ts} = R_{ts}C_{ts}, \tau_{t1} = R_{t1}C_{t1}$.

The least Square Fit was applied to calibrate τ_{ts} and τ_{t1} using voltage curve in 20 to 60 seconds by MATLAB toolbox.

In Fig. (**4**), because of holding one hour before, $R_{ts}C_{ts}$ and $R_{t1}C_{t1}$ circuits were zero state response during pulse current discharge in 10 to 20 seconds. At this time,

$$U_{cell1} = U_{oc} - IR_s - IR_{ts}(1 - e^{-\frac{t}{\tau_{ts}}}) - IR_{t1}(1 - e^{-\frac{t}{\tau_{t1}}}) \tag{5}$$

The least Square Fit was applied to calibrate R_{ts} and R_{t1} using pulse current discharge curve by equation 5 and MATLAB toolbox. Then C_{ts} and C_{t1} could be obtained from $\tau_{ts} = R_{ts}C_{ts}$ and $\tau_{t1} = R_{t1}C_{t1}$.

Parameter identification of the battery model resulted as shown in Table **1**, the parameters $R_s, R_{ts}, C_{ts}, R_{t1}$ and C_{t1} depended upon SOC.

5. MODEL VERIFING

In order to verify the parameter identification, building the simulation model in Matlab/Simulink, As shown in Fig. (**5**).

According to the Simulink model in Fig. (**5**), using constant current discharge to simulate and compare with experimental datas. The curve of test discharge was the same as simulation curve under the same discharge rate of battery. This showed that mathematical model could be fitted well to the the actual operation of the battery and the identification method was feasible.

CONCLUSION

Putting forward more intuitive and accurate circuit model of battery and completing system parameters identification based on the mathematical model now. Through MATLAB

Table 1. The results of model parameters identification of discharge.

SOC	$U_{oc}(V)$	$R_s(m\Omega)$	$R_{ts}(m\Omega)$	$C_{ts}(F)$	$R_{t1}(m\Omega)$	$C_{t1}(F)$
0.9	12.756	48.821	35.71	121.591	20.03	5018.123
0.8	12.591	51.679	29.34	140.145	32.32	3557.617
0.7	12.453	57.143	29	125.895	49.83	2135.827
0.6	12.319	65.5	32	114.385	53.25	1923.325
0.5	12.186	78.286	35.73	102.707	53.4	1975.587
0.4	12.053	90.714	25.86	140.566	107.2	835.874
0.3	11.982	101.5	17.69	204.89	177.3	463.829
0.2	11.934	111.929	11.35	330.231	266.6	316.002
0.1	11.898	121.964	2.805	1199.55	333.4	224.506

simulation, comparing the simulation datas and the experimental datas and verifying the correctness of the model to be applied to estimate SOC.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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