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State-of-Charge Observer using Generic lead-acid Battery Model

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***Abstract*— An accurate State of Charge (SOC) observer for rechargeable batteries plays a vital role in any kind of Battery Management Systems (BMS). It is important to enhance the lifetime of a battery and to provide an accurate estimation of available runtime of the battery to the user, especially in electric derive vehicles. This research work aims to estimate the SOC of a 12V 70Ah lead-acid battery using a generic lead acid battery model. The SOC observer based on generic model of lead acid battery is designed in SIMULINK Graphical User Interface (GUI) of MATLAB R2012a. In this technique, a lead acid battery is model using charging/discharging pulse test loads of 12A (slow discharge) and 150A (real cranking) to estimate their effects on battery current, battery voltage and SOC profile of the lead acid battery. The presented SOC observer provides a high level of accuracy in SOC estimation. The estimated SOC can be estimated more accurately by considering the effects of temperature and varying internal resistance of the battery. The SOC estimation results are computed under the pulsed/constant load test of 12A and 150A discharging current. The developed SOC observer is potentially extensible to other types of rechargeable batteries.**

***Index Terms*—SOC, BMS, MATLAB, Simulink.**

1) Introduction

As the automotive industry moves through the second decade of the 21st century, especially transportation industries have now convinced themselves to electrify their vehicles and to produce electric derive vehicles such as hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV) and electric vehicle (EV). The driving force towards the electrification of vehicles includes: Government incentives for buying electric derive vehicles, the economic & political problems related to oil dependency, the effect of oil prices on consumer's car buying habits, carbon dioxide emission & pollution awareness, and the effect of current & upcoming worldwide emissions regulations. Unlike traditional vehicles, electric derive vehicles require a different value chain and different processes to support them. Moreover, consumer perceptions of the practicality, functionality and the potential advantages of electric derive vehicles remain largely mixed in such areas as cost, savings, convenience, travel range and charging infrastructure.

In recent years, the rechargeable batteries have proven themselves as the primary source of clean energy for various applications such as transportation, grid storage & mobile systems. The evolution of electricity storage technologies ensures the appearance of more efficient batteries and the launch of electric cars with better performance comparable to that of fossil fuel cars. Due to the relative maturity of the batteries, much effort by academia and industries are devoted for making batteries reliable and affordable for the electrification of vehicles. In case of transportation, the detection of in-time battery failures and accurate estimation of SOC of the rechargeable battery are still a challenge for researchers to provide safety to users and vehicles too. Battery Monitoring means keeping a check on the key operational parameters during charging and discharging such as voltage, current, battery internal resistance, ambient temperature and charging/discharging cycles [1]. Obviously, a battery's stored energy & its performance are difficult to infer from electrically measured parameters of a battery. Therefore, the researchers are still heavily involved in the development of accurate SOC observers considering maximum battery parameters (voltage, current, internal resistance, temperature, consumption time, electrolyte reactions, corrosion, effect of aging on the grid/electrodes and charging /discharging cycles) affecting the performance of a rechargeable battery. In addition to the development of new batteries with better capacity and power capability, BMS - an independent system addressing the battery monitoring is also required to better utilize the capacity of the batteries and to provide diagnostic information for the benefit of the driver. An efficient BMS ensures the optimum use of the battery and monitors accurately the SOC of a battery.

The run-time information of battery's internal states - SOC, is the major interest for the development of efficient BMS. The SOC refers to the available charge inside the battery. This research paper aims to propose a generic lead acid battery model for on-line estimation of SOC profile of a lead acid battery for its automotive application.

2) Lead Acid Battery System Characteristics

In this research paper, the 12V/70Ah Exide Lead-Acid battery used in different automotive applications like a car has been selected as case study in development of a SOC observer. A generic lead-acid battery model has been designed in MATLAB/Simulink to analyze the charging/discharging characteristics of 12volts, 70Ah lead-acid battery system. These model characteristics have been used for estimating the SOC profile of lead acid battery. The two major ways of lead acid battery functioning in automotive application are [2]:

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a) Slow Discharge**:** When the alternator voltage is less than battery voltage (engine is not running), the direction of the current flow is through battery to load otherwise the current flows from alternator to load and to battery (when vehicle is running). Slow discharge of 12A constant current which is a lab simulation of the DC electric load after a real time measurement with the DC load in the car.

b) Engine Cranking**:** When engine has to startup, alternator is not running. Engine requires an initial high torque (about100 rev/min) in turn an initial high current is needed. The ability to reach to this high torque again depends on a number of factors, among which battery characteristics play an important role along with the engine cranking resistance (torque required at starting limit temperature), and the voltage drop between the battery and the starter. Thus battery should be able to supply heavy current (100A to 200A) for very short duration so that the alternator can take over the function. Engine cranking current of 150A for 5sec followed by a rest of 15sec simulates the engine cranking current.

The lead-acid battery model characteristics for two constant discharge currents 12A (SD) and 150A (RC) are shown in Figure 1.

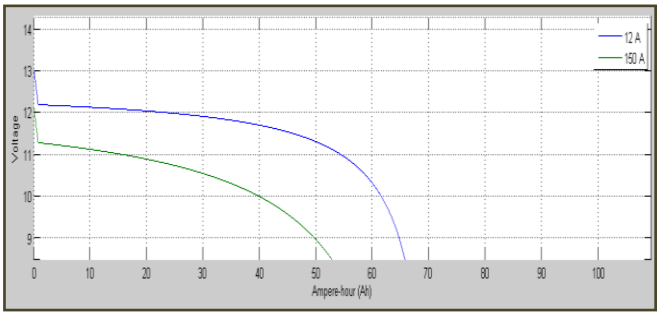

Figure 1: Voltage versus Ampere hour for different currents

The voltage of lead-acid battery decreases nonlinearly with SOC as the battery is being discharged. The voltage of lead-acid battery decreases rapidly at the beginning of discharge and slowly decreases linearly as it is discharged roughly beyond 80% SOC (normal SOC range of lead acid battery is 20%-80%). The lead-acid battery can easily be recharged, if the discharge current is given negative in generic lead-acid battery model. The relationship between voltage and charge in Ampere-hours removed from the battery depends upon the current with which it is charged, as well as whether it is charged or discharged. Hence, neglecting temperature in generic lead-acid battery model, it is possible to assume that the SOC of a battery varies with change in voltage and charging or discharging current.

3) STATE-OF-CHARGE OBSERVER

A large number of battery monitoring techniques had been explored in literature by many authors [3-16] and tried out to estimate the SOC of a battery. No foolproof indicators/tools for knowing and predicting the battery life have been evolved or devised so far. However, comprehensive controllers and instruments are now able to find failing cells without the battery test, while the battery system is online. But still, the battery SOC is not directly measurable and need to be inferred from other measurements. Thus, the development of a SOC observer which can infer the SOC based on online parameters is essential. In this work, a generic lead acid model is used to be incorporated in the development of the SOC observer for accurate SOC estimation of lead acid battery. In this SOC observer, the generic lead acid battery model is charged/discharged under different load conditions and corresponding changes in SOC profile are estimated.

The structure of SOC observer using generic lead acid battery model developed in MATLAB/Simulink is shown in Figure 2. The Simulink model of the SOC observer is facilitated with the following blocks:-

- Controlled Current Source
- Generic Battery Model
- Powergui
- Bus Selector
- SOC Display Module

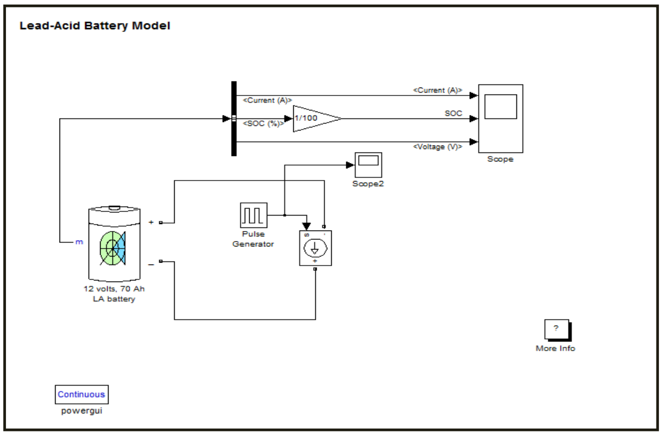

Figure 2: Simulink design of SOC Observer

The detailed descriptions of each block of proposed BMS are given below:-

a) Controlled current source: The Controlled Current Source block converts the Simulink input signal into an equivalent current source. The generated current is driven by the input signal of the block. The positive current direction is as shown by the arrow in the block icon. The Controlled Current Source block is initialized with a specific constant or pulsed discharging current of 12A and 150A for slow discharge (SD) and real cranking (RC) respectively.

b) Generic Battery Model: The Battery block implements a generic dynamic model parameterized to represent most popular types of rechargeable batteries. Here, it is configured as 12V, 70Ah lead acid battery model. Its equivalent model is implemented with the following equations:

Discharge model ($i^* > 0$)

$$f_1(it,i^*,i,Exp) = E_0 - K\cdot\frac{Q}{Q-it}\cdot i^* - K\cdot\frac{Q}{Q-it}\cdot it + \text{Laplace}^{-1}\left(\frac{Exp(s)}{Sel(s)}\cdot 0\right)$$

Charge Model ($i^* < 0$)

$$f_2(it,i^*,i,Exp) = E_0 - K\cdot\frac{Q}{it+0.1\cdot Q}\cdot i^* - K\cdot\frac{Q}{Q-it}\cdot it + \text{Laplace}^{-1}\left(\frac{Exp(s)}{Sel(s)}\cdot\frac{1}{s}\right)$$

Where,

E_0 = Constant voltage (V)
Exp(s) = Exponential zone dynamics (V)
Sel(s) = Represents the battery mode. Sel(s) = 0 during battery discharge, Sel(s) = 1 during battery charging.
K = Polarization constant (Ah−1) or Polarization resistance (Ohms)
i* = Low frequency current dynamics (A)
i = Battery current (A)
it = Extracted capacity (Ah)
Q = Maximum battery capacity (Ah)
A = Exponential voltage (V)
B = Exponential capacity (Ah)−1

The parameters of the equivalent circuit can be modified to represent a particular battery type, based on its discharge characteristics.

c) Powergui: The Powergui block allows the model to choose one of the following methods to solve your circuit:

- Continuous, which uses a variable step solver from Simulink
- Ideal Switching continuous
- Discretization of the electrical system for a solution at fixed time steps
- Phasor solution

The Powergui block is necessary for simulation of any Simulink model containing SimPowerSystems blocks. It is used to store the equivalent Simulink circuit that represents the state-space equations of the model.

d) Bus Selector: The Bus Selector block outputs a specified subset of the elements of the bus at its input. The block can output the specified elements as separate signals or as a new bus. In presented SOC observer, it is used to select battery current, voltage and SOC as outputs.

e) SOC Display Module: The estimated SOC profile of lead acid battery is displayed using the scope block of SOC observer as shown in figure 2.

4) SIMULATION RESULTS & DISCUSSION

The SOC observer presented in this research paper is simulated and tested using 12V 70Ah lead-acid battery which is preferably used for non-electric automotive. In this automobile, the battery supports engine cranking to start the vehicle and slow discharge to support electric load. The SOC profile of 100% charged lead acid battery estimated by the presented SOC observer under the constant discharge load of 150A for real cranking and 12A for slow discharge is shown in figure 3 (a) and (b) respectively.

The presented SOC observer may be extended to be used for the electric derive vehicles where the discharge load is dynamic. The SOC profile of 100% charged lead acid battery estimated by the presented SOC observer under the pulsed discharge load of 150A for real cranking and 12A for slow discharge is shown in figure 4 (a) and (b) respectively.

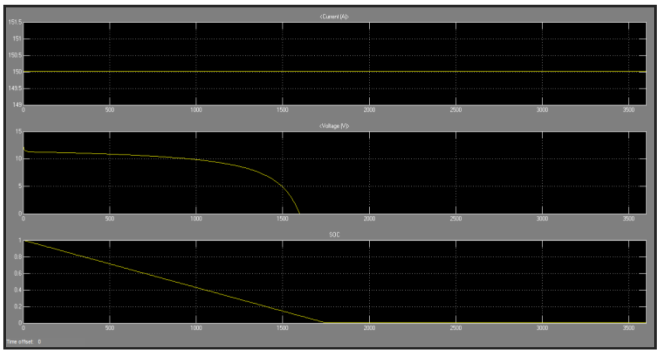

Figure 3 (a): Current, Voltage and SOC profile for the constant test load 150A (RC)

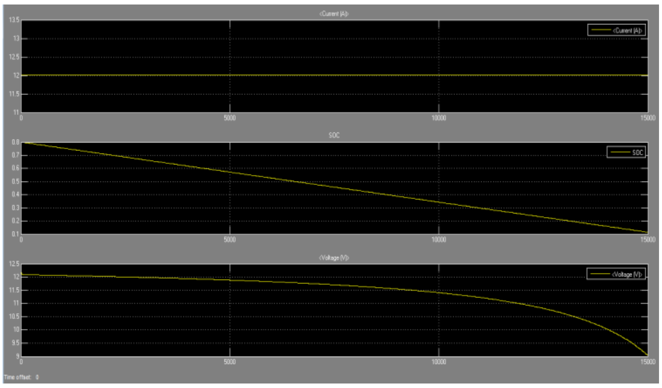

Figure 3 (b): Current, Voltage and SOC profile for the constant test load 12A (SD)

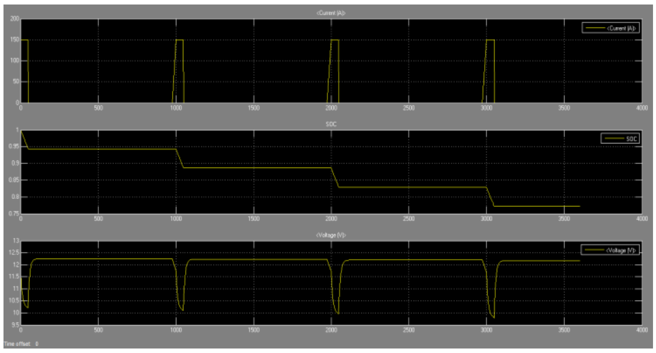

Figure 4 (a): Current, Voltage and SOC profile for the pulsed test load 150A (RC)

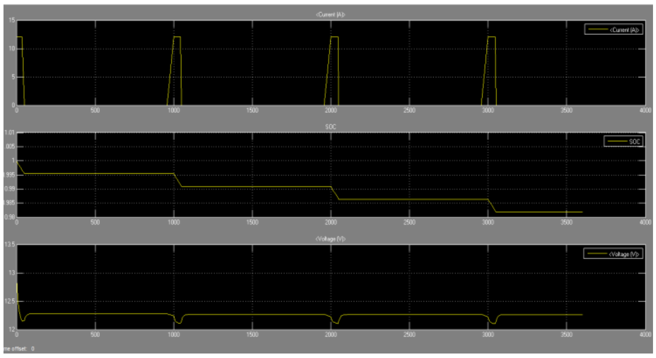

Figure 4 (b): Current, Voltage and SOC profile for the pulsed test load 12A (SD)

The figures 4 and 5 are drawn by neglecting the temperature effects and keeping the internal resistance constant i.e. 0.0017143 ohms. Figure 4 (a) shows that full charged battery linearly lasts in 1750s when continuously discharged at rate of 150A. Figure 4 (b) shows that full charged battery linearly lasts in 15000s when continuously discharged at rate of 12A. In Figures 5 (a) and (b), the pulsed discharging currents are considered to analyze the characteristics of the SOC observer, where SOC decreases linearly for 12A & 150A discharge currents till the zero value of test loads and they remain constant when discharge currents become zero.

5) CONCLUSIONS

The estimation of SOC is very important to find the amount of charge left in the rechargeable batteries for their automotive applications, especially in electric derive vehicles and power grids. The SOC observer provides an indication of the amount of time left for the battery to be used or the amount of time left for charging to complete. However, since a battery's characteristics are highly nonlinear, it is important to setup a robust model to map the nonlinearities for the purpose of accurate estimation. This research work presents a SOC observer using generic lead acid battery model. Although the SOC estimation results confirm the robustness of the presented SOC observer, but still it shows that the consideration of effect of temperature and varying values of internal resistance of a battery must be considered for accurate estimation of SOC. This research may be extended, in future to cover other battery chemistries, such as Lithium-ion batteries, NiCd and NiMH batteries.

REFERENCES

[1] Vinal, G, W, "*Storage Battery*", pp.130-336, IVth edition, John Wiley and Sons, New York, 1924-1955.
[2] T. R. Crompton, "*Battery"*, Hard Cover: Butter work, ed. March (1990).
[3] Dallas Semiconductors, "Inaccuracies of estimating remaining cell capacity with voltage measurements alone", Application Note 121, (2000).
[4] E.J. Dowgiallo Jr., "Method for determining battery state of charge by measuring A.C. electrical phase angle change", US Patent 3,984,762, filed 7 March (1975).
[5] E. Zaugg, "Process and apparatus for determining the state of charge of a battery", US Patent 4,433,295, filed 8 January (1982).
[6] K. Muramatsu, "Battery condition monitor and monitoring method", US Patent 4,678,998, filed 9 December (1985).
[7] S. Piller,M. Perrin, and A. Jossen, "Method for state of charge determination and their applications," *J. Power Sources*, vol. 96, no. 1, pp. 113–120, 2001.
[8] Martin Coleman, Chi Kwan Lee, Chunbo Zhu, and William Gerard Hurley, Fellow, IEEE "State-of-Charge Determination from EMF Voltage Estimation: Using Impedance, Terminal Voltage, and Current for Lead-Acid and Lithium-Ion Batteries" 2007 IEEE.
[9] Philips Internal Communications, (2005).
[10] J. Garche, A. Jossen, "Battery management systems (BMS) for increasing battery life time", Telecommunications Energy Special, 3, 81–84 (2000).
[11] G. Plett, "Extended Kalman filtering for battery management systems of LiPBbased HEV battery packs: Part 1. Background", J. Power Sources, 134, 252–261 (2004).
[12] G. Plett, "Extended Kalman filtering for battery management systems of LiPBbased HEV battery packs: Part 2", Modeling and identification, J. Power Sources, 134, 262–276 (2004).
[13] G. Plett, "Extended Kalman filtering for battery management systems of LiPBbased HEV battery packs: Part 3", State and parameter estimation, J. Power Sources, 134, 277–292 (2004).
[14] O. Gerard, J.N. Patillon, F. d'Alche-Buc, "Discharge prediction of rechargeable batteries with Neural Networks", Laboratories d'Electronique Philips S.A.S. France.
[15] A.J. Salkind, C. Fennie, P. Singh, T. Atwater, D.E. Reisner, "Determination of state-of-charge and state-of-health of batteries by fuzzy logic methodology", J. Power Sources, 80, 293–300 (1999).
[16] M. Schollmann, M. Rosenmayr, and J. Olk, "Battery monitoring with the intelligent battery sensor during service, standby and production," SAE 2005-01-0561.

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