Battery Chemistry Detection Algorithm Implementable with Intelligent Systems: A Step towards the Development of a Novel Charger Applicable for Multi-chemistry Environment

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Abstract

This paper introduces a theory for the development of a fully automated multiple chemistry battery charger. This can be possible through the detection of battery chemistry. The paper presents an algorithm to differentiate between Ni based, Li-ion and Sealed Lead Acid (SLA) batteries through the analysis of voltage profile during charging and discharging periods. The algorithm was implemented and tested in an intelligent charger capable of charging aforementioned types of batteries without any prior identification of battery type from the user. This industrially viable solution for developing multiple chemistry charger can easily be incorporated in any embedded system using minimum input and circuit arrangement connected to the battery.

1. Introduction

Portable batteries are considered to be a reliable and useful source of energy. Among the various types of batteries, rechargeable batteries hold a higher position [1] because of their reusability. The charging procedure of any rechargeable battery depends on the specific chemistry of that battery which makes the charging algorithm for different types of batteries distinct [1].

Up until now, mostly separate battery chargers have been used to charge different types of batteries. [1], [2]-[3] present charger design for NiCd and NiMH batteries in portable applications. A simple, fast and reliable technique for charging batteries by solar arrays is proposed in [4]. Description of a charger designed for Li-ion batteries is provided in [5]. [6] focuses on a design of a super fast battery charger based on National's proprietary neural network based NeuFuz technology. This approach continuously monitors the battery status, and modifies the charge current accordingly. It also eliminates the need for standard charge termination methods used in today's conventional chargers. A multi-phase battery charger to improve the current utilization of the power supply unit (PSU) and the over voltage problem during negative discharging period for a small capacity SLA battery is described in [7]. [8] proposed a phase-locked loop (PLL) circuit topology for battery charging. A very compact monolithic battery charger for NiCd, NiMH, Li-ion and Li-polymer was presented in [9]. The multi chemistry issues related to chargers are addressed in [10].

The main difficulty in developing charger for multiple battery chemistry is the detection of appropriate chemistry of the battery to be charged. All previous works addressed this issue by taking battery type as an input from the user. Moreover, no such attempt was made to develop a single charger capable of charging Ni based, Li based as well as Lead acid battery. The main focus of our work is to develop an intelligent charging method applicable for Ni based, Li-ion and Lead acid battery where no user input is necessary for battery type detection. Some of the previous works for multi-chemistry system used temperature sensing. But in this paper, the novel algorithm makes use of the voltage profile only, without any need of huge data storage and can be implemented with microcontroller based systems which can make the charging system hot pluggable and portable. Chemistry detection with only voltage profile measurement is surely a new concept in the development of intelligent multi-chemistry charging system with an enormous potential for future work and wide scope for industrial application.

Among the four types of batteries, NiMH and NiCd show almost similar charging and discharging characteristics [9].

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Table 1. Nominal voltages of rechargeable batteries [11]

Battery type	Nominal voltage per cell (V)	Discharge voltage per cell (V)
Li-ion	3.6	2.5
SLA	2	1.75
Ni based	1.2 / 1.25	1

Therefore, if we know that the battery is Ni based, we could use the intelligent charger irrespective of whether the battery is NiMH or NiCd. The remaining 3 major types of batteries have different charging and discharging characteristics. Ni based batteries have one unique characteristics that 15 mV per cell voltage drop occurs when the charging finishes. But when more than one cells are connected in series, the situation becomes complicated. Output voltage of multiple Ni based battery cells may overlap with Li-ion battery cells which can be realized from Table 1. Li-ion batteries must not be allowed to overcharge for safety. For this reason, it may not always be possible to identify Ni based batteries from charging characteristics. Moreover, Li-ion and SLA batteries have almost similar charging characteristics. Therefore, discharging is necessary in battery detection process. The overall algorithm is developed by analyzing numerous battery charging and discharging data. It was tested in a custom designed charger implemented by micro-controller based embedded system.

2. Proposed algorithm

As mentioned previously, analyzing the discharging characteristics is necessary for battery chemistry detection. A battery can be charged any time regardless of its state of charge (SOC). But it may not be possible to discharge a battery if it is in 0% SOC. Therefore, the detection process is started with a low, constant current charging for a short period of time followed by discharging up to end of discharge (EOD). In the process of discharging, the open circuit battery voltage and the voltage under load are continuously measured at a regular time interval from which some parameters are calculated. The parameters are defined in such a way that noticeable differences in the values of these parameters can be observed among different types of batteries. At the same time the values also lie in a logical range for a specific type of battery.

2.1. Constant current charging at 500mA for approximately 10 minutes

The main objective of charging is to prepare the battery for discharging. Additionally, there is a possibility of battery chemistry detection in case of Ni based batteries. This can only be possible when almost full charged Ni based battery is given and it reaches the End of Charge (EOC) point after being charged for about 10 minutes. Figure 1 shows that at EOC the open circuit voltage of the battery drops from the peak voltage by about 15 mV. Therefore, during charging, open circuit voltage should be constantly monitored at a regular time interval and checked if it fulfills the previously mentioned criterion. Since overcharging Li-ion batteries is harmful, charging may be stopped before 10 minutes if it is found that the voltage falls within charged Li-ion battery voltage range for different cell combinations. In that case, it is not ensured that the battery is Li-ion, but the prime objective for this checking is safety. Additional discharging is necessary because even if charging may be stopped assuming Li-ion, it may not be so.

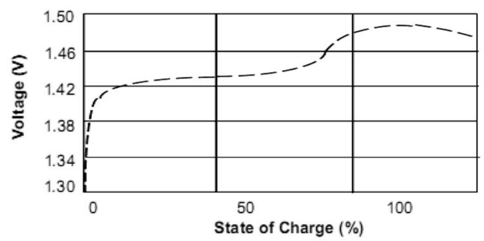

Figure 1. Typical charging profile of a Ni cell [11].

2.2. Discharging the battery

The main purpose of discharging batteries is to be able to differentiate them by their discharging characteristics which are significantly distinctive. In the process, the voltage profile is analyzed with respect to time where the batteries are allowed to discharge at a constant current of 400 mA. The discharging continues until the *End of Discharge (EOD)* is reached.

2.3. Voltage measuring scheme

During the discharging, battery voltage is being measured in two different situations alternatively and at 2 minutes time interval. The two situations are,

- Runtime voltage during discharging (V_{run} / V_{trough})
- Open circuit voltage with discharging stopped (V_{open} / V_{peak})

The term *runtime voltage* denotes the voltage under load, i.e., when the load draws the discharging current from the battery. The term *open circuit voltage* denotes the battery voltage without any discharging load, i.e., no discharging current is drawn from the battery.

Since the algorithm can be implemented in embedded systems, to accommodate with the memory and processing power, we keep five most recent data. Due to the regulation of the battery, voltage under load falls slightly from the open circuit voltage and while discharging the open circuit voltage falls to a specific value which can be determined by cell number and battery type. At *EOD*, both V_{peak} and V_{trough} curves show distinctive features. The main objective of measuring voltage and hence defining different parameters is to trace the distinction and detect battery type thereby.

2.4. Parameter definition

By measuring voltage or observing voltage changing trend it is not possible to differentiate batteries. Because cell voltage differs according to type, also different series combinations of cells make it impossible to predict anything from voltage only. We define some parameters which are normalized and bears information about the trend of the curve and lies in a predictable range. Four parameters are defined denoted by *N*, *L*, *dN* and *DV2* which would formulate the procedure for battery detection.

$$N = \frac{MA(dv)}{V_{peak}(t)} \times 5 \qquad (1)$$

$$L = \frac{MA(DV)}{V_{peak}(t)} \times 400 \qquad (2)$$

$$dN = \frac{N(t+1) - N(t)}{N(t)} \times 100 \qquad (3)$$

$$DV2 = MA(DV) \times 1000 \qquad (4)$$

Here,

$$dv = V_{peak}(t) - V_{trough}(t) \qquad (5)$$

$$DV = V_{peak}(t-1) - V_{peak}(t) \qquad (6)$$

The notation $MA()$ indicates moving average operation of the associated parameter. t is the time for which the parameters are being calculated. Since voltage is measured at a regular and fixed interval, when posting the values in graph, actual time interval is not shown. Rather values are posted against discrete natural number series showing only the trend of the curves with time.

2.5. Analysis of numerous battery data and setting a threshold value

Figures 2, 3 and 4 show the typical discharging characteristics for the three types of batteries. From these three curves, it can be realized that the trend of a discharging curve is indeed useful to detect battery type. For detecting the batteries, it is necessary to find EOD or a point near EOD. Theoretically EOD is defined as the safest value of open circuit voltage, V_{peak}, of a battery upto which it can

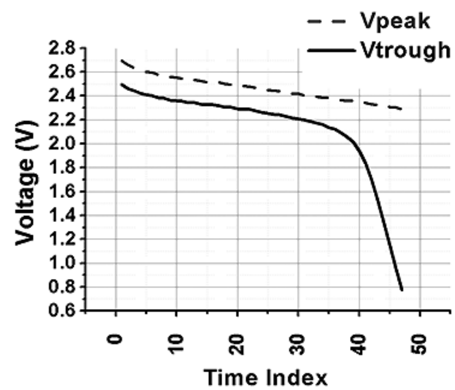

Figure 2. Typical discharging curve for Ni based batteries, obtained from 2 NiCd cells of 700 mAH capacity. The sampling interval was 2 mins.

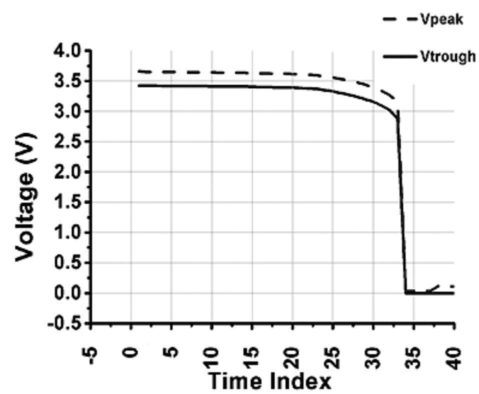

Figure 3. Typical discharging curve for Li-ion batteries, obtained from 1 Li-ion cell of 900 mAH capacity. The sampling interval was 2 mins.

be discharged. The parameters defined previously would be used to find the EOD. From Figure 2, it is clearly visible that difference between V_{peak} and V_{trough} starts increasing near the *EOD* and V_{trough} shows a sharp decrease which is characterized by the parameter N, where the difference between V_{peak} and V_{trough} is taken into account by dv. Sometimes, in order to perceive the sharp decrease of V_{trough}, rate of increase of N may have to be checked, for which dN is defined.

From Figure 5, it is clear that for N and dN, a threshold value can be defined which is 1 for N and 5 for dN near *EOD*. Similar curves can be found by similar analysis with numerous Ni based batteries of various capacities and number of cells. From analysis, it is found that both N and dN comply with aforementioned values near the *EOD*. Typical discharging trend of Li-ion batteries shown in Figure 3 reveals an interesting fact that, after reaching *EOD*, both V_{peak} and V_{trough} falls to zero almost at once, signifying the use of protection circuitry inside every commercially

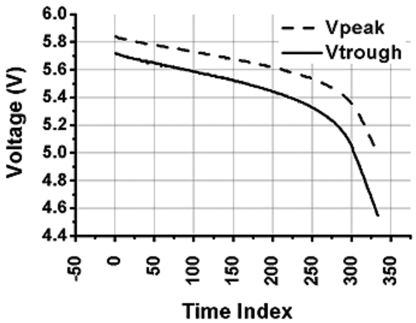

Figure 4. Typical discharging curve for SLA batteries, obtained from 3 SLA cells of 3200 mAH capacity. The sampling interval was 2 mins.

available Li-ion battery. This poses an extra challenge of detecting the battery slightly before *EOD*. For a Li-ion battery, the difference between V_{peak} and V_{trough} remains almost same up to *EOD*. But V_{peak} shows a drastic fall at the brink of *EOD*. Since the parameter L keeps the track of the change in V_{peak} over time, it should reach a certain threshold value near *EOD* and should be increasing. From Figure 6, the threshold value for the dominant parameter for Li-ion batteries, i.e., L can be chosen to be 4, where N shows almost a constant value and near *EOD*, it can increase up to 0.6 at best, though 0.8 was chosen for safety. Although Ni based batteries can be successfully differentiated from one type of parameter and its changing rate, the value of N should also be checked simultaneously along with L for Li-ion batteries. This is to ensure that old or defective Li-ion batteries, which may have poor regulation due to aging effects making the values of N greater than 1 near *EOD*, would not show erroneous results. The discharging characteristics of SLA battery in Figure 4 reveals the fact that it resembles the behaviors of both Ni and Li-ion batteries to some extent. SLA batteries usually have high capacity and its nominal voltage per pack available is also quite large compared to Ni based or Li-ion batteries. Therefore, regulation and drop in V_{peak} seems to be small resulting in a small N and L. For detecting SLA batteries, the parameter $DV2$ will be utilized, which is the non-normalized version of L. From (2) and (4), it is clear that, L can be obtained by normalizing $DV2$ with V_{peak} of that instant and some scaling factor. However, due to large capacities of commercially available SLA batteries, change in V_{peak} is small with time. Therefore, normalizing $DV2$ with comparatively large values of V_{peak} makes L so insensitive that it is hard to predict anything from L. For this reason, in case of SLA, $DV2$ is necessary. Figure 7 shows the parameter values along with V_{peak} and V_{trough}. The trend of the curves show that at *EOD*, the value of $DV2$ remains consistently above 3 for at least three samples when the values of N and L remain below 0.5 in all these instances. Sometimes at the beginning

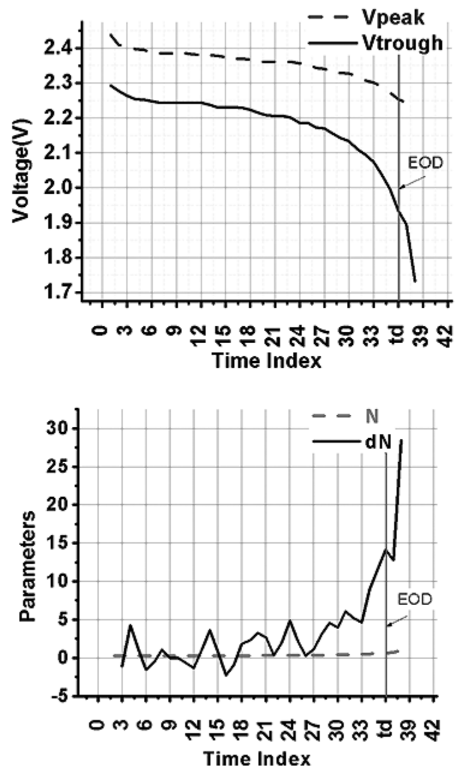

Figure 5. Battery discharging data along with parameters: N and dN [(1) and (3)] for a Ni battery of 2 cells and 4600 mAH capacity. The sampling interval was 2 mins, td is the time index of EOD.

of discharging, $DV2$ remains higher than 3 for other types of batteries but for those batteries the values of any of N or L or both remain above 0.5. Since L is the normalized form of $DV2$, the trend of the curve for both of these parameters are quite similar. But in SLA, the normalizing scale is different from that in Li-ion or Ni based batteries due to very low regulation along with higher nominal cell voltage.

2.6. Decision making scheme

From the previous subsection, a decision criteria can be set to differentiate between different types of batteries by tracking the values of previously defined parameters and comparing them continuously with their threshold levels. It was seen from repeated experimentation and is also revealed in the graph that at the onset of discharging the parameter values seem to be unsteady and show values varying in a wide range. Sometimes if the battery is totally discharged before entering to the detection procedure 10 minute charging is too small for it to regain its original regulation profile. In that case also, at early stage the parameters L and N may show comparatively high values. The appropriate action in that case may be to charge it again using the

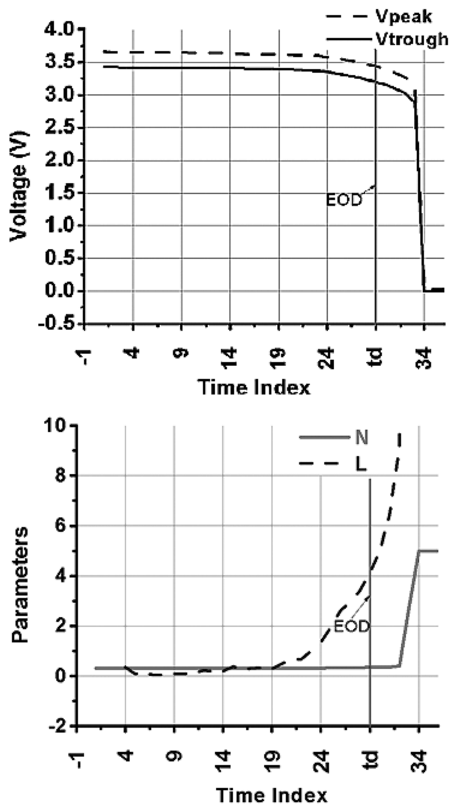

Figure 6. Battery discharging data along with necessary parameters: N and L [(1) and (2)] plotted versus time for a Li-ion battery of 1 cell and 900 mAH capacity. The sampling interval was 2 mins, td is the time index of EOD.

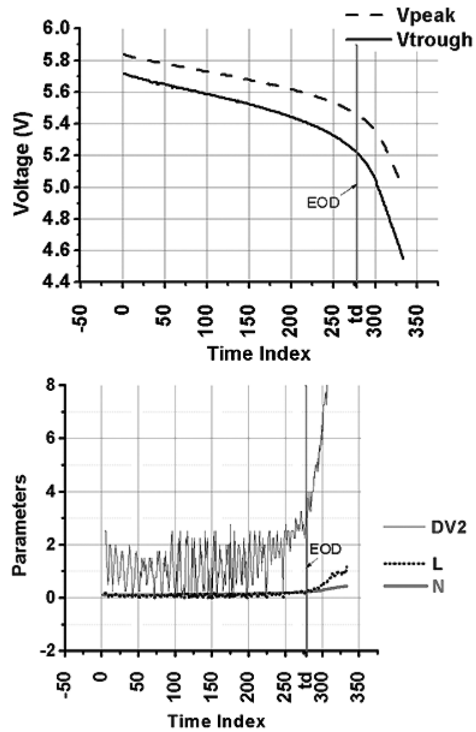

Figure 7. Battery discharging data along with necessary parameters: N, L and $DV2$ [(1), (2) and (4)] plotted versus time for an SLA battery of 3 cells and 3200 mAH capacity. The sampling interval was 2 mins, td is the time index of EOD.

previously used charging cycle of 10 minutes. From minute analysis of the curves for different batteries, it was found that if both L and N show values greater than 1 before taking at least 18 samples of parameters, the battery is safe to be charged again. Although this procedure essentially increases the time required for detection, it ensures accuracy and this portion can be skipped if faster detection is preferred. However, the parameters are compared with the thresholds all the time. The decision criteria can be summarized as in Table 2. These decision criteria are defined from numerous test data with logical approach to analyze the trend of discharging characteristics of different batteries.

3. Experimental results and verification

Our algorithm is mostly based on experimental results. To develop this algorithm, we thoroughly analyzed numerous experimental data. We obtained these data by studying the charging and discharging characteristics of different types of locally available rechargeable batteries. A list of locally available batteries is given in Table 3. A microcontroller based hardware was developed to test the batteries and obtain data, which were stored in the computer through serial port and plotted therefrom.

The discharging curves obtained from different batteries are analyzed and cross-checked to obtain an optimally generalized threshold values to differentiate between different types of batteries. The algorithm was verified by implementing a universal adapting battery charger capable of charging the 4 types of batteries automatically. This 'Universal Adapting Battery Charger' took part in the International Future Energy Challenge (IFEC) competition in 2007. When developing the algorithm, only the 4 types of batteries mentioned are taken into account, whereas similar algorithm can be developed to differentiate between other types of rechargeable batteries. The batteries widely used were the target in this work.

4. Conclusion

In this paper, a novel approach to determine the battery chemistry from charging and discharging characteristics has been introduced which is implementable using microcon-

Table 2. Decision in battery type detection

Condition	Decision
$N > 1$ OR $dN > 5$ for consecutive three times and increasing AND $N > 0.6$ all these times	Ni
$L > 4$ AND $N < 0.8$ for consecutive two times	Li-ion
$DV2 > 3$ for consecutive three times AND $N < 0.5$, $L < 0.5$ all these times	SLA

Table 3. List of tested batteries

Batteries	Manufacturers	Size
Li-ion	Anik, Nokia, Samsung	Cell Phone Batteries
SLA	CoolPower, Unicol, Free Tat Holdings	-
NiMH	Sony, Sanyo, Panasonic	AA, AAA
NiCd	Sanyo, Panasonic	AA, AAA

troller based embedded system. This online approach will make it possible to implement universal battery charger which will be intelligent enough to decide which charging method should be used by determining the battery chemistry.

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