Condition identification system for rechargeable batteries

Hristo S. Kilifarev[1]

Abstract – **In this paper are described the base characteristics of different types rechargeable batteries and some of functional possibilities of some real systems for their analysis. The base methods for defining of some important parameters of rechargeable batteries are shown. A general scheme of a device is presented which own the functional possibilities to make identification (analysis) of rechargeable batteries, to charge them and to make their service maintenance.**

Key words – **rechargeable batteries analyzer, charge-discharge curves, characteristics of rechargeable batteries.**

I. Introduction

In the present moment in the life of the contemporary man there are many devices, which have rechargeable batteries like power source. Mostly these devices are comparatively with small sizes and they are movable. Typical applications are the cell phones and the mobile radio devices, the camcorders, the laptop computers and the measurement devices, many handheld electrical tools and etc. Usually in the devices of that kind there are comparatively little rechargeable batteries in size, with small amount of capacity and little number of cells.

Other group batteries are these, which are used in stationary devices or in different type of vehicular machines. These rechargeable batteries are with comparatively big size, large amount of capacity and are with big number of cells. Typical applications are in backup power sources and in the automobiles.

A common property of the all kinds of rechargeable batteries is that after some exploitation period their parameters become worse. And it is necessary then to replace the batteries with a new. If the battery is comparatively cheap, but there is need from often replaces, or the change with a new battery is big amount of expenses, or if the batteries are big number – this procedure is economical disadvantage. In these cases it is good to take care to prolong the exploitation period of rechargeable batteries. This can be done with appropriate maintenance and when needed – to recover (revive) the batteries with worse parameters.

There are many different kinds of rechargeable batteries according to the used chemistry, the mechanical characteristics, the production parameters and the environment where they are used. Because of these reasons there exist many different algorithms to charge / discharge the different kinds of rechargeable batteries – every one kind of rechargeable battery requires special mode to be charged /discharged. From essential interest are the algorithms which achieve the recharge procedure in shortest time periods, but which give guarantee for saving their parameters (or make them betters) for entire exploiting period.

[1]Hristo S. Kilifarev is with Technical University – Gabrovo, 4 H. Dimitar str., 5300 Gabrovo, Bulgaria, E-mail: hri_100@abv.bg

Very often the reason rechargeable batteries to be destroyed are the charging devices, which are used.

In the market for electrical devices can be found chargers with a big variety - they are with very different parameters, with different principles to work and construction, and their price is different too. The biggest part of these chargers are cheap, they can support only one type of rechargeable battery and the way to do the charging is done mostly by use of one or two algorithms. A less part of the chargers in the market have some kind of protection circuits in their construction - in example protection circuit for the highest permissible temperature of the rechargeable batteries. For now in the very little part on the market there are chargers, which have abilities to make some ‘intelligent’ identification (analysis) for the current state of the rechargeable battery before and through the time of charging /discharging, and can adjust themselves according to the type of battery. The last described chargers have one disadvantage – they are comparative expensive devices and for that reason they are not appropriate for the mass user.

In this paper is propound a general solution for scheme of a state identification system for rechargeable batteries (in short a battery analyzer) and a charge device. The identification of rechargeable batteries is done in two stages. On the first stage the measurements and calculations of the all parameters, which can be obtained, are done. On the second stage in the base of firstly collected statistical data and the entered data by user, an appraisal is obtained for the current state of the rechargeable battery. The other functionality of this scheme to charge / discharge the batteries can be applied then, accordingly to obtained appraisal, to the measured / calculated parameters and the wishes of the user. A decision can be given by the device for the mode of work (normal charging, fast charging, discharging, maintenance, recover and etc.) and accordingly decision for the algorithms which will be used.

The same device can collect the statistical data used for the first stage – just the different types of rechargeable batteries and in different condition must to be analyzed and the data stored in the memory. This statistical data can be transferred to the device by the connection to a computer. The processing over the measured parameters by the device can be done with the computer in the same way.

II. Definition of the base terms and parameters for rechargeable batteryes

Cell – electro-chemical device, capable to deliver energy, which is a result from an internal chemical reaction to an external electrical circuit. The cell’s general construction consists of two electrodes and a electrolyte between them. The negative pole is *cathode* and the positive pole – *anode*. The electrolyte is a substance, which ensures ion-exchange conductivity between the electrodes.

Battery – it is build by one or more cells which can be connected serially (to increase the voltage), in parallel (to increase the current) or in combination. Often part of the battery is a special circuit for protection from higher temperatures of the package, from higher charging / discharging currents, from discharging to the level of cut off voltage and other events.

Chemistry – in the construction of the rechargeable batteries different materials are used which give them the different characteristics. Most important are the materials of the used electrodes, which give the name of the batteries. In the present time mostly used chemistries are Lead-Acid (LA), Ni-Cd, Ni-MH and Li-Ion (Li-Polymer batteries was developed soon and because of this they are not considered in this paper).

C – the unit for measurement of the battery (or the cell) capacity, which is related with the amount of energy that the battery can store and deliver. This unit is presented as Ah or mAh and is the value of the current, which the battery can deliver for 1 hour - before the voltage drops to the point of cut off voltage. The charge and discharge currents are given as function of C. In example for battery with capacity 1000 mAh if the charging current is 100 mA, then the battery will be charged for 10 hours and this current may be presented as 1/10 C or C/10. For the same battery, if the current is 1C (or 1000 mA), then the battery will reach full charge for 1 hour.

Middle voltage – this is the nominal voltage over the cell and this is the measured voltage over the cell, when it is discharged to 50% from the maximal capacity.

Cut off voltage (end of life voltage) – this is the measured voltage over the cell in the end of operating cycle when discharging. Under this point this is so called zone of *deep discharge*. It is possible as a result to have inverse polarity over the weaker cells in the battery which can make nonreversible chemical reactions in these cells and therefore to drop down overall performance of the battery. The good side of deep discharge is that with some limits removes the memory effect (see below).

Top voltage – this is the maximal voltage over the cell in its operational cycle and corresponds to fully charged battery. When continuing the charge after this value this is called *overcharge* and leads to rising of the temperature, and also to destroying of electrodes, vaporizing of electrolyte and other damages.

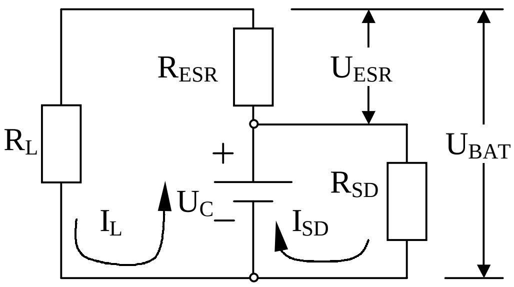

Fig.1. The equivalent scheme of a rechargeable battery

The voltage over the battery U_{BAT} is presented in Eq. (1) as:

$$U_{BAT} = I_L.R_L \quad (1)$$

But this voltage is equal to Eq. (2) too:

$$U_{BAT} = U_C - U_{ESR} \quad (2)$$

The drop of voltage over the equivalent serial resistance of the battery R_{ESR} is:

$$U_{ESR} = I_L.R_{ESR} \quad (3)$$

And the dissipation of the energy over R_{ESR} is:

$$P_{ESR} = I_L^{\,2}.R_{ESR} \quad (4)$$

From Eqs. (1), (2) and (3) can be obtained the next:

$$I_L.R_L = U_C - I_L.R_{ESR} \quad (5)$$

From where can be concluded that:

$$I_L.(R_L + R_{ESR}) = U_C \quad (6)$$

ESR (Equivalent Serial Resistance) – this resistance is the sum of the internal resistance of serial connected cells in the battery. This resistance appears to be serially connected to the resistance of the load (or the charging device), hence the current flow I_L is the same in the both. In the equivalent scheme in Fig. (1) this is presented as the resistor R_{ESR}. In consequence of this over this resistor appears the voltage drop U_{ESR} , which is proportional to values of I_L and R_{ESR} - Eq. (3). The energy dissipation then is in quadratic dependence from the value of the current flow, Eq. (4). When high amounts of dissipated energy P_{ESR} is reached, the battery temperature is rising and in some cases can result as ignition or explosion of the battery. The voltage drop over ESR is with inverse polarity in relation to the polarity of the battery U_C, which brings to lowering or to rising of the battery's voltage U_{BAT} respectively to rising of discharge current or rising of charge current. ESR depends from used chemistry, from the mechanical characteristics and form the age of the battery (see below for cycle life parameter).

In the Table I are shown typical values for ESR for the most widespread rechargeable batteries. Especially big influence over the battery's ESR has the temperature. When the temperature is lowered the ESR rising and over the high temperatures – ESR drops down.

Self discharge – this is a process of discharge, when there is not connected load. This is consequence from rising of the conductivity through the electrolyte. For Ni-based batteries this process is with the highest rate as can be seen in the Table I. This process is strongly nonlinear – batteries, which loose 30% of its capacity for one month, loose about 15-20% in the first 24 hours after the charging. The values in Table I are taken for 20ºC temperature. The rising with only 10ºC lead to doubling of self discharge rate. In the equivalent scheme from Fig. (1), the effect of self discharge is presented with the resistor R_{SD}.

Memory effect – this effect is typical for the rechargeable batteries with Ni-based chemistry (NiCd, NiMH). The cause for this effect is the lowering of effective surface of the electrodes when the crystalline structures of Ni compounds rising in size. The situations when this happened are after long time of inactivity or when the charge process is started before full discharge of the battery. The memory effect is reversible process with some limits through the *forming mode*. In the forming mode there have to be made up to 5 full cycles of charge – discharge. Other ways for repairing of the memory effect are the deep discharge and the charging in the mode with negative pulse (see below).

Cycle life – this value presents the number of charge-discharge cycles that can be completed and after which the performance of the battery drops so much so that the battery must to be replaced with a new one. Only the parameters of Li-Ion batteries do not depend from the number of charge-discharge cycles. The life of one such battery is about 1-3 years and depends from manufacturer and the way of usage. The influence of the cycle life over the batteries is related to dry out of the electrolyte (from leaks or from vaporizing), lowering of effective surface of the electrodes (destroying, oxidation, memory effect and etc.), mechanical changes (destroying of the separator, changes in the form of electrodes and etc.) and other defects. These defects are evince for the age of battery and can be revealed mostly as lowering of the maximal capacity, rising of ESR and curtail of time period for self discharge.

Charge-discharge curves profile – this is the shape of the curve which according to changes in the voltage, when a constant charge / discharge current is applied in dependence from the amount of energy in the battery (or the time). This curve is defined mostly by the chemistry type of the battery, the rate of charging / discharging, its internal resistance and from the temperature. In Fig. 2 are presented the typical charge curve profiles of the different battery types according to their chemistry. Here the profile for Li-Ion battery is received, when constant voltage method is used with current limiting (see below).

TABLE I
GENERALIZED PARAMETERS OF RECHARGEABLE BATTERIES BY THEIR CHEMISTRY

Chemistry / Parameter	LA	NiCd	NiMH	Li-Ion
ESR, [mOhm]	100 - 200	100 - 200	200 - 300	150 - 250
Self discharge, [% per month]	5	10 – 20	20 - 30	<10
Top U, [V]	2.4	1.35	1.4	4.1
Nominal U, [V]	2	1.2	1.2	3.7
Min. U, [V]	1.8	0.9	0.9	2.9
Cycle life	300	1500	500	500
Memory Effect	No	Yes	Yes	No
Overcharge Tolerate	high	middle	low	very low

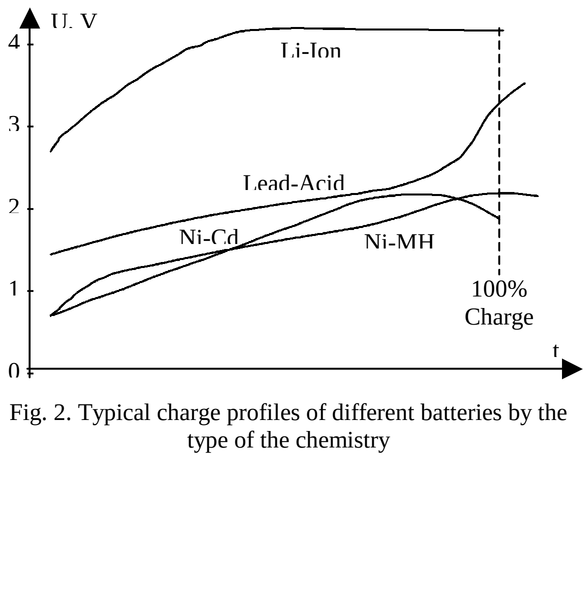

Fig. 2. Typical charge profiles of different batteries by the type of the chemistry

A *constant-voltage charger (C-V)* is a circuit that charges a battery by sourcing only enough current to force the battery voltage to a fixed value. Usually the maximal current is limited to some value.

A *constant-current charger (C-C)* is a circuit that charges a battery by sourcing a fixed current into the battery, regardless of battery voltage.

A *negative pulse charger* is a circuit that charges a battery like C-C method but there are short negative pulses in the current's shape.

III. METHODS FOR DEFINING OF COMMON PARAMETERS FOR RECHARGEABLE BATTERYES

The common parameters that characterizing rechargeable batteries and can be measured / calculated are:

1. Capacity – the reading is the most accurate when the full charge discharge cycle is done and the amount of discharged energy is calculated. The lower rates of discharge give more accurate results. Usually the rate of discharge currents is with about C/20.

2. Chemistry – it is possible to be recognized trough tracking of the charge and discharge profiles and also after comparison of some parameters values, which are peculiar for given rechargeable battery's type of chemistry with the stored statistical data.

3. Internal resistance – the reading of this parameter can be done after applying the sequence showed in Fig. 3 about 20 times and to take the middle value from the calculations results. The voltage over the battery is measured when through the sequence duration a constant current is applied. The sequence has positive and negative parts, which are symmetrical each other, and the duration of every step is about 10ms (the step 5 is about 200ms long). This is because the rising of the temperature or the level of capacity must be avoided. The calculation of internal resistance can be obtained with Eq. (7).

$$R_{ESR} = \frac{U_1 - U_4}{I_1 - I_4} \quad \text{, where} \qquad (7)$$

U_1 is the measured voltage through the positive current pulse duration – step №1 in the figure;

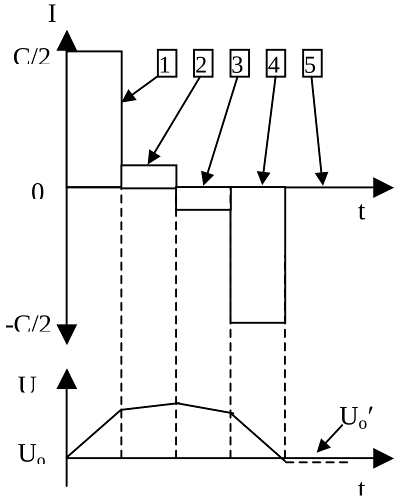

Fig. 3. Method for measurement of internal resistance and performance

U_4 is the measured voltage through the negative current pulse duration – step №4 in the figure.

4. Performance – this is appraisal for the energy expense necessary for the battery charging in relation to the amount of energy, which is stored in the battery. The same sequence from Fig. 3 is used to do this measurement, but here the pulses are with 1 to 5 minutes duration, the current rate is about C/5 to C/10, and the measurements are made less times. The relation between the voltages of the battery in the end of the sequence U_O' and this voltage in the beginning U_O, multiplied by 100 is the value of this parameter in percents.

5. Self discharge – this parameter approximately can be read if the rate of voltage falling is measured for period of several hours (or days) without connected load to the battery and after applying corrections for nonlinearity of this process.

6. Temperature – it is measured through a thermal sensor, which is mounted closely to the battery's case. This parameter is very important, because of his strong influence over the all battery's parameters and hence the need of corrections in measurements and calculations.

7. Charge level – this is the current level of stored energy in relation to the maximal amount of energy that can be stored. This parameter can be taken from charge-discharge profiles, current level of the voltage and internal resistance after comparison with statistical data.

8. State of health – appraisal for the battery's overall efficiency in the base of comparative analysis with stored statistical data and all obtained parameters.

IV. A GENERAL SCHEME SOLUTION

The propound for a general scheme solution is showed in Fig. 4. The main role is assigned to one programmable microcontroller, which common tasks are: 1) control over LCD display and keyboard – to bring out the information, navigate through the menus and data entering; 2) PWM for control over the power switches for charge and discharge of the batteries; 3) control and readings from one 5-channel ADC; 4) reading and writing from/to the memory chip; 5) digital control over adjustable power supply; 6) communication with the computer; 7) other tasks.

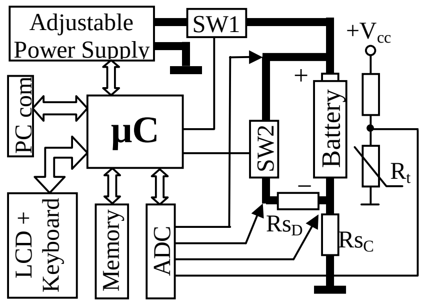

Fig.4. A general scheme solution for rechargeable batteries identification system

The algorithms for analyzing (identification) of rechargeable batteries are realized in the software, hence their changes and the addition of new functionality is not related to more hardware expenses.

V. CONCLUSION

The propound scheme solution is comparatively low self price but with high functionality. The computer communication extends this device and gives it more flexibility. The universality and low self price was the main purposes of this project.

REFERENCES

[1] Buchmann I. "Understanding your batteries in a portable world" Cadex Electronics Inc. http://www.cadex.com/

[2] Buchmann I. "Choosing a battery that will last" Cadex Electronics Inc.

[3] Simpson, C. " Battery Charging ", National Semiconductor