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Application report
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Programming of different charge methods with the BaSyTec Battery Test System

Important Note:
You have to use the basytec software version 4.0.6.0 or later in the ethernet operation mode if you use the calculate command as it is described in this application note.

Introduction

There are a lot of advanced charge methods known that are based on pulse charging or that take the history of the battery into account. It is well known that the charge method has an significant influence on the short term performance (capacity and internal resistance for the next discharge) but also on the long term performance (lifetime) of most battery chemistries. Therefore it is recommended to use the same charge method in laboratory tests as it is used in the target application. There are two possibilities, how customized charge methods can be carried out with the BaSyTec Battery test System::

1. The use of an original charge equipment in combination with the "EXTERNAL Option" of the BaSyTec equipment.
2. Simulation of the charge method by the basytec test system.

This paper concentrates on the second possibility. Different possibilities are explained by test plans and by measured curves.

Please take care of the rights of the charge methods. Many advanced charge algorithms are protected by patents and you are not allowed to use them in your products without licensing.

Simple charge methods

NiMH and NiCd Batteries

Constant current charge with termination by time:
Looking for NiMH batteries the standard charge method is a time limited constant current charge. The standard current is the 10 hour rate and the charge time is between 14 and 16 hours. This method is quite simple, but very slow and results in most cases in a high amount of overcharge. The following figure shows a test plan for such a charge method.

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D:\Bst\procedure\NC Laden.pln

Zeile einfügen | Zeile löschen | Registrierformat

	Ebene	Label	Befehl	Parameter	Abbruchkriterium	Aktion	Registrierung	Kommentar
1			Start					
2			Pause		t>60s		t=10s	Get open circuit voltage
3			Charge	I=0.1CA	t>16h		t=5min U=10mV	Charge with 0.1C Rate for 16h
4			Pause		t>60s		t=10s	Get open circuit voltage
5			Stop					

Figure 1: Test plan for a standard constant current charge for a NiMH or NiCd battery

The overcharge increases with battery age, as the capacity drops and the charge amount is unchanged. One improvement is the so called charge factor controlled charge method. This method counts the discharged Ah and the next charge is done with a defined charge factor. Typical values for the charge factor (NiMH batteries) is between 1.2 and 1.4. Figure 2 shows a test plan and the voltage for a charge factor based charge method.

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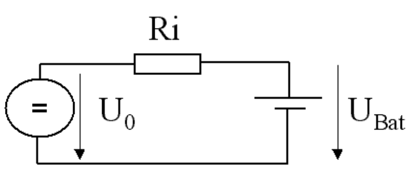
Insert line | Delete line | Registration-Format

	Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1			Start					
2			Pause		t>30s		t=5s	Get open circuit voltage
3			Discharge	I=500mA	U<1.0V		t=1min U=20mV	Discharge the battery
4			Charge	I=250mA	Ah>-1.2AhPrev		t=0.5s	Charge with a charge factor of 1.2
5			Pause		t>30s		t=0.5s	Get open circuit voltage
6			Stop					

Figure 2: Test plan (top) for a charge factor based charge after a cc discharge of a NiMH battery

The test plan uses the internal value AhPrev, what is the charge amount of the previous step (here discharge step) multiplied by the charge factor (here1.2) to terminate the charge step. The negative sign (-1.2) is necessary, as the discharge charge amount is negative (Nomenclature of the current: charging: positive current; discharging: negative current). It is important that the battery starts a fully charge state, otherwise the charge procedure will be terminated to early.

Another simple charge method is done by a simple constant voltage source in combination with a resistor. The current flowing through the battery is then the difference between the voltage source and the battery voltage divided by the resistor.



$$I = \frac{U_0 - U_{Bat}}{Ri} \qquad (1)$$

This means that the current is decreased if the voltage increases. The BaSyTec Battery Test System do not support this control method as a native control method. Therefore it is necessary to define the charge current within a calculate statement. The following figure

shows a test plan for this charge method. The calculate command represents exactly equation (1), where I1 is the charge current and U is the battery voltage. The voltage U0 is set to 1.65V. The resistance Ri is represented by 1V/2A what is equal to 0.5Ω.
It is recommended to do first the multiplication with 2A and finally the division by 1V. The used brackets clearly define the calculation order in the calculation statement. An other order can result in a rounding error, especially if the resistance would be calculated first. The reason therefore is that the system internally operates with raw integer values and also calculates with integer values. It is possible to handle large numbers, as the internal resolution is 96 bit. Therefore it should be avoided to divide numbers that are in the same range.

D:\Bst\procedure\Example_U0R_Charge.pln

Insert line | Delete line | Registration-Format

	Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1			Start					
2			Calculate	I1=(2A*(1.65V-U))/1V				Calculate the charge current
3			Pause		t>30s		t=10s	Get Open circuit voltage
4			Discharge	I=1A	U<0.8V		t=30s	
5			Pause		t>30s		t=10s	
6			Charge	I=I1			t=10s	Charge with calculated current
7			Stop					

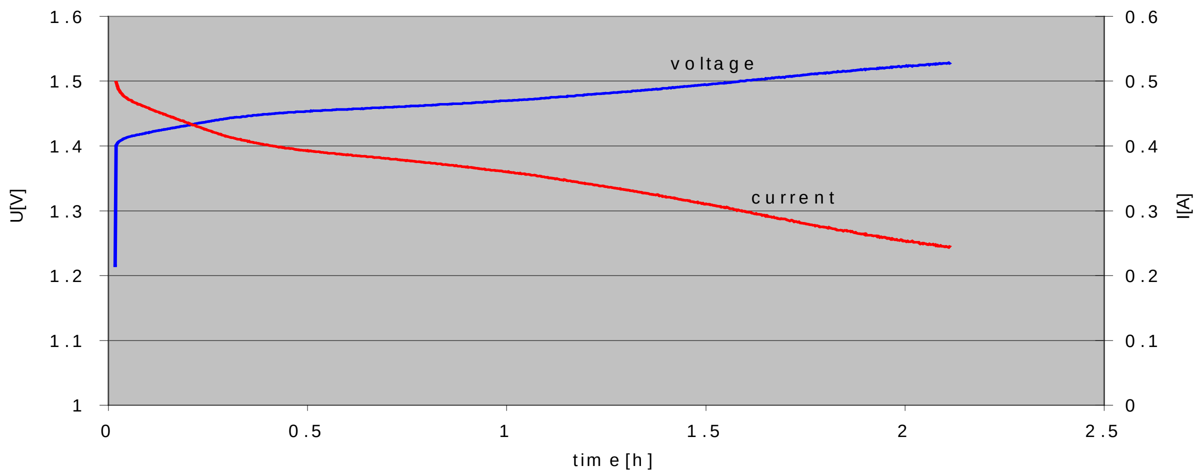
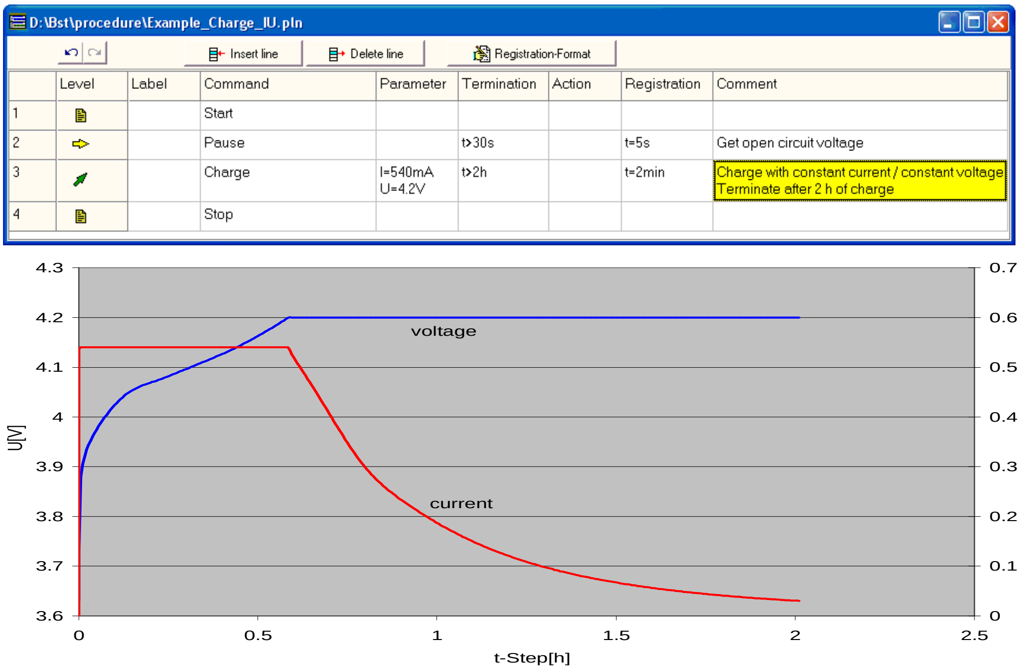


Figure 3: Test plan (top) and voltage (bottom) for a charge method based on a voltage source and a internal resistance

Li-ion and lead acid batteries

The standard charge method for Li-ion and lead acid batteries is the constant current-constant voltage (cc/cv) charge method. In comparison to the cc charge method for Ni based batteries the cc/cv method is a two step charge method. The second charge step is necessary to avoid overcharging (li-ion) or to limit the overcharge amount to a acceptable level (lead acid). Figure 4 shows a test plan for a cc/cv charge method for a Li-ion battery.



	Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1			Start					
2			Pause		t>30s		t=5s	Get open circuit voltage
3			Charge	I=540mA U=4.2V	t>2h		t=2min	Charge with constant current / constant voltage Terminate after 2 h of charge
4			Stop					

Figure 4: Test plan (top) and voltage/current curves (bottom) for a cc/cv charge method as it is used for Li-ion batteries

As high voltages on Li-ion batteries limit the battery lifetime it is recommended to terminate the charge process if the battery has reached the full state of charge. This termination is done by the time or the charge current. If the charge current goes below a given value (typical 1/10 to 1/30 of the 1C rate) the charge process is terminated.

Improved charge methods

To improve the charge methods the side reactions must be taken into account. The electrochemical side reactions increase in activity if the battery comes closer to the full state of charge. In case of the full state of charge the whole charge current is flowing into the side reactions. This results in overcharging, heating and maybe water loss or drying out of the cell. Therefore the charge parameters should be adapted to the speed of the side reaction or the detection of side reaction can be used to terminate the charge process.

NiMH and NiCd batteries charge termination

Sealed NiCd and NiMH batteries generate heat if the side reactions are active. This characteristic is used to terminate a constant current charge. There exist two different possibilities for detecting the increase in heat generation. The first possibility is to analyze the temperature development of the cell. The second possibility is to analyze the cell voltage, as the voltage will drop when the cell heats up.

Termination by analyze the temperature measurement

There exist two possibilities: The first possibility is to stop charging if the temperature increases for a give value, typically 10K. The second possibility is to analyze the slope of the temperature and to stop charging if the slope reaches a given limit (typical value 1K/min).

Termination by analyze the voltage of the cell

this method analyses the voltage drop if the battery temperature increases (caused by increase of the activity of the side reactions). This method is called the –delta U or -ΔU charge termination method. This is the most common used fast charge method for NiCd and NiMH batteries. Typical values for the voltage decrease detection level are in the range of –2 to –20 mV/cell. Whereas for NiMH –2 to –10 mV/cell are typical and for NiCd cells values up to –20mV/cell are possible.

The following example shows a test plan for a cc charge that is terminated by a -ΔU termination method. Additionally a time limit is defined, to limit overcharging in case of failure in -ΔU detection.

D:\Bst\procedure\Example_Charge_dU.pln

Insert line | Delete line | Registration-Format

	Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1			Start					
2			Pause		t>10s		t=1s	Get OCV
3			Set	t-Set=0s				
4			Charge	I=1CA	t>5Min U>1.8V		t=20s U=10mV	Charge the first few minutes with deactivated -delta U to avoid termination by passivation effects.
5			Charge	I=1CA	UMax-U>5mV t>1.3h U>1.8V		t=20s U=10mV	Terminate on -delta U with 5mV Savety termination on time and voltage
6			Pause		t>10s		t=1s	Get OCV
7			Stop					

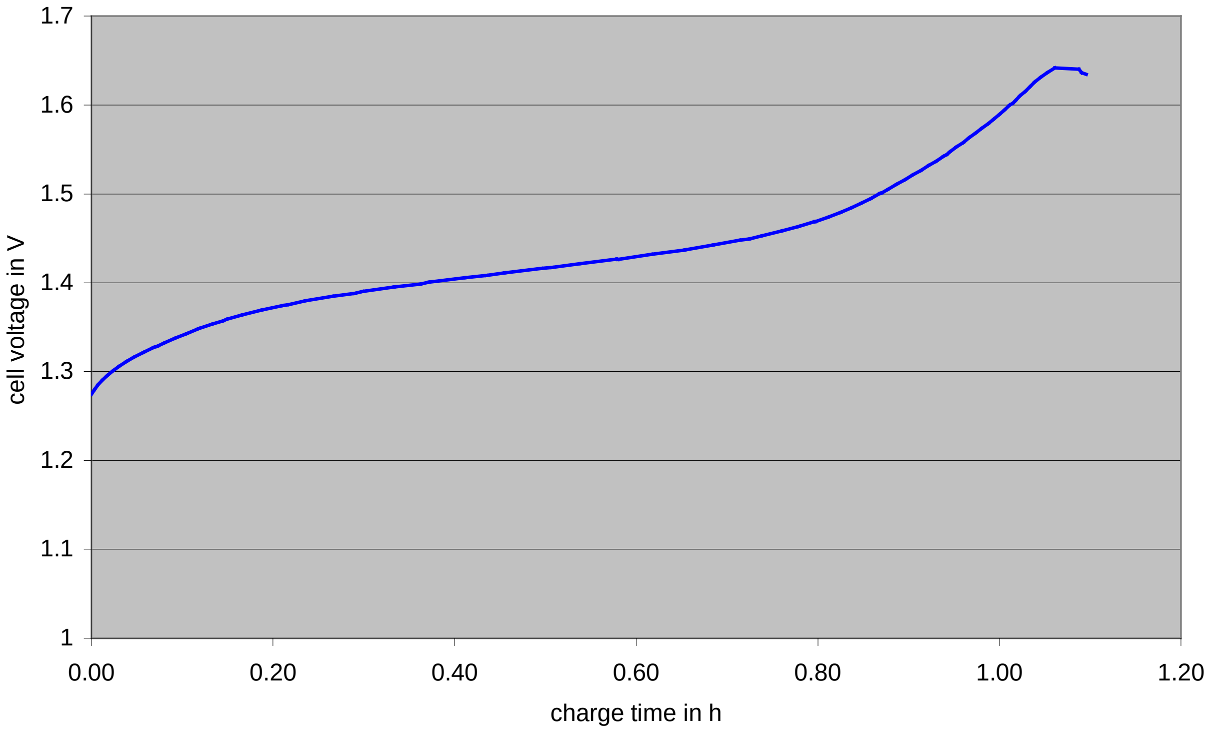


Figure 5: Test plan (top) and voltage curve (bottom) for a -ΔU terminated cc charge method (NiMH Battery)

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Pre-charge for NiMH and Li-Ion Batteries

Some charge controllers for NiMH and most charge controller for Li-Ion batteries have a pre-charge or conditioning charge phase before the fast charge phase is started. Within the pre-charge phase the battery is charge with a small current (≤ 0.1C-Rate) until a minimum battery voltage (NiMH approx. 0.8V, Li-ion approx. 2.8V) is reached. The pre-charge phase avoids charging of damaged batteries.

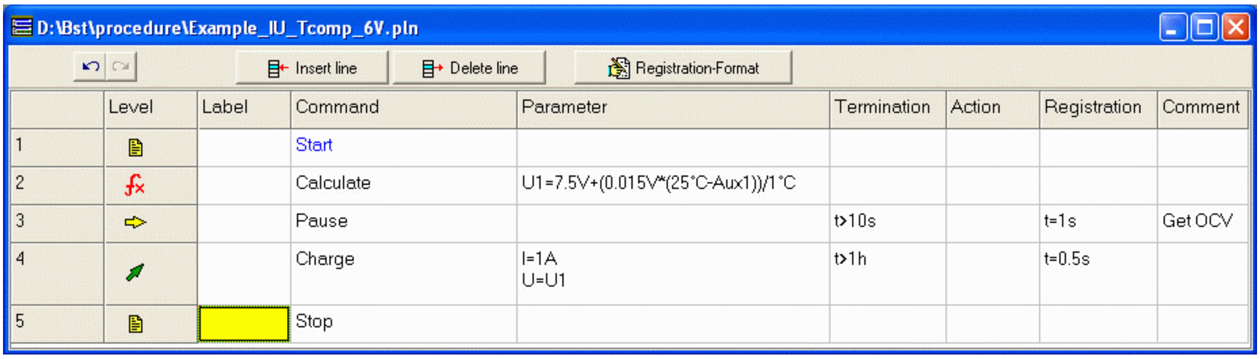
Lead-acid battery temperature compensated cc/cv charge method

To improve the recharge ability at low temperatures and to avoid overcharging at high temperatures the control voltage of the cv charge phase is adapted to the battery temperature by a linear relation:

$$U_{Ch} = U_{Ch,25} \cdot (1 + (\upsilon - 25) \cdot \alpha)$$

With
U_{Ch}: Charge voltage at temperature υ
$U_{Ch,25}$: Charge voltage at 25°C
υ: Battery temperature
α: temperature coefficient (typically –3 ..-6mV/K for one cell)

Figure **6** shows a test plan for a temperature compensated charging voltage for a 7.5V lead acid battery. Alpha is –5mV/(K cell) what is -15mV/K for a 6V battery. The calculation of the charge voltage is done by the calculate command. Again the calculation command uses internally the integer values of the test machine. Therefore the calculation order is again important.
From the calibration data of the system the factors for all analogue channels can be found. In the system we used 15mV is equal to an internal value of 31 and 1°C is equal to an internal value of 38. Therefore internally the alpha value would be 0 (31/38) as the test system cannot handle floating point values. To avoid this rounding error, the calculation of alpha is split in two parts, as it is shown in the following figure.



	Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1			Start					
2			Calculate	U1=7.5V+(0.015V*(25°C-Aux1))/1°C				
3			Pause		t>10s		t=1s	Get OCV
4			Charge	I=1A U=U1	t>1h		t=0.5s	
5			Stop					

Figure 6: Test plan for charging with a temperature compensated voltage

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Advanced charge methods

Pulse charging for NiMH and NiCd batteries

In case of higher currents the ohmic losses of the contacts will change during charging (caused by heating). In case of -ΔU termination criteria, this can result in wrong termination. To avoid this a four wire measurement is necessary or alternatively a current free voltage measurement. The second method is often used in portable products, where four wire arrangement is to expensive. The current free measurement works as follows:
The charge current is periodically interrupted for some ms. Within this pause the voltage is measured and used for the termination criteria. The following test plan shows an example where the -ΔU termination criteria used on this current free voltage.

D:\Bst\procedure\Example_Pulsecharge_NC_1.pln

Insert line | Delete line | Registration-Format

	Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1			Start					
2			Pause		t>10s		t=1s	
3			Discharge	I=2A	U<1V		t=5s	First discharge the cell
4			Pause		t>10s		t=1s	
5			Charge	I=1.5A	t>1min		t=5s	Do an initial charge to avoid wrong termination
6		LOOP	Cycle-start		du>0		Count=2	Repeat pulse charge until du > 0
7			Calculate	UR=last([REST]:U)				Get the voltage at the end of the rest
8			Calculate	UMax=max([LOOP]:last([REST]:U))				calculate the maximum voltage
9			Calculate	dU=UMax-UR-0.005V				Calculate the voltage drop - 5 mV
10			Charge	I=1.5A	t>0.99s		t=5s	Charge pulse
11		REST	Charge	I=0A	t>10ms		t=5s	Rest pulse
12			Cycle-end	count=0				
13			Pause		t>10s		t=1s	
14			Stop					

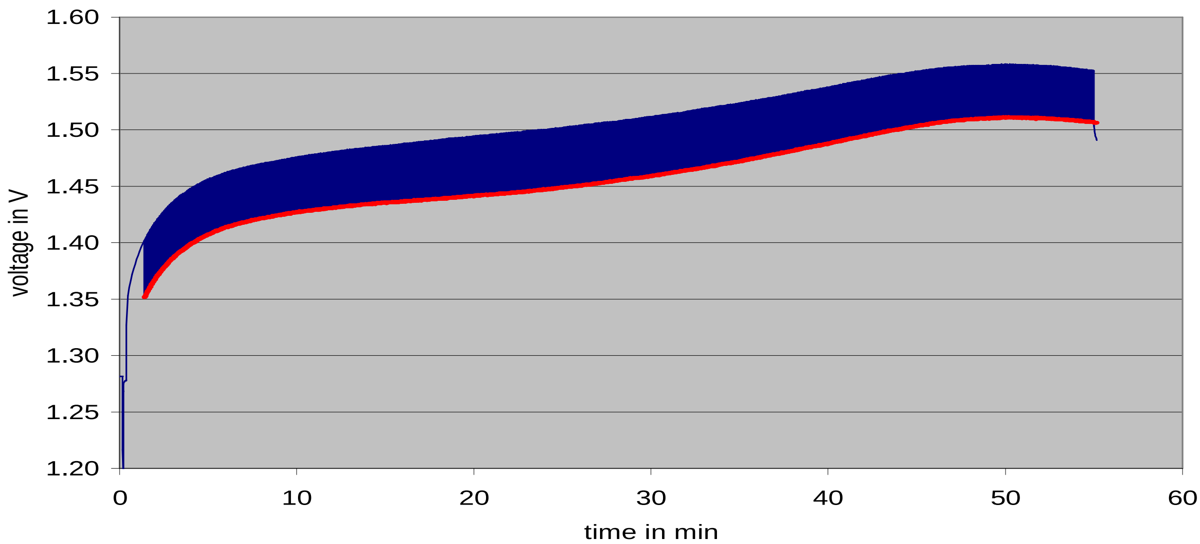
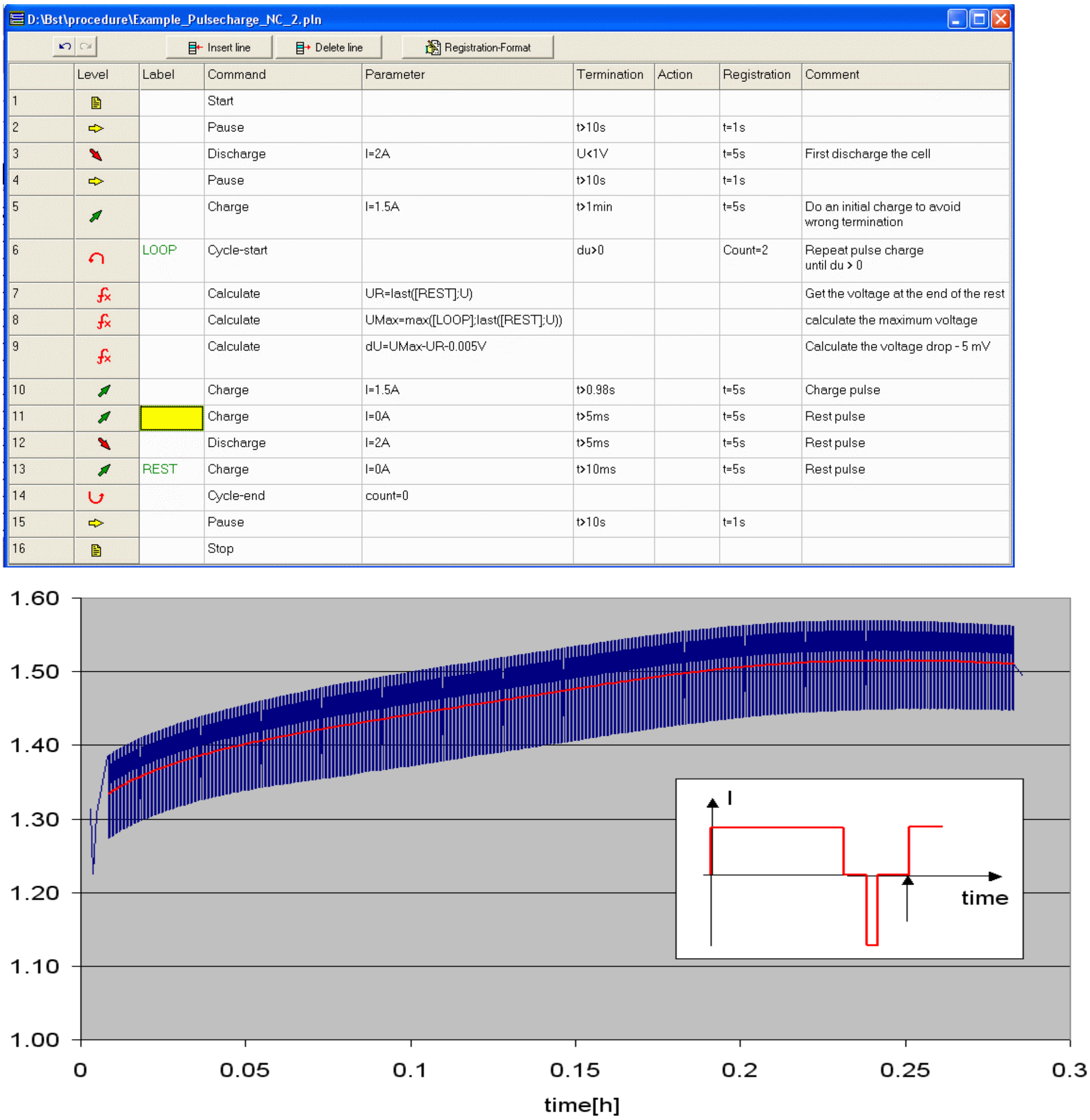


Figure 7: Test plan (top) and voltage curve (bottom) for a NiCd pulse charge regime where the current free voltage (red curve) is used for a -ΔU termination criteria. Blue: Battery voltage, red: Voltage at end of pause

It is also possible to use discharge pulses within the charge pulse regime, as it is done by some charge algorithms. The following figure shows a test plan where discharge pulses are used in the charge pulse regime.


D:\Bst\procedure\Example_Pulsecharge_NC_2.pln

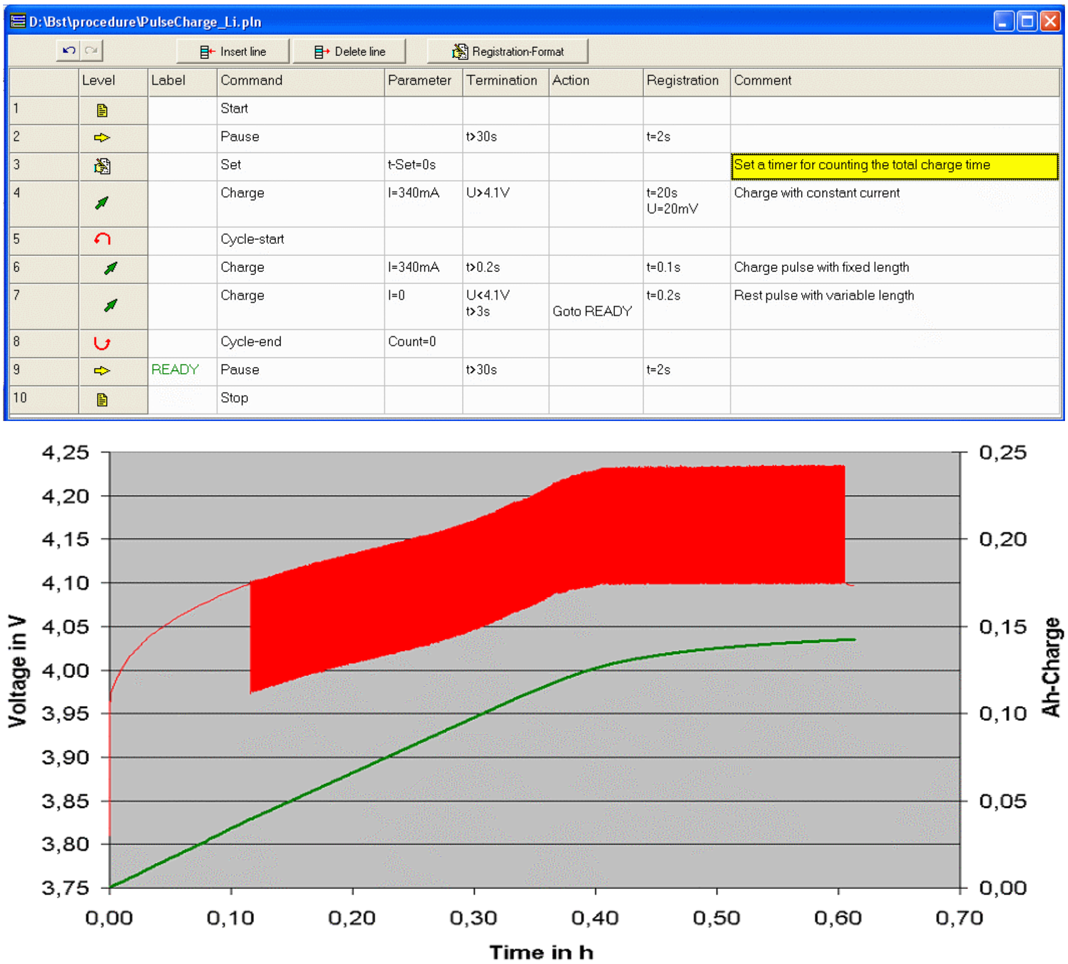
	Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1			Start					
2			Pause		t>10s		t=1s	
3			Discharge	I=2A	U<1V		t=5s	First discharge the cell
4			Pause		t>10s		t=1s	
5			Charge	I=1.5A	t>1min		t=5s	Do an initial charge to avoid wrong termination
6		LOOP	Cycle-start		du>0		Count=2	Repeat pulse charge until du > 0
7			Calculate	UR=last([REST]:U)				Get the voltage at the end of the rest
8			Calculate	UMax=max([LOOP]:last([REST]:U))				calculate the maximum voltage
9			Calculate	dU=UMax-UR-0.005V				Calculate the voltage drop - 5 mV
10			Charge	I=1.5A	t>0.98s		t=5s	Charge pulse
11			Charge	I=0A	t>5ms		t=5s	Rest pulse
12			Discharge	I=2A	t>5ms		t=5s	Rest pulse
13		REST	Charge	I=0A	t>10ms		t=5s	Rest pulse
14			Cycle-end	count=0				
15			Pause		t>10s		t=1s	
16			Stop					

Figure 8: Test plan (top) and voltage curve (bottom) for a NiMH pulse charge regime with discharge pulse where the current free voltage after the discharge pulse (red curve) is used for a -ΔU termination criteria. Blue: Battery voltage, red: Voltage at end of second pause

Pulse charging of Li-ion batteries

Pulse charging of li-ion batteries is done in some applications where the control circuit should not dissipate heat. The battery is charged with a constant current until the charge voltage limit (CVL) of 4.2V (4.1V) is reached. Then the charge is continued by a pulse current regime that has 2 steps. In the first step the battery is charged with the defined charge current for a fixed time of some hundred ms. The voltage goes above the charge voltage in this phase. A rest time follows. The rest period is finished if the voltage drops again under the charge voltage.

In some applications the rest period has a minimum duration. This pulse regime is repeated until the rest period duration exceeds a given time (Rest Period Finish Time RPFT). The RPFT is selected in that way that the average charge current is at the end of the charge between 1/10 and 1/20 C rate. Figure 9 shows a test plan and a measured curve for such a pulse charge regime. The battery had a state of charge of approximately 75% at the beginning of the charge procedure. The charge voltage limit is 4.1V and the charge pulse length is 200ms.


D:\Bst\procedure\PulseCharge_Li.pln

	Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1			Start					
2			Pause		t>30s		t=2s	
3			Set	t-Set=0s				Set a timer for counting the total charge time
4			Charge	I=340mA	U>4.1V		t=20s U=20mV	Charge with constant current
5			Cycle-start					
6			Charge	I=340mA	t>0.2s		t=0.1s	Charge pulse with fixed length
7			Charge	I=0	U<4.1V t>3s	Goto READY	t=0.2s	Rest pulse with variable length
8			Cycle-end	Count=0				
9		READY	Pause		t>30s		t=2s	
10			Stop					

Figure 9: Test plan (top) and voltage curve (bottom) for a Li-ion pulse charge regime

Depending on the charge parameter and the battery age it is possible that the protection circuit will switch the battery off.

IR free charging for lead acid batteries

This charging method is sometimes discussed for lead-acid batteries. It is based on a standard cc/cv charge method, however the control voltage within the CV charge phase is not the battery terminal voltage but it is the resistance free battery voltage. Therefore all voltage losses caused by the internal resistance are compensated. To get the resistance free voltage, the charge current is periodically, for example every second, interrupted.