Bulletin of Electrochemistry 15 (9-10) September-October 1999, pp 368-371 0256-1654/99/$ 3-50

COMPUTER CONTROLLED SOC MONITOR FOR LEAD ACID BATTERIES

S VINCENT, Y MAHADEVA IYER and M DEVASAHAYAM

Central Electrochemical Research Institute, Karaikudi 630 006. INDIA

A computer controlled state of charge (SOC) monitor for lead acid (LA) batteries was developed. This instrument has been developed with a powerful software and hardware package to monitor the SOC of the battery through measuring its internal resistance by means of step current pulse technique. Experimental results along with system descriptions and schematic diagrams are presented in this paper.

Key Words: Step current pulse technique, internal resistance, ADC and DAC.

INTRODUCTION

Lead acid batteries are used as power sources in battery powered vehicles, air crafts and submarines etc. In telecommunication systems, computer centres and emergency wards of hospitals the UPS (uninterrupted power supplies) systems are backed up by batteries. To ensure reliable and efficient service we are greatly in need of battery health monitoring systems to alert the operators to maintain the batteries against abuses like over charging, under charging and reverse charging etc., so that the battery systems function as more efficient and reliable power sources. To meet this thrusting need of battery health monitoring system, a computer controlled state of charge (SOC) monitoring instrument has been developed.

SOC of a battery indicates the ratio of the residual capacity at a given instant to the maximum available capacity. A thorough knowledge of SOC can be extremely useful in predicting the residual capacity, and more significantly it can help to increase the cycle life by proper control of the degree of charge and the depth of discharge. In the case of maintenance free lead acid batteries, this technique is of marked importance for evaluating the variations in SOC due to progressive self-discharge during the operation. Classical and evolved group of tests are available to assess battery's SOC. But most of these test methods have serious drawbacks like long time requirement for SOC measurement, non linearity of the measured parameter being correlated to SOC, dependency of measuring parameters on either the type of batteries or on the process of charge/discharge conditions etc. Whereas a practically useful SOC measuring technique must be fast, simple to use and should not cause any change in the fundamental parameters of the electrochemical system of the battery and it should be applicable to all types of the lead acid battery systems. Of the classical SOC measuring methods, the internal resistance test method, is found to be more practical and simple technique which provides instantaneous display of SOC, after measuring out its internal resistance, R_i, by step-pulse current charging and correlating it to the charge level of the battery.

Characterization of battery operation depends on impedance parameters such as charge-transfer resistance and double layer capacitance, which are closely associated with the internal resistance (R_i) of the battery. The internal resistance, R_i, is one of the most important cell parametres. R_i is a strong indicator of cell efficiency, state of charge and capacity. The internal resistance is often quoted as a characteristic parameter. However, the meaning of the term 'internal resistance' has to be considered with some caution in a battery, because it is not a simple ohmic resistance, causing certain voltage drop in response to current flow.

* The internal resistance of a battery system is not an ohmic resistance but it depends on the current.
* It is different for discharging and charging reactions, because of the unsymmetrical property seen in the case of current/voltage characteristic curves obtained during the forward and reverse reactions.
* The internal resistance is increased at the reduced temperature because of the reduced conductivity, and due to the retarded kinetic parameters, such as exchange current density, diffusion coefficient or transport numbers.
* R_i depends on the state of charge of the battery.

Hence, development of an instrument to monitor SOC, by internal resistance measuring technique will find a greater

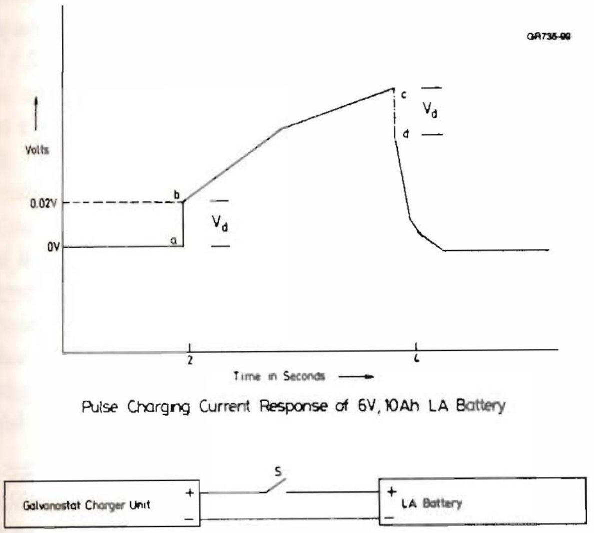

Fig.1. Pulse charging current response of 6V, 10Ah LA battery.

potential use in battery industries, battery operated vehicles, equipments and their related R&D laboratories.

EXPERIMENTAL

The state-of-charge measuring method

The internal resistance test method which by direct current interrupt or step-pulse current technique is adopted to determine the state of charge of the battery, has been incorporated in the developed computer controlled charge level monitor. Unlike other SOC monitoring techniques, this current interrupt method is a simple technique and it is able to give out SOC measurement in a very short time, without perturbing the electrochemical system of the battery. This technique involves two phases of operation; first in measuring the value of internal resistance, R_i, from the transient response of the battery system to the sudden interruption of the charging circuit and the second in obtaining the SOC value from the calibrated plot of SOC Vs R_i. The transient response of the battery system reveals both the resistive and non-resistive components of the battery's electrochemical system. The transient response of a lead-acid battery when the step-pulse current was applied was as shown in fig 1. observed in a storage oscilloscope.

The trace of the battery voltage in response to the step pulse charging current is as shown in Fig.1. The amplitude of the galvanostatic charging pulse current is one in twenty parts of the total battery capacity (C) and the pulse width chosen is 5 seconds. The portion marked as a-b in the trace corresponds to the voltage drop, V_d, voltage drop across the internal resistance of the battery, due to sudden rise in current at the leading edge of the pulse. The next portion b-c of the trace signifies battery's electrochemical response due to the reactive components of the system like double-layer capacitance etc., which is not of use for our present study. The portion c-d of the transient response having equal amplitude with that of the portion a-b, results from the same voltage drop, V_d, across the battery resistance, R_i, due to sudden decrease in charging current at the trailing edge of the pulse.

The internal resistance, R_i, is calculated as:

$$R_i = \frac{V_d}{I_c}$$

where I_c, the charging current = (1/20)*C

where C denotes total battery capacity.

With suitable hardware incorporated in the PC based instrumentation, this value of V_d obtained from the transient response is data acquired. From the value of V_d, and the applied charging current I_c, R_i is calculated as shown above, and saved in memory against several values of SOC of the battery during several operating cycles of the battery to have a calibration plot of SOC Vs R_i. Through arithmetic software sub-routines incorporated to perform linear least square (LLSQ) technique, slope (m) and intercept (c), the straight-line parameters are determined. With the values of slope and intercept stored in memory, the instrument can carry out SOC measurement for any type of lead acid battery.

The hardware package

The main components of the computer-controlled instrument are as depicted in Fig. 2. To obtain the magnitude of rapid change in battery voltage from the battery system's response to pulse- charging current, the high-speed data acquisition serves to capture the transient response. The main components of the PC based instrument are as follows:

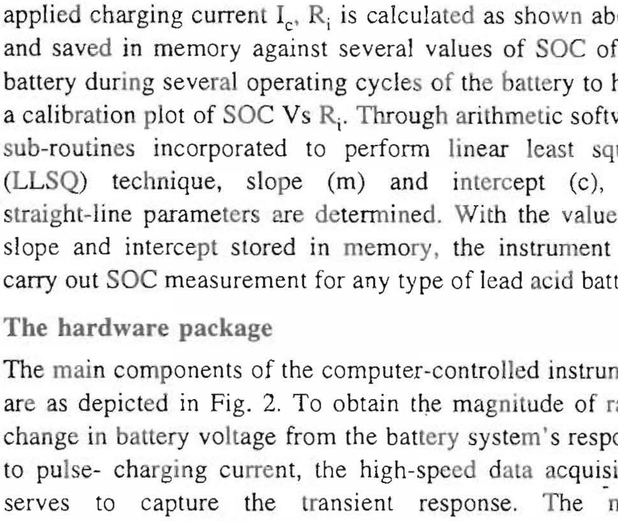

Fig.2: Circuit diagram of the computer controlled instruement.

1. PC add-on card with eight 12 bit bipolar ADC channels and two 12 bit DAC channels

2. Galvanostatic charger and

3. Interface unit.....

The ADC in add-on card performs high speed data acquisition with 25 µsec conversion time.

The galvanostatic charger connected to DAC I channel of the PC add-on card plugged into one of the PC buses, is programmed through the control software to generate a charging current pulse whose pulse width is 5 seconds long and the charging current amplitude is chosen in accordance with the value of the capacity of the battery as selected in the set up menu of the instrument. The interface unit comprises a high pass filter, peak hold circuit and a buffer amplifier. The high pass filter is so designed that the slow varying signal as seen in the transient response, between the two pulse edges, which is the response of the reactive components of the battery, is filtered out and at the output of the filter only the voltage spikes with amplitudes equalling that of the voltage drop V_d, are allowed to appear.

These two voltage spikes one in positive direction and the other in negative direction, are inputted to the peak hold detector circuit with an inverting amplifier connected to its input. The peak hold detector designed with a proper circuit design, is capable of measuring both the positive and negative voltage spikes picked out from the transient response by the high pass filter. Both these spikes corresponding to the V_d, voltage drops obtained during the charging pulse ,by the high pass filter and the peak detector circuits are then data acquired by the ADC II channel. In between two data acquisitions to be carried out the peak hold detector circuit is reset by the DAC II channel. The ADC I channel is employed to measure the open circuit voltage of the battery to be tested in order to inspect whether the battery is in good condition or in bad condition.

Software design

A user friendly menu driven software package which has been developed in GWBASIC for the PC based instrument, comprises several optional menus such as set up menu, measurement menu and calibration menu that are displayed in main menu which appears just after executing the instrument's software program.

The set up menu provides facility for the user to enter the battery specifications such as the Battery voltage, number of cells, Battery capacity and its make. Then on choosing the measurement menu, the instrument first reads the Open circuit voltage (OCV) of the battery through ADC I channel being enabled by its data acquisition software sub-routine. Then the reading is repeatedly taken for its consistency. Then the voltage is checked whether it lies within the safe-limits. As it is claimed that for a 2 V lead acid cell, the fully charged condition occurs when the cell voltage goes above 2.3 V, and the fully discharged condition occurs when the cell voltage goes below 1.7 V. The cell is said to be in a bad condition when the cell voltage goes below 1.5 V. The battery voltage is calculated using the value of n, number of cells, obtained from the specifications inputted in the set up menu. If it is within the limits, it proceeds further or it just displays that the battery is in a fully charged, fully discharged or in a bad condition Therefore when the OCV of a battery obtained through the data acquisition, falls below the value of n x 1.5 V (n= no. of cells), then the instrument rejects the battery by displaying that the battery is in bad condition

The percentage value of state of charge is measured in measurement menu. In order to obtain the value of %SOC, R_i monitoring technique is to be performed To carry out the internal resistance measuring technique, the computer controlled galvanostat applies a charging current pulse whose amplitude, set through the control software sub-routine, should match with the C_{20} value (where C_{20}=C is capacity in Ah)(20), which is too low to perturb or polarize the electrochemical system of the battery. During the pulse charging current, the data acquisition program is enabled twice; one at the leading edge and the other at the trailing edge of the pulse. To reset the peak hold detector before capturing the internal voltage drop, V_d, at the trailing edge of the pulse current, a control software program is executed to enable the DAC II channel which in turn switches on relay whose N\O (normally open) contact is connected as a reset switch of the peak detector. The voltage drop across the internal resistance, V_d, obtained at both the pulse edges through high pass filter and the peak hold detector circuits of the interface unit, is data acquired and the two values of V_d are compared . If the two values of V_d are not equal the control program asks the user to repeat the internal resistance measuring technique in order that accurate R_i measurement is carried out. With the values of slope and intercept obtained from the calibration plot, the value of % SOC is calculated after measuring the internal resistance as described below, and SOC in percentage is displayed.

The calibration menu, enables the user to calibrate any type of lead acid batteries and asks the user to carry out number of pulse current experiments to measure R_i, over a batch of batteries of same type and capacity but charged at different states of charge (%SOC). A calibration plot of % SOC Vs R_i is then obtained. An arithmetic software program to enable LLSQ technique is then executed to obtain slope and intercept values of the linear curve fitted using the data obtained on % SOC Vs R_i. Then these values of slope(m) and intercept (c) are stored in memory. With these straight

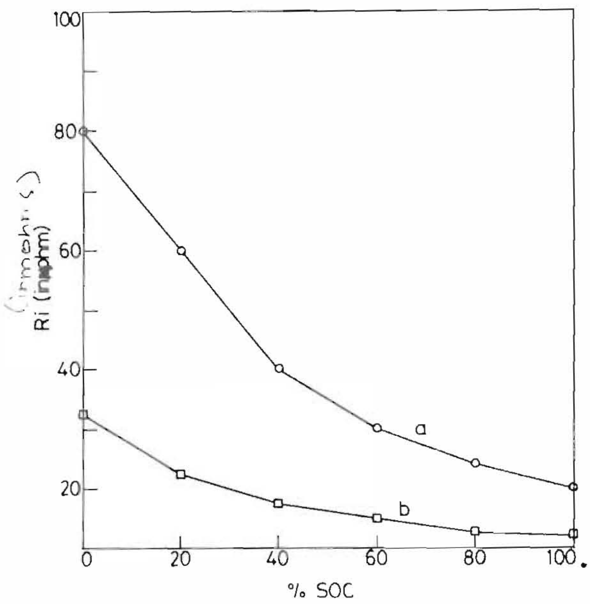

Fig.3: Plot of State of charge vs. Ri.

line parameters, battery of unknown %SOC can be determined. After carrying out the R_i measuring technique over the battery of unknown % SOC, an arithmetic software is executed to carry out the mathematical operation of the equation given below.

$$\% \text{ SOC} = \frac{R_i - C}{M}$$

where C is the intercept and M is the slope of the calibration plot. And the value of %SOC is displayed as a result of the R_i measurement technique.

RESULTS AND DISCUSSION

The graphical plot as depicted in fig 3, is the calibration plot of %SOC Vs R_i values obtained for a series of R_i expts., against known %SOC values. The calibrated battery is an indigenous make Lead Acid Battery with 12 V, 60 Ah capacity. The slope and intercept of the curve obtained were determined using LLSQ method and were saved in a data file. Every type of the battery to be calibrated will have its own data file containing these slope and intercept values obtained from the respective calibration plot.

When %SOC measurement was carried out on a battery of same type as that shown in Fig 3, its R_i value was measured as 320 mohms.

The internal resistance R_i of the battery = 320 mohms

%SOC = R_i-intercept/slope

using the values of slope=-1.869

and intercept=419

State of charge = (Internal Resistance - Intercept)/slope

= (320-419)/-1.869

= 53.45%

The SOC value indicated by the monitor had been confirmed by actually determining the residual capacity available which was found to approximately tally with -5% error.

CONCLUSIONS

The following are the conclusions

1. The developed SOC monitor can serve as a quality monitoring tool in all Battery laboratories to estimate the internal resistance, as often required in designing a battery in view of its characteristics like performance, quality and efficiency etc.
2. It can function as an On-line SOC monitor in battery industries, provided suitable hardware/software package having multi-channel measurement and remote monitoring facilities, is incorporated.
3. The monitor can as well adapt the same measuring technique, in assessing the SOC/R_i values of all other versions of batteries. For other storage batteries like Nickel-Cadmium batteries, it can be tried to evaluate the Internal Resistance and State-of-health.
4. As the measurement technique, employing a step-pulse current, Ip, with its value only equivalent to C_{20}, the battery system will not get polarized and hence the measured R_i value will be the true value.
5. Quick read out experimental results over the R_i and State of Charge values, enables the user to evaluate more number of batteries over a short duration as each experimental period will last from 2 to 5 seconds.

REFERENCES

1. H A Kiehne, *Battery Technology* Hand book,(1989).
2. R T Barton and P J Mitchel, *J. Power Sources,* 27(1989) 287- 295.
3. Stevenson and Dyson, *J. Power Sources,* 40 (1992)39-46.
4. Feder and Croda, *J.Power Sources,* 40(1992) 235-250.
5. S A Elangovan, *J.Power Sources,* 50(1994) 33-45.
6. D Berndt, Maintenance free Batteries. Research Studies Press Ltd. England (1993).