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Application report

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Date of last change 08.02.2006

Testing protection circuits for lithium batteries with the BaSyTec Battery Test System

1 Introduction

As lithium batteries are very sensitive to overcharge, over-discharge and over-current, they have to be protected with a protection circuit against these items. As they may explode and injure the user especially at overcharge, product liability forces all distributors and dealers to ensure that the batteries they provide are equipped with an active protection circuit and that the protection circuit works properly.

There are several requirements for these protection circuits:

- Precise voltage measurement to detect overcharge.
- Fast reaction times to switch off, especially for overcurrent (usually < 10ms).
- Reliable ability to switch off.

And several conditions where they have to switch off:

- Battery voltage exceeds overcharge detection voltage.
- Battery voltage below overdischarge detection voltage.
- Current exceeds overcurrent limit (both for charge and discharge direction).
- Battery temperature exceeds the overtemperature level.

After having switched off (which is a reversible process) it switches on again if the error condition has been removed, which means that the load or the charger have been disconnected. Usually this is detected by the voltage, which can also be measured when testing the protection circuit.

Figure 1 shows a typical schematic drawing of a lithium ion battery pack. Next to the active protection circuit ① as described above there are also passive protection elements used in the battery pack. For additional over-current and over-temperature protection a polyswitch ② is used and the cell itself has safety elements ③ (valve and shut down separator).

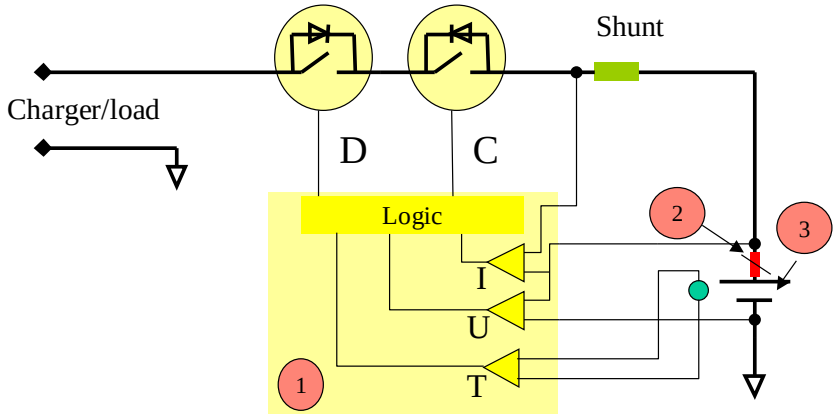

Figure 1: Battery Pac with active and passive protection system

2 Requirements for the test system

The test system to test the protection circuits has to provide very fast and precise voltage control, even if the external circuit is opened. As many protection circuits do not withstand voltages more than 7V even for several µs, the requirement for the test system is quite high. BaSyTec Battery Test Systems of the GSM series are able to meet this requirement, please ask.
The other item is that the test system should have a fast time resolution, as provided in all BaSyTec Battery Test Systems.

3 Test procedures and measurement example

There are two possibilities for the test:

1. **Test without a battery**

In this case, there are two voltage/current sources necessary to test: one simulating the battery side and one simulating the charger or load. For the battery side, one constant voltage source at about 3.5V is sufficient if its impedance may be switched between high impedance (to test the voltage parameters) and low impedance (to test the over-current conditions). An appropriate option is available for the BaSyTec Battery test systems. The big advantage of this kind of test is that it is quite fast, as the batterie's state of charge does not have to be adjusted for the separate tests and that the precision for the voltage parameters is a bit better as the current flowing doesn't influence the readings. The disadvantage is that malfunctions caused by the assembly of the protection circuit to the battery are not detected.

2. **Test with the battery**

As a high battery current disturbs the results by the ohmic drop, the battery current has to be kept low when measuring the switch off voltages. Therefore, there are tests which have to be done at different states of charge:

Tests at high state of charge

1. OCDV Overcharge detection voltage
2. OCDT Overcharge detection time
3. OCRV Overcharge release voltage
4. DOC Discharge overcurrent
5. DODT Discharge overcurrent detection time
6. DORV Discharge overcurrent release voltage

The discharge overcurrent tests are done at high SOC to prevent the protection circuit switching off because detecting the over-discharge detection voltage.

Tests at low state of charge

7. COC Charge overcurrent
8. CODT Charge overcurrent detection time
9. CORV Charge overcurrent release voltage
10. ODV Overdischarge detection voltage
11. ODDT Overdischarge detection time
12. ODRV Overdischarge release voltage

It is not possible to measure the overtemperature detection temperature.

Table 1 is an example for the protection circuit tests performed at high state of charge. In the first step (line 8), the battery is sufficiently charged first. The voltage values OCDV, OCRV and DORV (see the labels in the test plan) are measured by waiting until the current falls to zero or rises again, the detection times are measured with a high constant current and the overcurrent is measured by linearly increasing the discharge current.
All values are put into variables with the calculate command with the advantage of finding them in separate data table columns, which much facilitates doing a summary, for example putting together all data of different batteries into one table with a script.
The high registration in line 19 forces to switch the test system to a high sampling rate to ensure exact detection time measurement.
Additionally, in lines 18 and 19 a defined voltage step is created which enables the BaSyTec Battery Test System to measure the internal AC resistance of both battery and protection circuit simultaneously with the overdischarge detection time. If the AC resistance is high it is a hint that the protection circuit is not properly assembled or that the battery is bad.

Table 1: Example test plan for tests at high state of charge

	Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1			Start					
2			Calculate	OCDV=last([OCDV];U)				
3			Calculate	OCRV=last([OCRV];U)				
4			Calculate	OCDT=max([OCDT];t)				
5			Calculate	DOC=last([DOC];I)				
6			Calculate	DORV=last([DORV];U)				
7			Calculate	ODDT=max([ODDT];t)				
8			Charge	I=1CA U=4.2V	I<200mA		U=20mV I=20mA	Ensure that the battery is sufficiently charged
9		OCDV	Ramp-u	U1=4.2V U2=5V slope=50mV/s	I<100mA U>4.6V		t=1s U=20mV I=20mA	Measure Overcharge Detection Voltage
10			Charge	U=5V	t>1s		t=1s	
11		OCRV	Ramp-u	U1=5V U2=3V slope=-50mV/s	I>100mA I<-100mA		t=1s U=20mV I=20mA	Measure Overcharge Release Voltage
12			Charge	I=2A U=4.2V	I<200mA		U=20mV I=20mA	Ensure that the battery is sufficiently charged
13		OCDT	Charge	I=2A U=4.5V	I<100mA t>3s		t=1s U=20mV I=20mA	Measure Overcharge Detection Time
14		DIS	Discharge	I=1A	t>1s		U=20mV I=20mA	Switch on the protection circuit again
15		DOC	Ramp-i	I1=-1A I2=-5.2A slope=-100mA/s	I>-500mA		t=1s U=20mV I=20mA	Measure Discharge Overcurrent
16		DORV	Ramp-u	U1=2V U2=5V slope=100mV/s	I>100mA I<-100mA		t=1s U=20mV I=20mA	Measure Discharge Overcurrent Release Voltage
17			Charge	I=1A U=4.2V	t>1s		U=20mV I=20mA	Switch sure on the protection circuit again
18			Discharge	I=0.5A	t>100ms		U=20mV I=20mA	Measure Impedance 1. step
19		ODDT	Discharge	I=5A	I>-100mA		t=1ms	Measure Overcurrent Discharge Detection time + impedance
20			Stop					

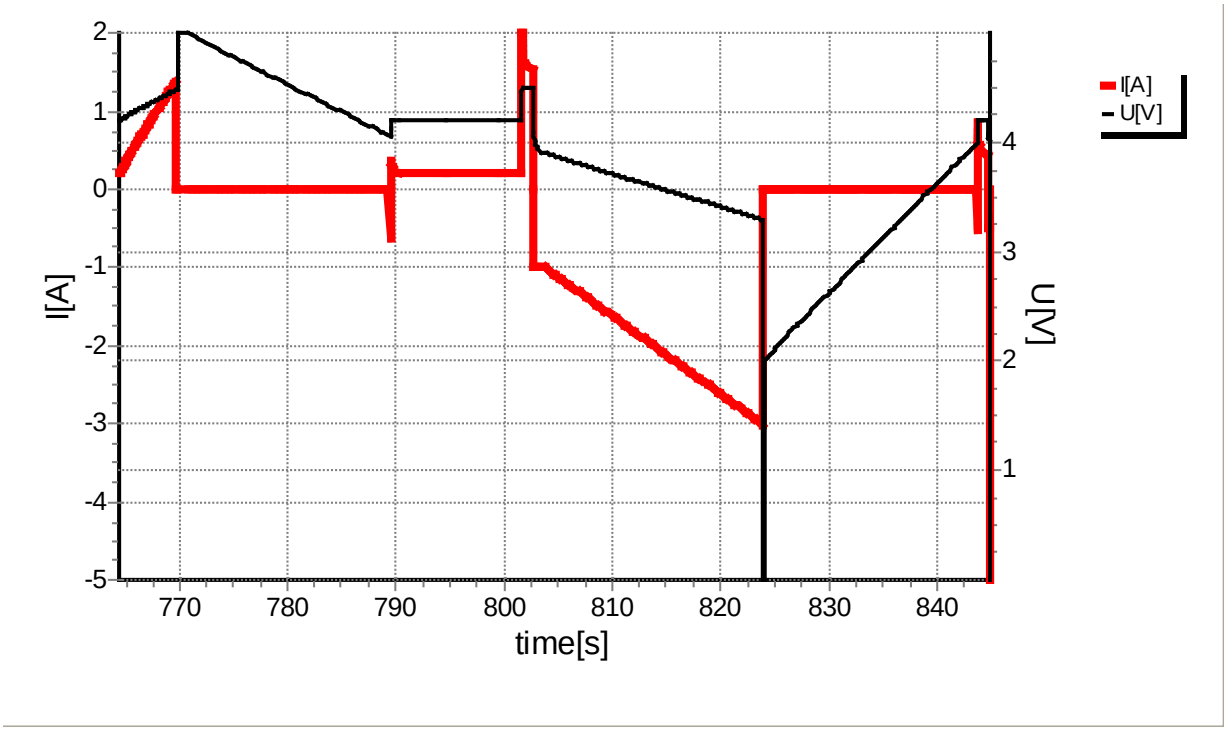

Figure 2: Voltage and current for high state of charge test (Table 1)

In Figure 1, you see the voltage and current for the test at high state of charge, without the initial charge step skipped.
In the first step (until 770s), the voltage is increased until the charge current falls to zero (thick, red line). The voltage at the maximum current is the switch off voltage (OCDV).
Then, the voltage is decreased again until there is some current again (OCRV).
The voltage is set to 4.5V and the time until the circuit switches off (OCDT) is measured (@ about 803s).
The discharge current is increased then (804 to 823s) and the cut off current (ODDC) is measured.
The last step with the 5A discharge current is to measure the discharge overcurrent detection time.
The following values have been detected by this test:

1.	OCDV	Over charge detection voltage	4.479V
2.	OCDT	Over charge detection time	1.020s
3.	OCRV	Over charge release voltage	4.050V
4.	DOC	Discharge overcurrent	3.014A
5.	DODT	Discharge overcurrent detection time	7ms
6.	DORV	Discharge overcurrent release voltage	3.999V
		AC resistance (including cables)	149mOhm

Table 2: Example test plan for tests at low state of charge

	Level	Label	Command	Parameter	Termination	Action	Registration	Comment
1			Start					
2			Calculate	ODV=last([ODV]:U)				
3			Calculate	ODRV=last([ODRV]:U)				
4			Calculate	ODDT=max([ODDT]:t)				
5			Calculate	COC=last([COC]:I)				
6			Calculate	CORV=last([CORV]:U)				
7			Calculate	CODT=max([CODT]:t)				
8			Discharge	I=2A U=3V	I>-200mA		t=5s U=20mV I=20mA	Ensure that the battery is sufficiently discharged
9		ODV	Ramp-u	U1=3V U2=0V slope=-50mV/s	I>-100mA U<0.5V		t=1s U=20mV I=20mA	Measure Overdischarge Detection Voltage
10			Charge	U=2V I=2A	t>1s		t=1s	
11		ODRV	Ramp-u	U1=2V U2=4V slope=100mV/s	I>100mA I<-100mA		t=1s U=20mV I=20mA	Measure Overdischarge Release Voltage
12			Charge	I=1A	t>1s		t=5s U=20mV I=20mA	Switch sure on
13		ODDT	Discharge	I=2A	I>-100mA t>3s		t=1s U=20mV I=20mA	Measure Overdischarge Detection Time
14			Charge	I=1A U=4.2V	t>1s		t=1s U=20mV I=20mA	Switch on the protection circuit again
15		COC	Ramp-i	I1=1A I2=5.2A slope=100mA/s	I<500mA I>5A		t=1s U=20mV I=20mA	Measure Charge Overcurrent
16		CORV	Ramp-u	U1=5V U2=2V slope=-100mV/s	I>100mA I<-100mA		t=1s U=20mV I=20mA	Measure Charge Overcurrent Release Voltage
17			Charge	I=1A U=4.2V	t>1s		t=1s U=20mV I=20mA	Switch sure on the protection circuit again
18		CODT	Charge	I=5A	I>-100mA		t=1ms	Measure Charge Overcurrent Detetction time
19			Stop					