A New, Reliable and Easily Implemented NiCd/NiMH Battery State Estimation Method

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Abstract

This paper presents a new and reliable battery state estimation method for Ni-Cd and Ni-MH batteries used in portable applications.
The proposed method performs the following two basic functions. The first one determines battery state, detecting deteriorated batteries. The second one guarantees a safe fast-charge without negative effects on battery life, analyzing the previous charge state of the battery.
Due to this method can be easily implemented, effective and universal NiCd/NiMH battery fast-chargers can be obtained by using few and inexpensive components.

I. Introduction

New applications [1] (portable electronics and communications) are increasingly demanding batteries with mainly the following characteristics:

- High energy density to reduce the size and the weight of batteries.
- Long service life to achieve a high number of charging/discharging cycles.
- Fast-charge capability to have the possibility to charge the battery in less than one hour.

NiCd batteries have been in use for years in commercial applications and, despite the fact than some advanced systems have a higher energy density, they are still the most used batteries in a wide range of applications [2] because of its high specific power, long cycle life and fast charge capability (improvements made in NiCd technology in the last few years have contributed to this situation).
NiMH system is a good alternative to NiCd system [3]: NiMH cells have a behaviour on charge and on discharge very similar to NiCd cells - they can be interchanged without problems - and their energy density is higher. With regard to disadvantages [4]: NiMH cells are less tolerant of high charge rate, heavy discharges or working at high temperature.
Fast-charge (in one hour) and ultra-fast charge (in less than half an hour) are very useful in new applications where battery is quickly discharged (time is saved and the need for spares or larger batteries is reduced).
However, determining battery state before starting fast-charge process is absolutely necessary. On the one hand, if battery has irreversible damage, the charge would not be accepted. On the another hand, depending of battery charge state, charging process must be modified to guarantee the effective capacity and the cycle-life of the battery.

II. System overview

Different methods have so far been proposed to give an accurate indication of battery charge state (remaining energy) but they have no result enough accurate or practical:

- Measurement of battery internal impedance [5]
  This type of methods requires very complex calculations. Moreover, its validity is not sufficiently tested in Ni-Cd and Ni-MH cells.

- Memorizing of battery charging/discharging history [6]
  The effective capacity of a battery is modified as a function of environment temperature, discharging current, age of the battery and so on. Thus, determining the instantaneous energy remaining in the battery by keeping account of the discharge/charge time and the charge/discharge current is not a very accurate method. In any case, the main problem is that often, two or more batteries are alternatively used in portable applications; so, recording the history of each one becomes difficult and not very practical.

The flow diagram of the new battery state estimation method proposed in this paper can be seen in Fig. 1.

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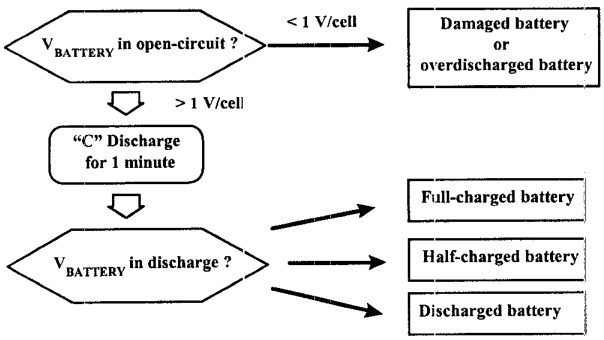

Fig. 1. Flow diagram of method proposed for estimating battery state.

The complete process has two different steps:

- Measurement of open-circuit battery voltage to detect if battery is damaged.
- Measurement of battery voltage on discharging in order to know battery charge state.

In following sections, each of this stages and its implementation will be described. The proposed method is based on measurement of battery voltage under several specific conditions. Thus, the measurement system becomes very simple.

III. Detection of damaged battery

Battery damage is detected by measuring the open-circuit battery voltage (see Fig. 2).

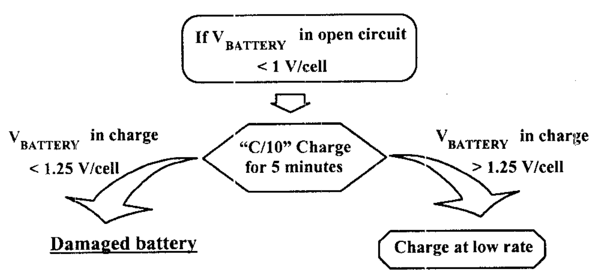

Fig. 2. Method proposed for the detection of irreversible damage in the battery.

Battery manufacturers recommend not discharging cells below 1V/cell. Due to cell voltage being higher in open circuit than in discharge conditions, an open-circuit voltage less than 1V/cell shows an overdischarged battery and usually a damaged battery.

In this case, a low charge current (C/10) must be used until the battery is recovered: $V_{battery}$ is increased to 1.25 V/cell (this voltage is the value that a discharged cell in good conditions reaches at the start of charging).
If the battery is overdischarged due to self-discharge or occasional bad use, battery voltage is over 1.25 V/cell in less than 5 minutes. However, if the battery is damaged, battery voltage remains lower after this time because charge is not accepted.
Therefore, if battery voltage remains lower than 1V/cell after 1 or 2 minutes or lower than 1.25 V/cell after a few minutes (5 minutes) the charging procedure must be interrupted: the charge is not being accepted because the battery has irreversible damage.
It should be pointing out that an aged battery (when the effective capacity of the battery decreases to the 80% of nominal capacity) will not be detected with this method. Full charging of the battery and a later full discharging in order to measure the effective capacity is the way to detect an aged battery. However, this process takes a long time and it would only be necessary a few times during the life of the battery. Thus, detecting an aged battery has not been included in the process.

IV. Estimation of battery state

Knowing exactly the energy remaining in a battery is very difficult but it is not necessary if the main objective is to achieve a safe fast-charge of the battery.
In this case, an aproximate knowledge of the battery charge state is sufficient: **full-charged battery**, **half charged battery** or **discharged battery**. Depending on the initial state of the battery, the charging process must be modified to avoid any damage to the battery.

Discharged battery

Fast-charge in this zone can result in permanent damage if battery is fully discharged. Thus, the battery must be charged with a low current (C/10) until battery voltage increases to 1.25 V/cell. Then, the fast-charge can take place.
Due to battery powered devices switching off before the battery is full-discharged, in most cases, battery voltage increases suddenly to 1.25 V/cell when the charging process is started. However, if the battery is full-discharged or overdischarged its voltage increases more slowly.

Half-charged battery

If battery charge is started in this zone, the effective capacity of the battery could be reduced.

Tests show that the effective capacity of NiMH batteries remain similar of nominal capacity (see Fig. 3) after more than 100 cycles of charge/partial discharge (in this case, until the 25 % of nominal capacity); the reduction (a 10 % with a final voltage of 1.15 V/cell) in the effective capacity of NiCd batteries (see Fig. 4) disappears after one full-discharge.

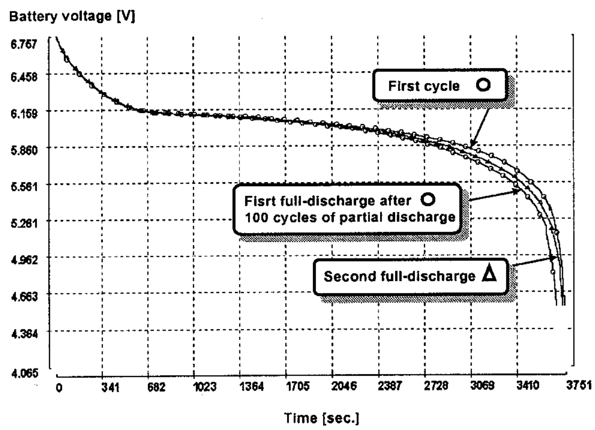

Fig. 3. Full-discharge curves of a 6V NiMH battery under specific conditions.

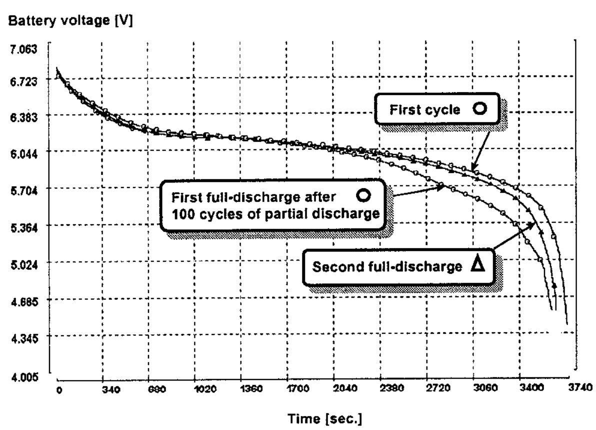

Fig. 4. Full-discharge curves of a 6V NiCd battery under specific conditions.

The main conclusion is "memory effect" does not have influence in usual applications (where the battery is occasionally full-discharged). From this point of view, discharging a half-charged battery before beginning the fast-charge process would not be necessary.

However, batteries can lose effective capacity due to overcharging, self-discharging and so on (these losses are often mistakenly attributed to the "memory effect") and experts agree about the best way to avoid all these problems: discharging the battery before charging.

Therefore, discharging a half-charged battery to 1 or 0.9 V/cell before fast-charging process is convenient (the total time of charge process increases but the cycle-life and the effective capacity of the battery are not reduced). Also, this step simplify considerably the design of accurate fast-charge end methods (the battery charge state in fast-charge starting is always known).

Full-charged battery

Fast-charge in this zone is dangerous and it could become destructive by increasing the temperature on overcharging. In this case, only trickle charge (a current rate just slightly above the self dicharge rate) must be applied until the battery is removed from the charger. In this way, the battery is kept in the right conditions for using at any given time.

Ni-MH batteries are more sensitive than Ni-Cd batteries at low-level continous charge, but trickle charge at low enough current (C/20 to C/40) is not problematic.

IV. a. New battery charge state estimation method

Previous discussion establishes three zones of charge state for NiCd and NiMH batteries: this aproximate estimation of battery charge state is used to choose the right fast-charge method.

The following step is to develop one method that allow us to determine reliably and easily the state of the battery (full-charged, half-charged or discharged).

Measurement of open-circuit battery voltage fails to clearly represent the energy stored in a battery at an specific time. Sometimes, battery voltage in open-circuit is high (it looks as if the battery was half-charged). However, this voltage decreases quickly on discharging (showing that the cell is actually discharged). Therefore, battery voltage on discharging is a better indicator of battery charge state [7].

Discharging profiles in Ni-Cd and Ni-MH batteries depend too much on discharge rate. Thus, to draw conclusions from several results, the same discharge rate must always be used.

Fig. 5 shows some voltage-versus-energy curves for NiCd or Ni-MH cells that have been discharged at the same rate (age and/or temperature could be the cause of differences).

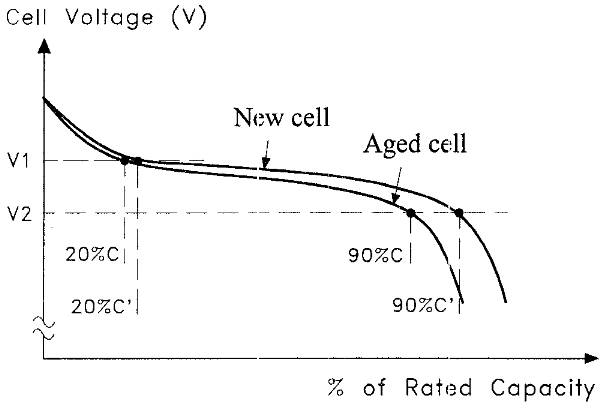

Figure 5. Voltage versus energy curves for NiCd or NiMH cells discharged at the same rate.

Curves looks essentially flat but it can be concluded that:

- If ($V_{cell} \geq V1$) the cell is fully charged (remaining energy $\geq 80\%$ of total energy)
- If ($V_{cell} \leq V2$) the cell is discharged (remaining energy $\leq$ 10% of total energy)
- If $V2 < (V_{cell}) < V1$ the cell is half-charged

In order to reduce the necessary discharging-time to obtain a relation between battery voltage and battery charge state, a high discharging current has been chosen. Thus, the method proposed to estimate the charge state of the battery (see Fig. 6) consists of reading battery voltage for a short time (1 minute) while the battery is being discharged at a "C" rate. Battery voltage at the end of this short discharging process shows battery charge state.

It should be pointing out that discharging process is immediately ended if battery voltage decreases below 1 V/cell to avoid overdischarging the battery.

V. Implementation

The method proposed to determine the state of the battery (detection of damaged battery, estimation of previous battery charge state) can be easily implemented. Due to this method is based on measurement of battery voltage under several specific conditions, measurement system becomes very simple:

- Battery voltage can be sensed through a simple amplifier block. Later, the measurement must be filtered (only an R-C filter) to limit the effect of voltage jumps caused by battery and/or external noise.
- If all key voltage values are memorized in volts per cell (V/cell), the system designed can be used independently of nominal battery voltage.
- Although a regulated discharge current is necessary to determine correctly the battery charge state, this regulation is also convenient to minimize full-discharge time in he case of battery initially half-charged.

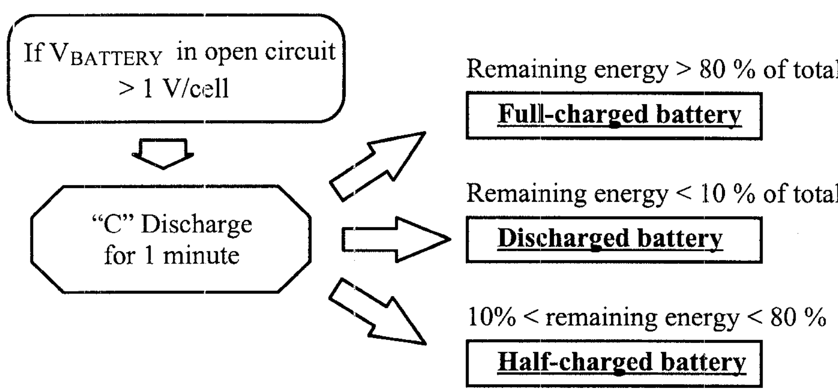

Fig. 6. Battery charge state estimation method.

VI. Experimental results

All methods proposed in this paper have been widely confirmed experimentally. An universal test-bench for fast-charging was previously developed in order to facilitate research.

The implemented test-bench allows us:

- All type of charging/discharging tests (specially designed power stages) at constant ambient temperature (ICP 800 electronically controlled oven, Memmert).
- The monitoring of main parameters - battery current, voltage and temperature, and ambient temperature - with the "2620A Data Acquisition Unit" (Fluke).
- The storing of data sampled for a later study (LabView + bus GPIB).

Figures 3 and 4 show some results obtained using this test-bench.

VII. Conclusions

This paper presents a new and reliable battery state estimation method for Ni-Cd and Ni-MH batteries used in portable applications. This method detects deteriorated batteries and guarantees a safe fast-charge (without negative effects on battery life) analyzing the previous charge state of the battery.
The proposed method is not dependent on the kind of charge and it is valid for both NiCd and NiMH batteries. Moreover, due to this method can be easily implemented, effective and universal battery fast-chargers can be obtained by using few and inexpensive components.

VIII. References

[1] J. Heydecke, H.A. Kiehne (VARTA), "*Portable NiCd and NiMH Batteries for Telecom Applications*", Eighteenth International Telecommunications Energy Conference (INTELEC), 1995.

[2] F. Putois, "*Market for Nickel-Cadmium Batteries*", Journal of Power Sources, vol. 57, 1995.

[3] N. Furukawa, "*Development and commercialization of nickel-metal hydride secondary batteries*", Journal of Power Sources, vol. 51, 1994.

[4] Alminauskas, V., Johnson, W. "*Comparison of AA NiMH cells with AA NiCd cells*". Intersociety Energy Conversion Engineering Conference (IECEC'96), pp. 1168-1170, 1996.

[5] Damlund, I. "Analysis and interpretation of AC measurements on batteries used to asses state-of-health and capacity condition". INTELEC'95, pp. 828-833, 1995.

[6] Philips Semiconductors "NiCd and NiMH rechargeable battery management", Philips Data Book, 1994.

[7] Djordjevic, A.B. "Simulation of the discharge curve by short-time discharge based on the power of internal resistance". Journal of Power Sources, N°50, pp. 97-108, 1994.