Modeling of 36V Lead Acid Battery for the 42V Automotive System Simulation

H.S. Yun, J.H. Lee, B.H. Cho
School of Electrical Engineering
Seoul National University
Seoul, Korea
Email: hsyun1@snu.ac.kr

***Abstract*—Modeling of the battery for 42V PowerNet system is presented. For the Battery Management System (BMS) algorithm in a Mild hybrid vehicle, accuracy in the battery model is crucial. The battery model is needed for the BMS algorithm as well as for the system computer simulation for the energy management. The battery model was composed of impedance elements and each element of the model is estimated by the analysis of the terminal voltage. The result of the model is confirmed by experimental data.**

I. INTRODUCTION

Due to the increase of electric power payloads in today's automobile, a 42V power system has been considered and is being developed to replace the existing 14V power system. It significantly improves the problems associated with the alternator and the wiring harness which are caused by an increase in the current level. The currently developing 42V PowerNet system employs a mild-hybrid concept using the ISG (Integrated Starter and Generator). It features the idle stop/go and recovering the regenerating energy during braking to improve the fuel economy and to reduce the emission. For a mild hybrid system, the 36V Battery Management System (BMS) becomes crucial for the system's operational efficiency and reliability. An accurate battery model is very important not only for the BMS algorithm but also for the development of the system control logic that must be aided by the system simulation. The battery was previously modeled with impedance parameters using impedance spectroscopy equipment that depends on the SOC (State of Charge), the temperature and the charging and discharging current [1][2]. This approach requires long time for the measurement process.

In this paper, parameter estimation is done by the analysis of the terminal voltage. This approach is quite suitable for modeling the battery for the system simulation, and the accuracy is verified by comparing the experiment data with the simulation data.

II. BATTERY MODEL STRUCTURE

The battery charges and discharges by the chemical reactions between the electrolyte and the active materials. The OCV state occurs when the concentration of electrolyte becomes equilibrium. In the OCV state, an overpotential is observed when the battery charges and discharges. The overpotential can be modeled by the impedance composed of a series equivalent resistance, and impedance characteristics of a double layer and a diffusion layer [3]. The series equivalent resistance represents the resistance of the electrode and the electrolyte. The double layer is composed of a double layer capacitance and a charge transfer resistance. The double layer capacitance is the capacitance caused by a charge distribution between the electrode and the electrolyte and charge transfer resistance is caused by the transferring charge resistance between the electrode and the electrolyte. The diffusion layer is caused by the grade of concentration of the electrolyte near the electrode. This effective impedance is also called the Warburg impedance. The diffusion layer can be represented by several R-C parallel circuits. Fig.1 shows an equivalent battery model which consists of the OCV and the overpotential impedance as described above.

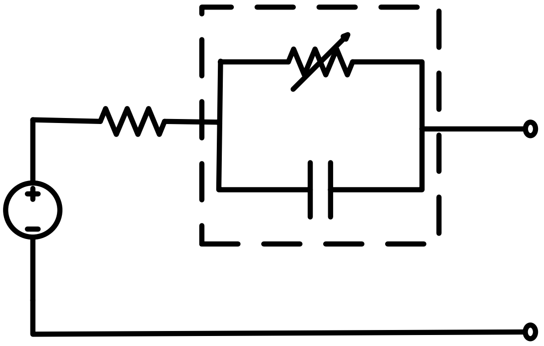

Fig. 1. Battery impedance model

The voltage source, V_{ocv} represents the OCV and R_s represents the series equivalent resistance. The overpotential impedance (Z) is characterized by the double layer and the diffusion layer. The overpotential impedance can be configured by two or three R-C parallel circuits. In this paper, the overpotential impedance is configured by one R-C parallel circuit to reduce the number of parameters. This approach is verified by the comparison of the battery voltages through simulation and experiment each other.

III. BATTERY MODEL PARAMETERS ESTIMATION

A. *OCV (Open Circuit Voltage)*

The OCV can be estimated by the Nerst equation [4] by the chemical approach. But in this paper, all parameters of the battery want to be estimated with the analysis of the battery voltage. Therefore, the OCV is estimated by the voltage of the OCV state, which occurs when the concentration of electrolyte is at equilibrium. The rest time in which the battery is at equilibrium can be estimated from the measurement as shown in Fig 2.

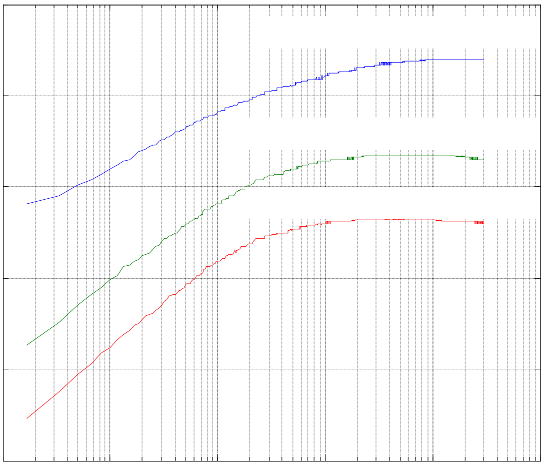

Fig. 2. OCV rest time test

The rest time measurement is to be done at different SOC and discharge current levels. First, the battery becomes fully charged and then discharges at a rate of 10A up to SOC 80%. The voltage is measured after the open circuit at SOC 80%. After more than 2 hours, the battery discharges at a rate of 100A up to SOC 60% and then the voltage is measured after the open circuit is at SOC 60%. Also this test is done at a rate of 200A up to SOC 40%.

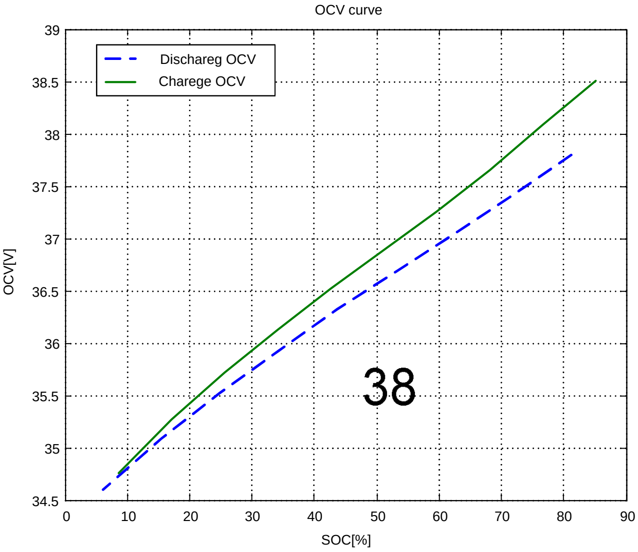

Fig. 3. OCV curve

37.5

From the test results, it can be seen that the voltage approaches steady state after 2 hours from the open circuit. Therefore, the rest time is estimated to be 2 hours. The OCV test has to be done at different SOC since the OCV is depends on the SOC. As shown in Fig. 3 the OCV test is done at different SOC levels. The discharge OCV curve tests at a rate of 4A discharge up to SOC levels wanted to measure OCV and then the voltage is measured after 2 hours from the open circuit. This test is also done at a rate of 4A charge and at different SOC levels for an estimation of the charge OCV curve. Due to the difference in the charge and discharge OCV curve, the state has to be defined whether the state is charging or discharging before the open circuit. To solve this problem, the OCV curve is estimated to average discharge and charge OCV curve.

B. *R_s resistance*

R_s is the series equivalent resistance. Therefore, R_s can be estimated with the initial voltage drop when the battery discharges. Fig. 4 shows the measured results at different currents when the battery discharges. The measured discharge currents are 4, 10, 20 and 40 amperes. The Y axis represents the initial voltage drop at different discharge currents, and the X axis represents discharge currents. Therefore, the slope of Fig. 4 is equal to R_s. The value of the estimated R_s is 19.8m**Ω**.

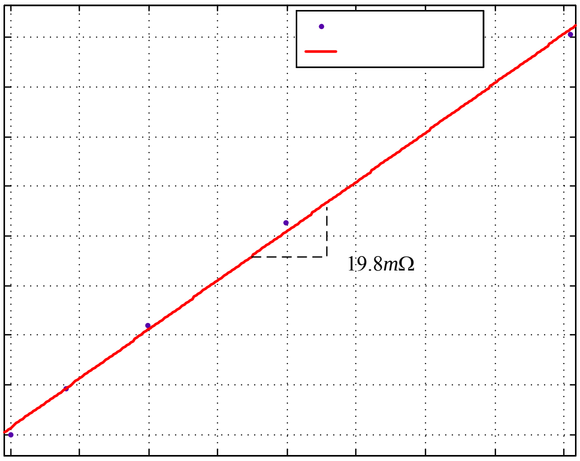

Fig. 4. R_s resistance test

C. *Overpotential impedance*

The overpotential impedance is modeled by one R-C parallel circuit. To estimate overpotential parameters, the constant current charge measurement is done such as in Fig. 5. As shown in Fig. 5, the OCV curve and charge data curves have the same slope from SOC of 10% to 70%. This section is that the capacitor of the overpotential impedance is fully charged and then the overpotential impedance shows the only resistive component.

10A dis

100A dis

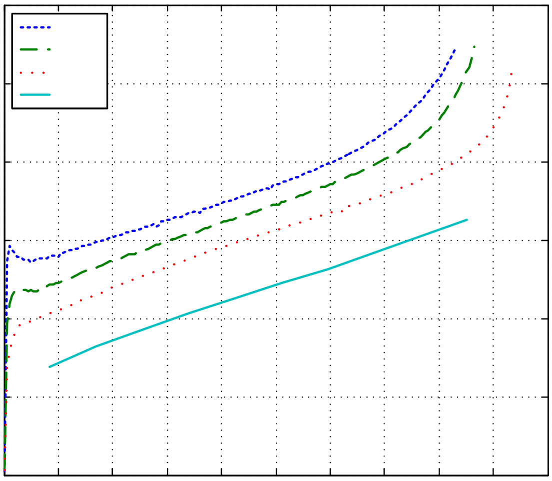

Fig. 5. Constant current charge data and OCV

The difference between the OCV curve and the charge data curve is the overpotential. In the section, SOC of 10% to 70%, the constant overpotential can be taken at each current. The overpotential will increase above SOC 70% due to the diffusion effect. The 42V system is operated primarily in the SOC 60% to 80% range. If it is assumed that the battery has a constant overpotential at SOC 60 to 80%, the overpotential impedance is only defined by one R-C parallel circuit in Fig. 1. Therefore, overpotential has to subtract the voltage of R_S. With the constant current discharge measurement at different currents, we can also estimate the overpotential at different discharge currents as in Table. 1.

Current [A]	-40	-20	-10	-4	4	10	20
Over potential [V]	-1.35	-1.23	-0.93	-0.75	1.38	1.88	2.2

(Negative value represents discharge)

Table. 1. Current vs. overpotential

Table.1 shows the overpotential data at different currents. The relation between overpotential and current can be estimated by the Butler-Volmer equation (1). The parameters of the Butler-Volmer equation can be obtained from the data in Table.1. The current and overpotential data are fitted by the Butler-Volmer equation as shown in Fig. 6. This approach can reduce the test time since the extra data can be estimated by using this equation without having to test. The Butler-Volmer equation explains the relation between current and overpotential, and therefore the resistance parameter in the R-C parallel circuit can be estimated using this equation.

$$i = i_0[e^{\frac{-\alpha\eta F}{RT}} - e^{(1-\alpha)\frac{\eta F}{RT}}] \qquad (1)$$

Where,
i : current, i_o : exchange current, α : transfer coefficency
η : overpotential, R : gas constant, T : absolute temperature
F : faraday constant

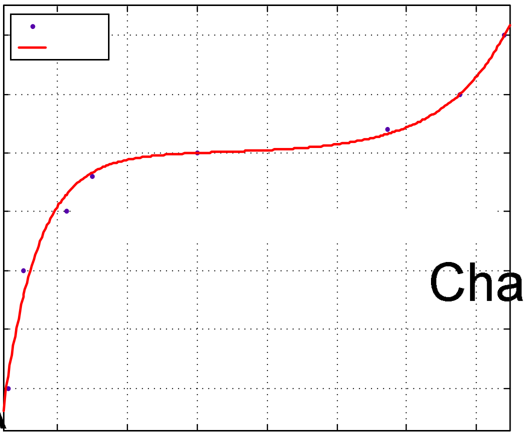

Fig. 6. Overpotential and current fitting

Fig. 7 presents the simulink model of the overpotential impedance. The overpotential impedance composed of R-C parallel circuit is configured by the Butler-Volmer equation and a capacitance. The capacitance is estimated by the simulation result continually to fit the real battery voltage. The tested capacitance value is 100 farad.

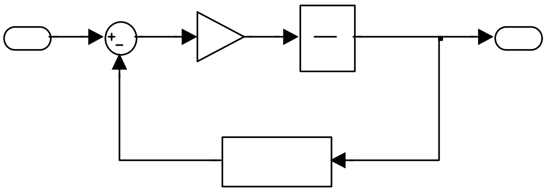

Fig. 7. Simulink model for overpotential impedance

IV. BATTERY MODEL VERIFICATION

To verify the battery model, the test profile and the data of the battery voltage are needed. The test profile is the current profile in FTP mode. The battery model is tested by current profile, and the simulated voltage data of model is compares the measured voltage data of battery such as Fig. 8. The error is measured under 1V in overall test. In this test, it is verified that the model is suitable for the 42V system simulation.

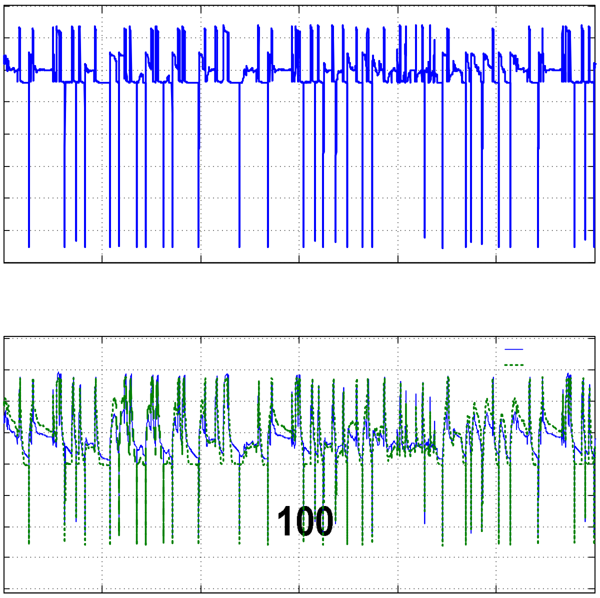

Fig. 8. The battery model verification with FTP mode

V. CONCLUSION

The battery model parameters are estimated by the analysis of the measured voltage data. The overpotential impedance is modeled by one R-C parallel circuit to reduce the number of parameters, and the overpotential impedance is estimated by the Butler-Volmer equation and simulation test. Using the Butler-Volmer equation can reduce the test time by estimating the extra data without having to test. This modeling approach is confirmed by testing with the current profile in FTP mode. In this paper, the accuracy of the model of the overpotential is verified under the assumption that the battery operates primarily in the 60% to 80% SOC range.

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