Battery Charging Algorithm for Universal Low Power Battery Charger

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Abstract* – This work proposes a battery identification algorithm for an universal low power battery charger. The universal low power battery charger is defined as a charger that works with universal input voltage and can charge any type of battery, with any cells connection configuration. However, in order to adapt the output voltage to the proper battery type and cells configuration, analysis of the connected battery must be done for identification right at the beginning of the charging process. Furthermore, the algorithm must also identify the end of the charging process in order to indicate it to the user. The features of voltage and current charge profile were used in order to find unique features of each battery, which was used to build the proposed algorithm. For this work, the four most popular rechargeable batteries were taken into consideration: Lead-acid, Nickel-cadmium, Nickel-metal-hydride, and Lithium-ion. The full flowchart of algorithm is provided and explained in details, and experimental results will be given to show its performance.

I. Introduction

The increasing use of portable equipments requires use of battery, which allows independence of the grid. Until a near past, only dischargeable batteries were used. However, since this type of battery is one time used only, the increase of its usage is generating an enormous amount of waste, which is causing environmental problems. So, the advent of rechargeable batteries came as promising effective solution. Nowadays there are a relatively large amount of rechargeable battery types. Among the most popular commercial available batteries are: Lead-acid, Nickel-cadmium, Nickel-metal-hydride, and Lithium-ion batteries. Along with the rechargeable batteries, the equipments necessary to recharge them also was developed. However, each different type of battery requires a different type of charging methodology [1]. Besides the battery type, the cells configuration also changes the nominal voltage of the battery. Therefore, the currently available battery charger is battery type and cell configuration developed. In other words, each battery type and cell configuration uses a different battery charger. As a result, it is common in residencies or workplaces a high number of battery chargers.

Aiming to solve the problem previously described, researches all over the word are working in the development of the so called universal adaptive battery charger. The universal low power battery charger is defined as a charger that works with universal input voltage and can charge any type of battery, with any cells connection configuration. This type of research has two main challenges, the power circuit that works in such wide range, and a control that can adapt the power circuit operation the appropriated battery type and cell configuration [2, 3, 4]. In its turn, one of the main problems of the control is to identify the battery type, cells configuration and the end of the charging process to properly adapt the power circuit operation. Therefore, it is very important to develop an algorithm that guide the controller that applies the appropriate voltage in the start of the process, then, from the measured values of the battery voltage and current, it identifies the battery type and cells configuration. This algorithm, once correctly identified the battery type and cell configuration, must also, from the battery voltage and current, establishes the end of the charging process, turn-off the power circuit, and signalize it to the user.

Therefore, this paper proposes a battery identification algorithm for an universal low power battery charger. The features of voltage and current charging profile are used in order to find unique features of each battery, which was used to build the proposed algorithm. Analysis of the four most popular rechargeable batteries: Lead-acid, Nickel-cadmium, Nickel-metal-hydride, and Lithium-ion, are done in order to extract their features and obtain the algorithm. The full flowchart of algorithm is provided and explained in details, and experimental results are shown to prove its effectiveness.

II. Analysis of the Charging Process of the main Battery types

In order to develop the algorithm to identify the type of battery, estimate the number of cells in series connection, and to determine the instant that the batteries are fully charged, a review of batteries manufactures datasheet was done. This section presents a brief description of the batteries as well as highlights their main features.

The nickel based batteries have similar features. If constant current is used to charge these type of battery, the battery voltage will increase as the charge progress, and will reaches a maximum value when the charge is completed. After reaching this maximum value, the battery voltage starts to increase. It is important to highlight that this happens independent of the discharge level of the battery, the temperature, and so on. Therefore, the detection of the completion of the charge can be done through the detection of voltage peak [5]. In other words, the voltage is monitored, and when there is a drop, it means that the voltage had reached its peak and starts to dropped, and the battery is charged. This method is called “-ΔV cut-off charge system”.

The current level used to charge the battery should be between 0.5C mA and 1C mA, where C is C-rate current. Overcharges may occur if a small current is use, because the -ΔV may be too small, and when the drop after peak is detected, it might be too late. The maximum charge current depends on the battery type, and manufacturers curve is necessary in order to determine the appropriated value. Figure 1 shows typical voltage and current curves for Nickel based batteries. Notice that there is a voltage peak before the actual voltage peak that features the full charge of the battery happens, which may result in premature full charge detection. Premature full charge detection can be avoided by delaying the peak detection algorithm, i.e., it starts to run only sometime after the battery starts to charge. The voltage drop value must also be properly defined, otherwise it may cause false charge full detection.

In its turn, Sealed Lead-acid (SLA), as recommended by manufacturers, should be charged using constant current for a period until the voltage reaches the nominal value [6]. A similar method can be applied to Lithium Ion batteries [7]. After this point, the voltage is controlled to be constant. This method charges the battery by controlling the current at 0.4 C and controlling the voltage at 2.45 V per cell. When the current is 10 % of initial current (0.4 C), the charging process is over. Figure 2 shows typical voltage and current profiles for Sealed Lead-acid batteries.

III. Battery Identification Algorithm Description

In order to efficiently and safely charge the batteries, it is important to correctly identify the battery type and cells configuration [8]. This type of information helps to define the voltage and/or current used by the control as reference inputs. So, aiming to find an algorithm to do battery identification, analysis of charging characteristics was done, as well as some experimental data was generated in order to validate the algorithm. The developed algorithm flowchart is shown in Figure 3. It will be the base of all process of battery identification. All the parameters shown in the algorithm were experimentally obtained.

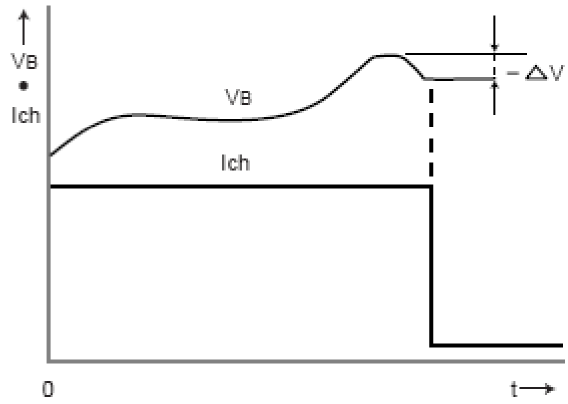

Fig. 1. Charge Characteristics of the -ΔV Cut-off Charge System for Nickel Based Batteries.

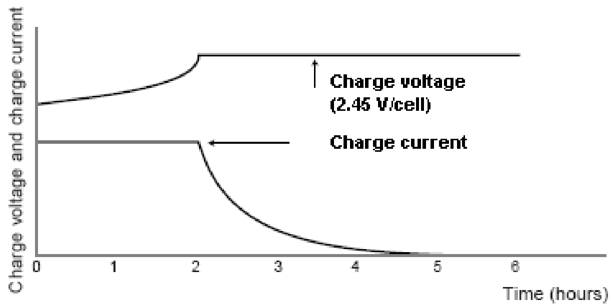

Fig. 2. Charge Characteristics of the Constant Current Charge Method for Sealed Lead-Acid and Nickel Based Batteries.

One of the objectives of this algorithm it was the inclusion of this in a charger of batteries of low cost, therefore with limitations in the processing (for an effective identification of all of the types and configurations of batteries, for the accomplished studies it is necessary a considerable processing capacity, RAM memory and EPROM) hardware.

For so much, she opted for an algorithm that assisted all the batteries and their configurations, that it didn't damage them, without the need of identifying the chemistry of the battery.

Being like this, an effective method was defined. That method is supplied a constant current during the first part of the charging to the voltage in the terminals of the battery to arrive in a certain value, passing then to the second stage of the charging, where it stays the constant voltage in the terminals of the battery to the current to arrive in 5% of the initial current of charging (first part of the method).

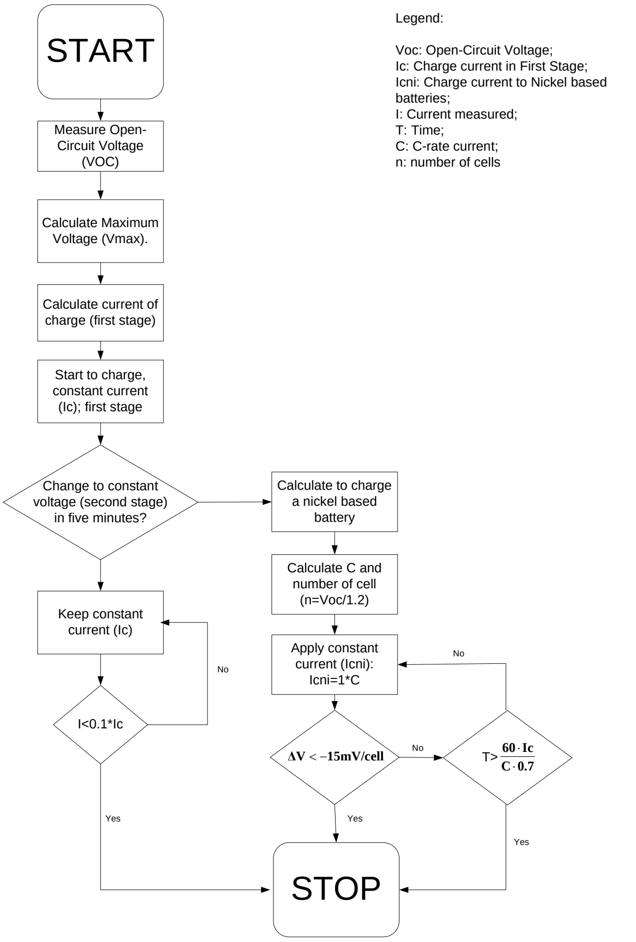

Fig. 3 – Flowchart of the Battery Identification and Charging Strategy Algorithm

Firstly it is made the measure of the voltage in open (Voc) circuit, to esteem the possible number of cells of each battery type. The estimate of the number of cells consists of relating the voltage in open circuit in the beginning of the process for the value of Voc for cell of each battery and then to round for the whole closer. For a nickel based battery, Voc=1.2V / cell, for one of lithium-ion, Voc=3.6V / cell and for the one of lead acid, Voc = 2.1V /cell.

Starting from then, with the number of cells, it is considered the possible maximum voltage for the charging of each type. For batteries of nickel, the maximum value would be of 1.45 V, for the batteries of lithium ion, the limit would be 4.2V and for the lead-acid batteries it would be of 2.4 V.

Then, for comparison with the obtained (one for each chemistry) values, the found smallest is used. The choice of an inferior value to the appropriate in a given temperature results in an inferior charging to 100%, but in compensation there won't be risks of damaging the battery for overcharge.

The advantage of this approach is that no battery would be damaged; however it would probably never be carried totally. As form of minimizing this sub-optimized it could be made simple tests after the transition of constant current for constant voltage.

The simplest test and of great reliability it is to monitor the behavior of the current when it happens for the way of constant voltage. A test of 10 minutes, for instance, would be already enough to make a decision. A constant current in that period, it is concluded then that is a battery of Nickel. In case the classification done by OCV has been Nickel the charging will be contained or changed for a temporized trickle charge.

In case the classification has been different from Nickel would have two cases:

1. The voltage that determines the change of constant current for constant voltage was smaller than the correct. In this case, it would return to a charging the constant current that would be interrupted by the detection of the voltage pick or variation of negative voltage. To avoid the detection difficulty it could be opted for a trickle charge.

2. The voltage that determines the change of constant current for constant voltage was larger than the correct. As the voltage of Nickel doesn't grow in the same way like Lead acid or Lithium ion, the algorithm would "be locked" in the way of constant current to the destruction of the battery. We could adopt two approaches. The first, and maybe the most difficult, would be to detect the negative variation of voltage and case she happened to contain the charging. The second alternative would be to monitor the tax of growth of the voltage. The other alternative would be to monitor the tax of growth of the voltage. These two alternatives would be implemented during the charging the constant current.

The most difficult problem is to do the distinction between the batteries of lithium ion and the batteries of lead acid. The advantage of this algorithm is that never the maximum voltage will be crossed by cell.

The detection using the resistance seems interesting, however, it is necessary to emphasize that the jump only happens when the battery was already damaged. Therefore, it would be valuable if could establish which the chemistry being carried before voltage of the battery reaches the maximum allowed by any type.

The identification consists of analyzing the profile of the voltage during the initial period of the charging, that is common to all the batteries. If during the first 5 (five) minutes it moves in way of constant current for way of constant voltage, the battery of it will be a nickel based.

Identified the nickel battery, we will apply the charging the constant current with ΔV negative.

The possibility to carry a nickel battery with the same algorithm of charging of the other batteries won't go will damage the same. The only risk will be an incomplete charging of the battery (the battery will carry little less than 100%).

IV. Experimental Results

The algorithm was experimentally tested to verify its effectiveness. In order to do that, a few batteries were charged, and their current and voltage profile was observed. Since the charging process of the NiMH is similar to the NiCd, only results for the NiCd will be given.

A prototype built in the laboratory was used to test the battery identification algorithm, as well as the charging process algorithm and charging stop criteria. In the first case, a lithium-ion battery was used. The algorithm correctly identified it and properly controlled and stopped the charging process when the battery was charged. Figure 4 shows the current and voltage profiles during the charge process of a lithium-ion. From the figure it is possible to notice the first part of the charging process, when the current was constant at 0.5 amperes for about 45 minutes, then is starts to drop. After about 35 minutes, it almost reaches zero, and the battery was considered charged. Therefore, this battery was charge in around 1 hour and 20 minutes.

In the case, the algorithm was tested for a SLA battery. Again, correct identification occurred and the charging process was well controlled and its end was recognized. Figure 5 shows the profiles of the current and voltage during the period that the battery was being charged. The figure shows that during the first part of the charging process the current was 1.3 amperes. As result, the battery voltage increases until reaches 7.3 volts. At the second part, the voltage was constant and the current starts to drop until reaches less than 0.2 amperes. The battery then was evaluated as fully charged and the process ended. This battery took 4 hours to be fully charged.

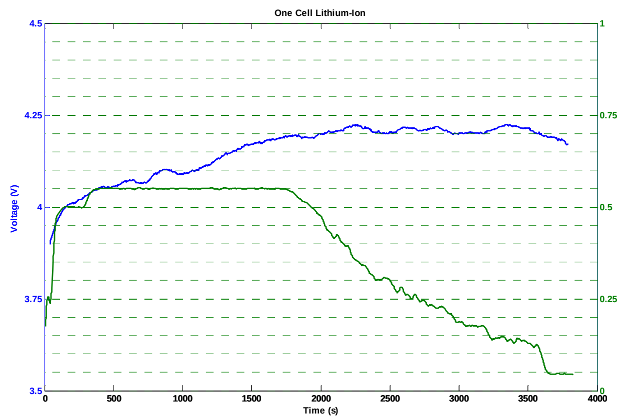

Fig. 4. Current and Voltage Charging Profiles of a Lithium-Ion Battery.

Figure 6 shows the current and voltage profiles during the charge process of a NiCd battery. Basically, as can be seen in the figure, the current was kept constant from the begining of the charge process in around 0.5 amperes. The voltage starts to slowly increase, until about one and half hour later, when it reaches its peak value and starts to decrease. At this point, the battery was considered charged and the charging process ended.

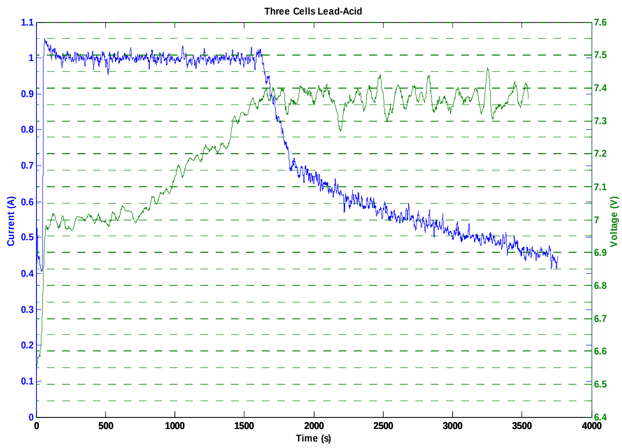

Fig.5. Current and Voltage Charging Profiles of a SLA Battery

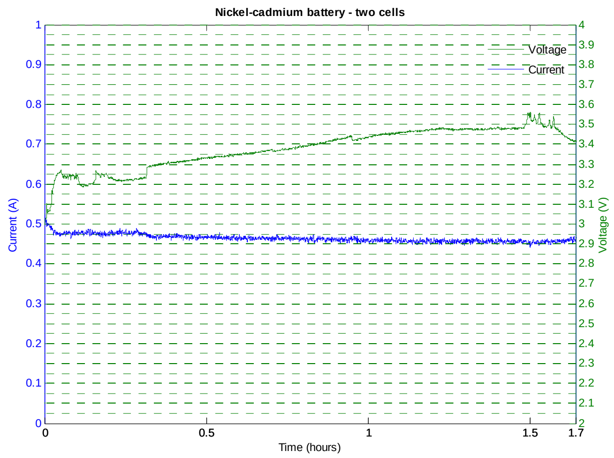

Fig. 6. – Current and Voltage Charging Profiles of a NiCd Battery.

V. Conclusions and Final Considerations

This paper proposed a battery identification algorithm to be used by a universal battery charger. The algorithm can identify the main four commercially available battery types: Lead-acid (SLA), Nickel-cadmium (NiCd), Nickel-metal-hydride (NiMH), and Lithium-ion. It not only identify the battery type, but also estimate the number of cell connected in series, and detects when the battery is fully charged. A detailed description was presented, and experimental results were given to validate the algorithm.

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