A RAPID CHARGER FOR BATTERIES WITH FUZZY LOGIC

INTRODUCTION

Portable appliances, ranging from Walkmen, portable and cellular phones, camcorders, notebook PCs, to electric tools and shavers, are becoming increasingly popular. Most of these devices use rechargeable batteries of the Nickle-Cadmium (NiCd) type. The advantages of this battery type are high peak current, low cost, and the availability of a complete spectrum of sizes and shapes. Unfortunately, NiCd batteries also have disadvantages:

- Charging batteries that are not completely empty will decrease battery capacity (memory effect).
- Over-charging of the battery also decreases capacity and life cycles.
- Over-discharge damages the battery.

Alas, the charge level of a NiCd battery cannot be measured easily. Many indirect parameters have to be considered for a charge level estimation. Hence, many applications use an intelligent, microprocessor controlled system for power management. The charge level estimation is a complex, multi-parameter signal interpretation for which no good mathematical model exists. On the other hand, a lot of engineering expertize is available that can be used to design a fuzzy logic solution. Another reason to use fuzzy logic is that fuzzy logic can help implementation of quite complex systems using very little RAM and ROM resources. Hence, low-cost microcontrollers can be used for this complex signal interpretation task.

This application note shows an overview of using fuzzy logic to implement an intelligent fast battery charger. It assumes prior knowledge of the ST6 fuzzyTECH EXPLORER EDITION fuzzy logic development tool.

1 RAPID BATTERY CHARGERS FOR PORTABLE TOOLS

BOSCH Corporation of Germany used fuzzy logic for the design of their new NiCd rapid charger AL12FC (Ref. 1) The name means: ”AL” for ”Akku-Lader” (battery charger), ”12” for 12 minute charging time, and ”FC” for ”Fuzzy Controlled”. BOSCH designed this charger for electric tools, such as a portable drill. The users of these tools cannot wait for the standard 14 hour charge time of a NiCd battery. Hence, many companies have designed rapid chargers that charge the NiCd battery in just 12 minutes. The problem of these chargers in general is that, due to the high charge current, even an over-charge of one minute can permanently damage the NiCd battery. Due to this, the average live expectancy of about 1000 charging cycles drops down to 300 cycles. Also due to the higher likelihood of under-charging, the capacity of the batteries degrades.

Figure :1 Temperature and voltage of a NiCd battery during rapid charging process using a constant current charge

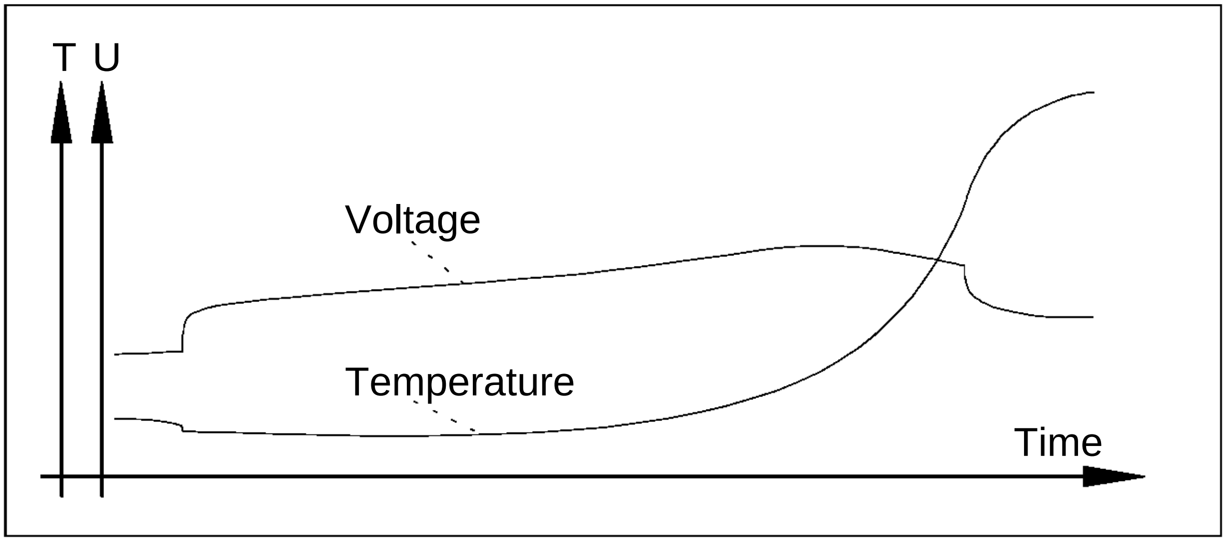


Figure 1 shows the temperature and voltage of a NiCd battery during charge. The batteries used have an integrated temperature sensor. The objective for the charger controller is to determine the ideal shut-off point. The problem is that many parameters influence the ideal shut-off point:

- The used NiCd battery can be from different manufacturers, hence showing slightly different characteristics.
- The temperature sensor is mounted differently with different batteries.
- The charge level at the beginning of the charging point is unknown. Many users do not completely discharge the battery prior to charging.
- Age and the history of the battery are unknown to the charger as one charger is used for many NiCd batteries in most cases.
- The number of cells in the battery is unknown.
- The environment temperature is unknown (only the battery temperature is known).

2 CONVENTIONAL RAPID CHARGE ALGORITHMS

To determine the ideal shut-off point for the charging process, a number of conventional methods exist. The most popular ones are:

- Negative Delta U

This algorithm is the most commonly used for rapid charge. During charge, the voltage maximum is determined, and, after it has been detected, the current is shut off (figure 1seq bild nicd1However, the ideal shut-off point lies before the voltage maximum. Also, in some cases, no voltage maximum occurs. This is the case for batteries not been used for a long period, as the individual cells self-discharge differently over time. With hot batteries (>40°C), the maximum is very flat, if not non-existent. With cold batteries (<10°C), the voltage may reach the maximum well before the battery is completely charged.

- Voltage Threshold

This approach uses a fixed threshold for the voltage to determine the shut-off point. The disadvantages are similar to 1.

- Delta T

The charge is shut off when the actual temperature raises more than 15°C over the pre-charging temperature. This approach heats up the batteries unnecessarily and batteries that are already hot cannot be charged as the temperature rise would destroy the battery.

- Time Limit

This most simple approach shuts off the charging process after a certain period of time. Rapid chargers cannot use this, as the initial condition of the battery is unknown.

The previous generation of BOSCH rapid battery chargers use a negative delta U algorithm. In addition to the low life cycles of the batteries, the large number of possible disturbances caused frequent error shut-offs during operation. The only solution is to not restrict the charge control to just a single parameter but to combine them. However, due to the complex inter-dependencies of the parameters a simple way to combine the parameters does not exist.

Figure 2: Structure of the fuzzy logic system. In total, the fuzzy logic system consists of 4 inputs, 8 rules, and 1 output

For these reasons, BOSCH used fuzzy logic to evaluate the charge condition and to determine the ideal shut-off point. The fuzzy logic system monitors temperature and voltage signal over time. By that, it estimates internal conditions of the chemical charging process. BOSCH implemented the fuzzy logic system on the ST6 microcontroller from SGS-THOMSON Microelectronics, that provides 2 KB of ROM and 32 Bytes of RAM. The fuzzy logic system uses 4 input variables, one output, and 8 fuzzy logic rules. The computing time is about 10 milliseconds, much faster than required for this application. In addition to the fuzzy logic system, the ST6 hosts other code that controls LED indicators and self-checks of the charger.

Figure 3: The linguistic input variable "Temperature" is defined by three linguistic terms

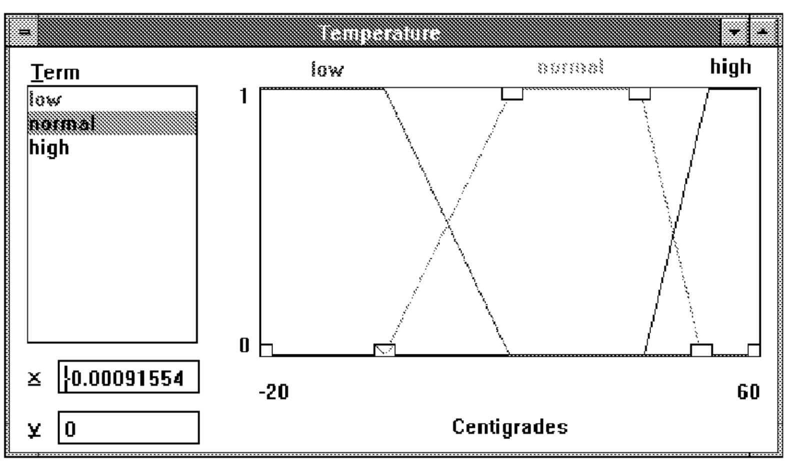
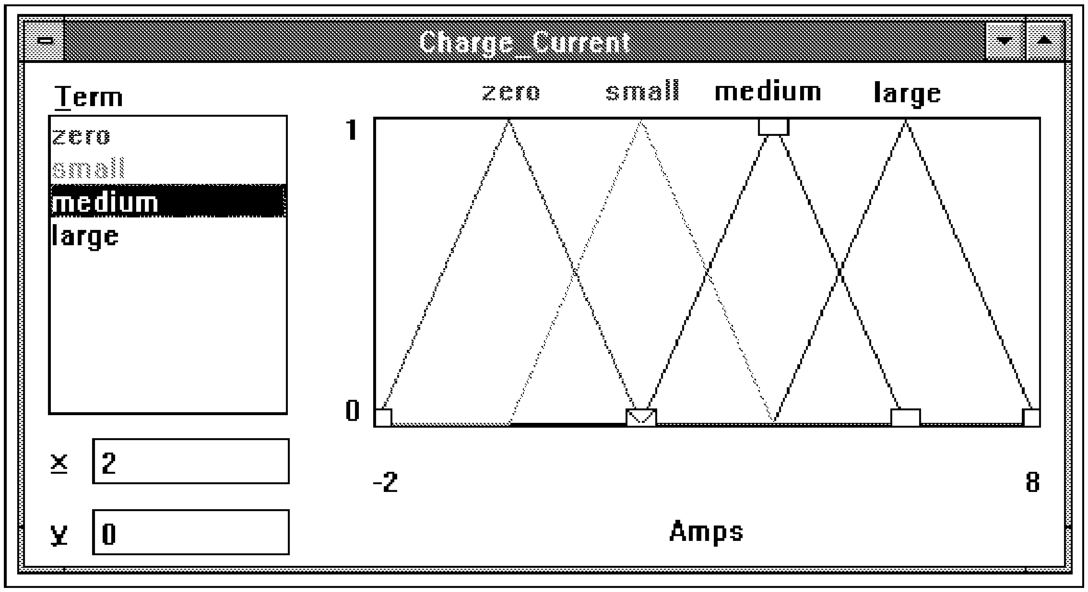


Figure 2 shows the structure of the fuzzy logic system while Figure 3 plots the linguistic input variable "Temperature" and figure 4 the linguistic variable "Charge_Current". All membership functions use Standard-MBFs that can be efficiently computed on a ST6. Figure 5 lists some of the fuzzy logic rules used in the system.

Figure 4 : The linguistic output variable "Charge_Current" is defined by four linguistic Terms



2.1 Summary

Using fuzzy logic, the new charger revealed many advantages over the previous charger, that used a conventional (negative delta U) algorithm:

Figure 5 : Rule base of the fuzzy logic system.

Spreadsheet Rule Editor

Matrix	IF				THEN	
Utilities	Delta_Temp	Delta_Volt	Temperature	Voltage	DoS	Current
1				high	1.00	zero
2			low		1.00	small
3	positiv		normal		1.00	small
4		positiv	normal		1.00	large
5	negativ		high		1.00	small

- Smaller temperature increase of the NiCd battery during charging. This results from an increased charge efficiency.
- Shorter charge time for the same charge level.
- No more error shut-offs during charging.
- The specified temperature range of the charger was extended from 10 - 45°C to 0 - 60°C
- The live expectancy of the NiCd batteries used extended to 3000 cycles.

The methods used in this case study can in principle also be used for other types of rechargeable batteries. Also, the discharging process can be monitored and optimized in a similar way. Other applications of fuzzy logic power management include charge gauges that determine the remaining charge of rechargeable batteries. The applications of these power management functions are in electric cars, portable digital assistants, and cellular phones.

2.2 Reference

Ref 1 : Flinspach, G., Osswald, A., Wolf, P. und Surmann, H., ”Schnelladeverfahren für NiCd-Batterien”, in v. Altrock/Zimmermann (Ed.), ”Fuzzy Logic - Anwendungen”, Oldenbourg Verlag, München (1993).

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