Battery cell type test

Test of following batteries has been performed: nano-tech LiFePO4 and nano-tech Li-PO (most likely cobalt oxide cathode) both from Turnigy power systems, and both packs contains 2 battery cells. All test results has been summed up in this journal.

Size and energy density comparison

	LiFePO4[1]	Li-PO[2]	Difference
Dimensions(L x W x H)[mm]	131.8 x 14.8 x43.2	88 x 25.8 x 33.8	
Volume [cm^3]	84.27	76.74	LiFePO4 is 12% > Li-PO
Weight [g] (incl. wires etc.)	168	144	LiFePO4 is 12% > Li-PO
Capacity [mAh] (datasheet at 20C discharge)	3000	3000	0
Battery voltage [V]	6.6 (3.3 per cell)	7.4 (3.7 per cell)	
Wh per liter (based on datasheet capacity)	234.96	297.1	LiFePO4 is 21% < Li-PO
Wh per kilogram (based on datasheet capacity)	84.27	158.33	LiFePO4 is 47% < Li-PO

Table 1 - Comparison based on "datasheet" values

[1] For "datasheet" see: http://www.hobbyking.com/hobbyking/store/__23826__Turnigy_nano_tech_3000mAh_2S1P_20_40C_LiFePo4_Receiver_Pack_.html (Date: 23-04-2013)

[2] For "datasheet" see: http://www.hobbyking.com/hobbyking/store/__23821__Turnigy_nano_tech_3000mAh_2S2P_20_40C_Lipo_Receiver_Pack_.html (Date: 23-04-2013)

Effective Capacity Measurements

As no datasheet with detailed information about capacity temperature dependency is available, measurements has been performed. Following parameters are common for both tests:

- Ambient temperature set to 8°C, to simulate worst case Eco-marathon temperatures.
- Constant Discharge Current = 4A (Approximately equivalent to 100W load for final 24V system)

LiFePO4

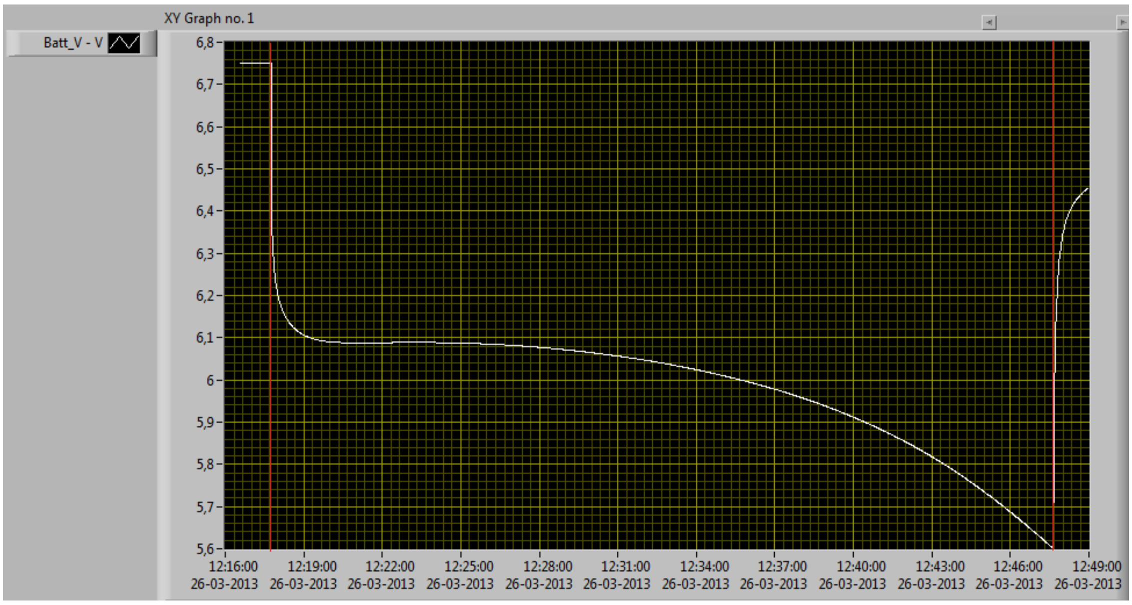


Figure 1 - Voltage as function of time (LiFePO4)

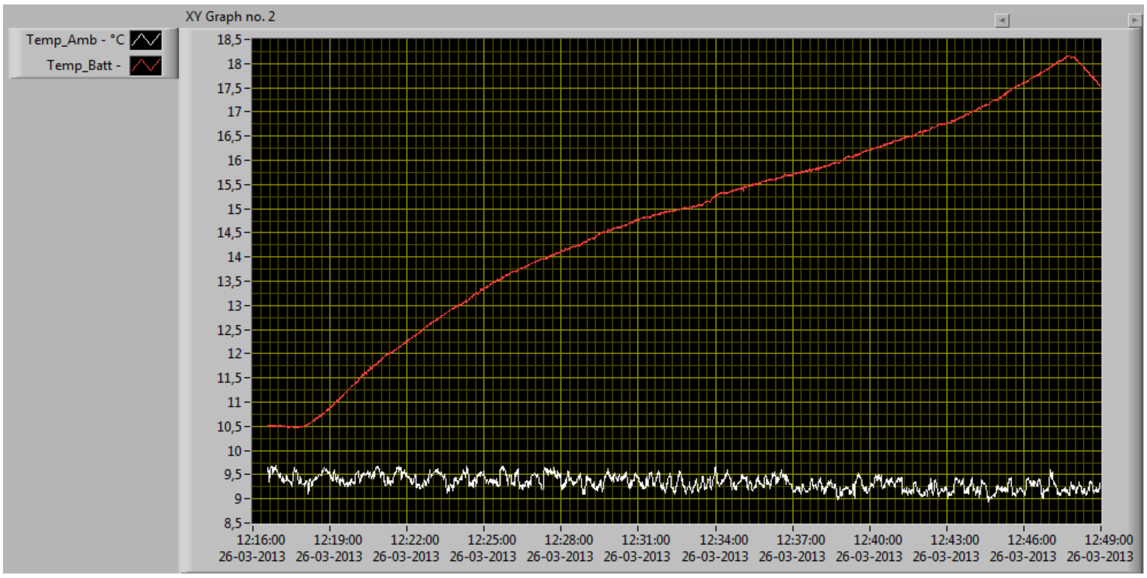


Figure 2 - Temperature during discharge (LiFePO4)

Voltage limits: Battery charged to 3.6V per cell, discharged to 2.8V per cell.

Measured capacity: $\mathrm{T_{Discharge}}[\mathrm{h}] * \mathrm{I_{Discharge}}[\mathrm{A}] = 0.5 * 4 = 2\mathrm{Ah}$

Conclusion: Performs below expectations.

Li-PO

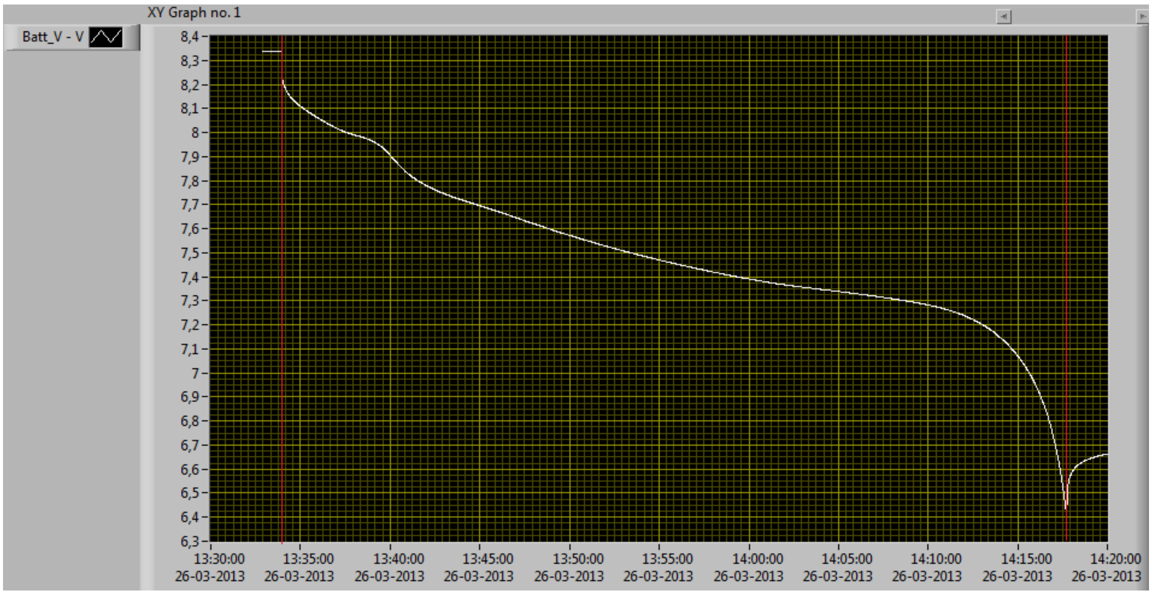


Figure 3 - Voltage as function of time (Li-PO)

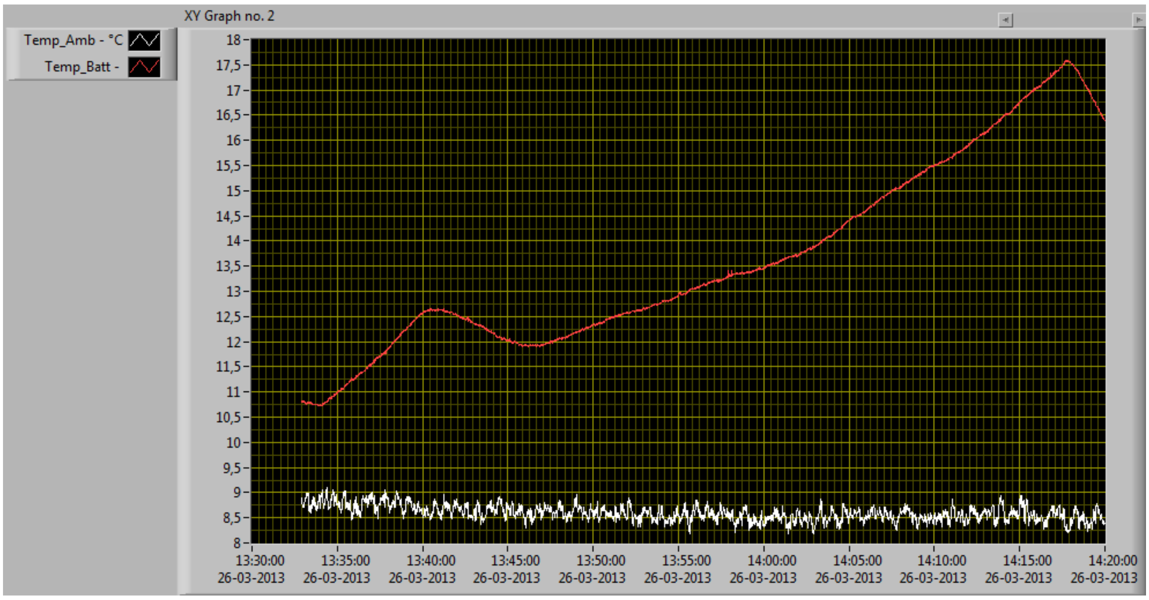


Figure 4 - Temperature during discharge (li-PO)

Voltage limits: Battery charged to 4.2V per cell, discharged to 3.2V per cell

Measured capacity: $T_{Discharge}[h] * I_{Discharge}[A] = 0.73 * 4 = 2.9Ah$

Conclusion: Only slightly below specified capacity even at this temperature.

Internal Resistance Measurements

To measure the internal resistance of the batteries, a constant current load has been adjusted in steps of 2A. Hereafter, delta voltage has been compared to delta current. To ensure that the voltage drop is a result of the internal resistance and not a result of SOC reduction over time, the calculations are based on voltage measured right before and 5 seconds after the load step is applied.

LiFePO4

Ambient temperature= 8°C, SOC = 100% at measurement start.

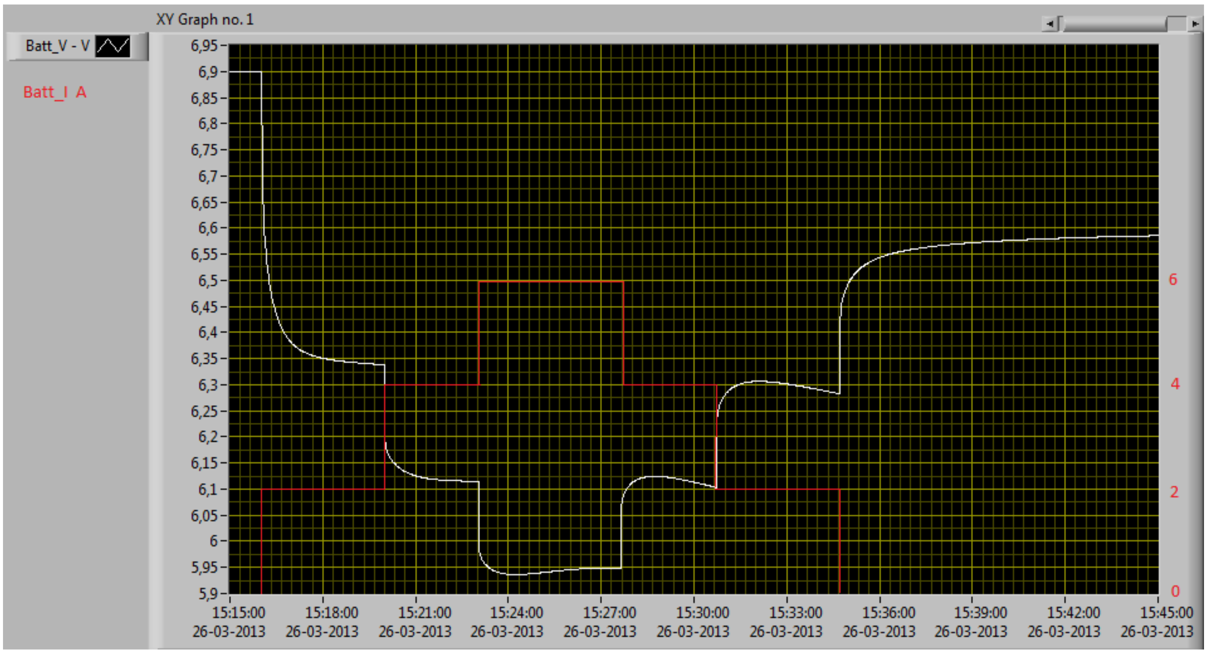


Figure 5 - voltage response when load applied in steps of 2A (LiFePO4)

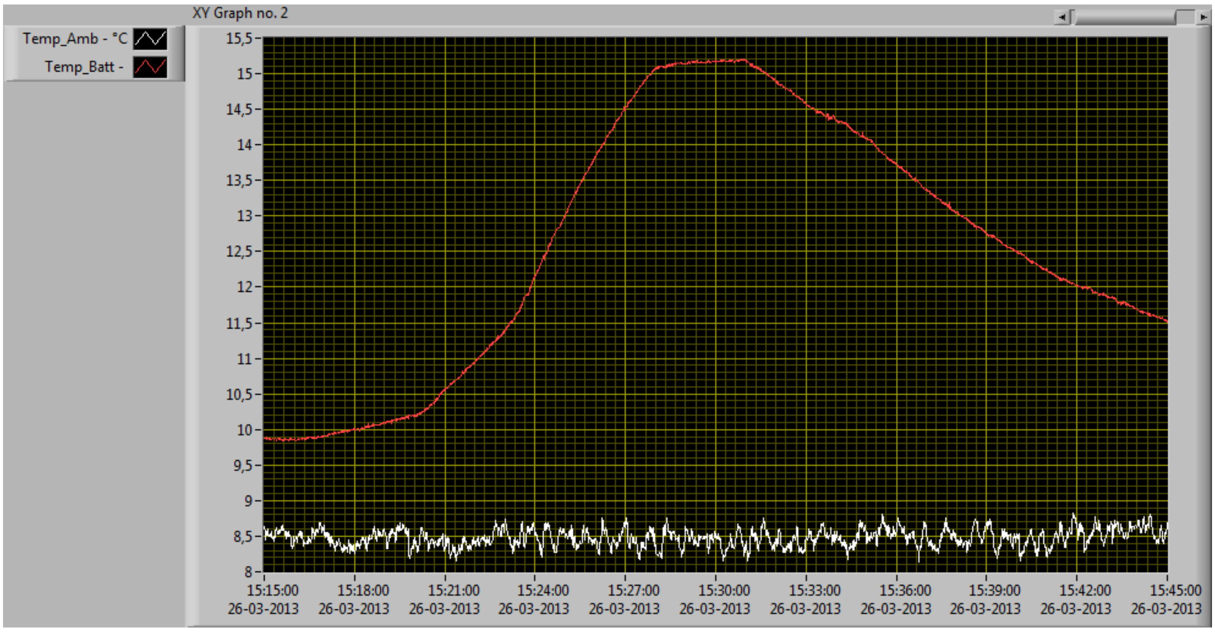


Figure 6 - Temperature response at load variations (LiFePO4)

Internal Resistance Calculations (start SOC = 100%)

Internal resistance is calculated as following:

$$R_{Internal\ (battery)} = \Delta V/\Delta I = \left|V_{Before\ Load\ Step} - V_{5\ Sec.\ later}\right| / \, 2A$$

Load variation	Internal Resistance (battery) [mΩ]	Internal Resistance (Cell) [mΩ]	Batt. Temperature at time of measurement [°C]
2 to 4A	82.8	41.4	10
4 to 6A	72.4	36.2	11.5
6 to 4A	69.6	34.8	15
4 to 2A	75.3	37.7	15.2
2 to 0A	88.9	44.5	14.3

Li-PO

Ambient temperature= 8°C, SOC = 100% at measurement start.

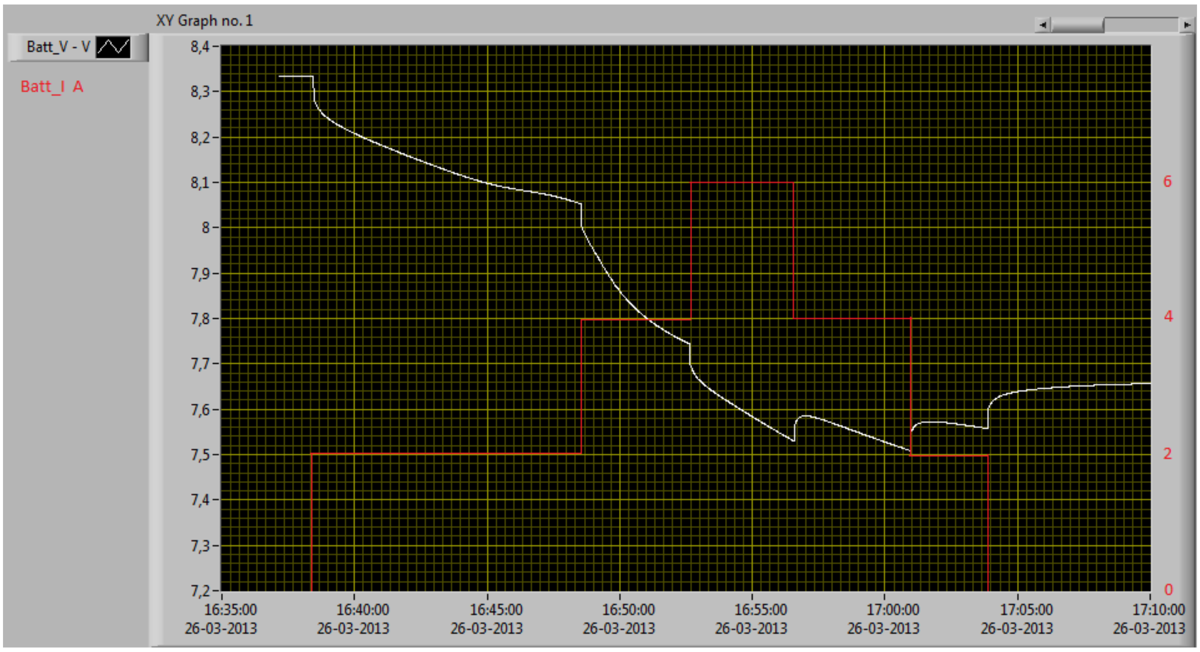


Figure 7 - voltage response when load applied in steps of 2A (L-PO)

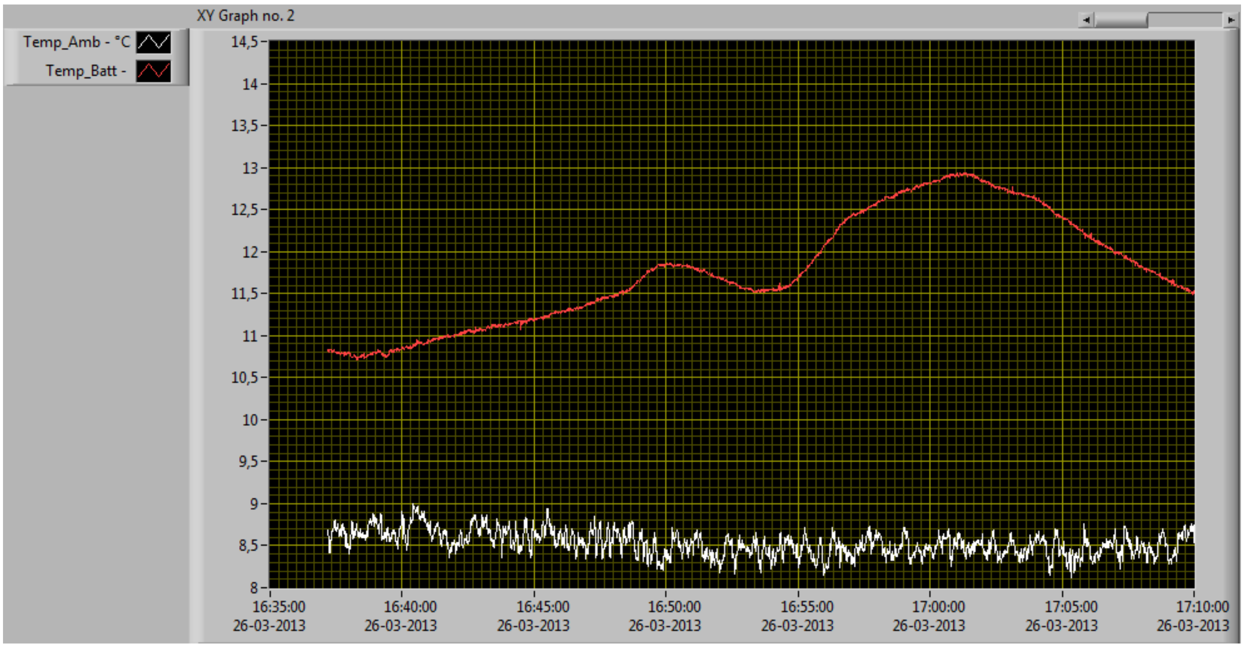


Figure 8 - Temperature response at load variations (Li-PO)

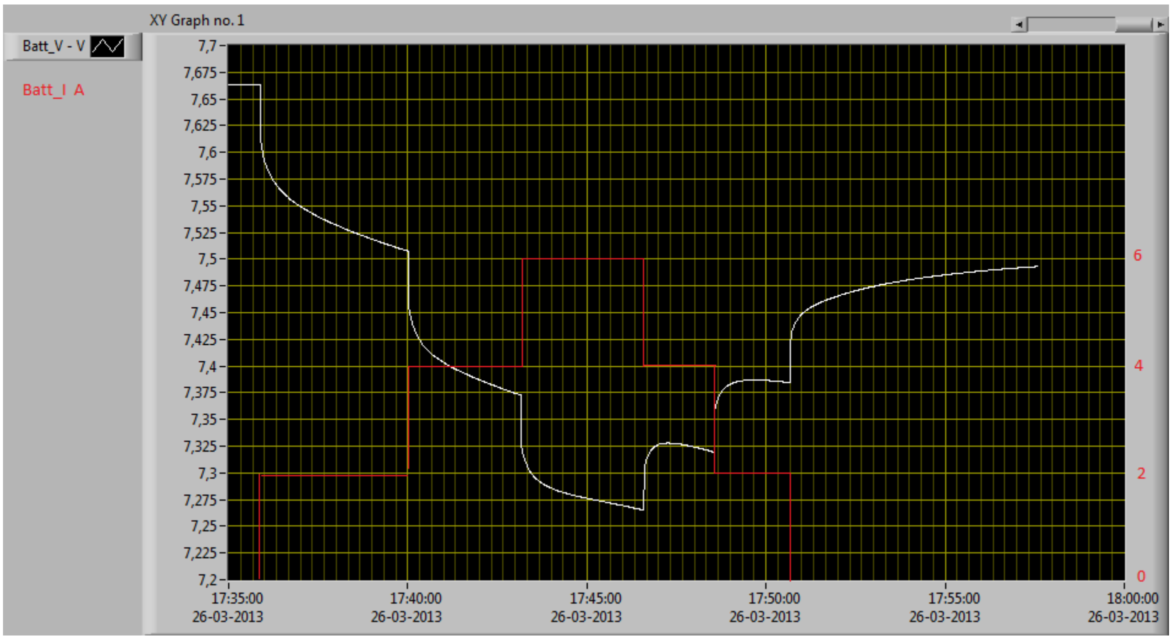
Internal Resistance Calculations (start SOC = 100%)

Internal resistance is calculated as following:

$$R_{Internal\ (battery)} = \Delta V / \Delta I = \left| V_{Before\ Load\ Step} - V_{5\ Sec.\ later} \right| / 2A$$

Load variation	Internal Resistance (battery) [mΩ]	Internal Resistance (Cell) [mΩ]	Batt. Temperature at time of measurement [°C]
2 to 4A	28.3	14.2	11.5
4 to 6A	27.4	13.7	11.5
6 to 4A	23.2	11.6	12.4
4 to 2A	23.9	12.0	13
2 to 0A	25.7	12.9	12.7

Ambient temperature= 8°C, SOC = 50% at measurement start.



Figur 9 - Voltage response at 50% SOC (Li-PO)

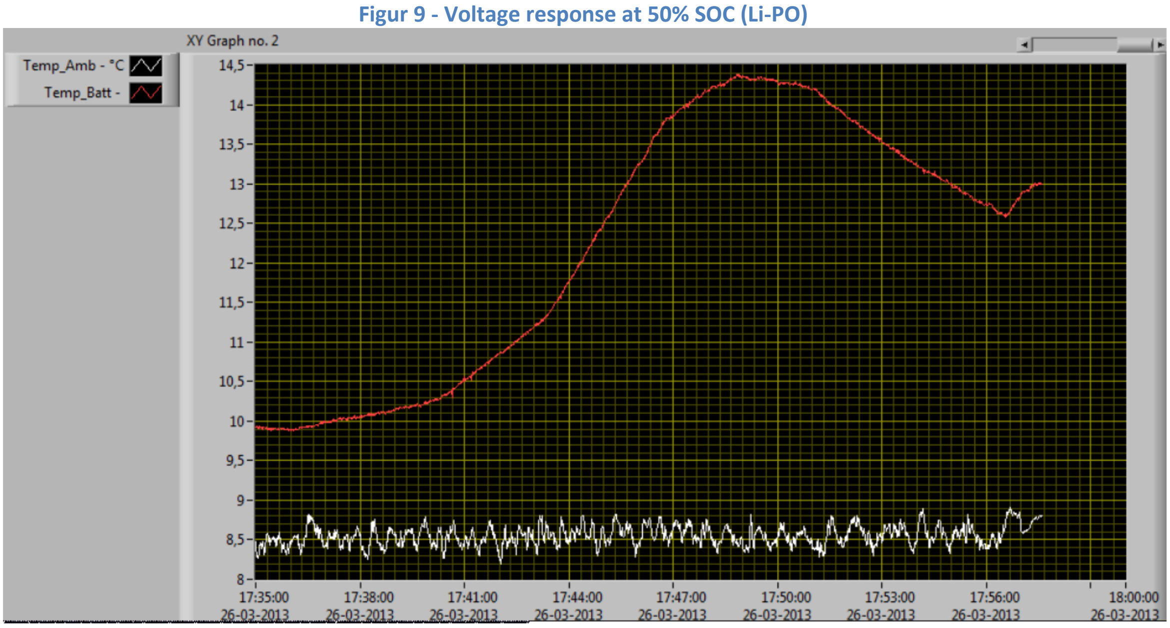


Figure 10 - Temperature response at load variations (Li-PO, SOC=50%)

Internal Resistance Calculations (start SOC = 50%)

Internal resistance is calculated as following:

$$R_{Internal\ (battery)} = \Delta V / \Delta I = \left| V_{Before\ Load\ Step} - V_{5\ Sec.\ later} \right| / \ 2A$$

Load variation	Internal Resistance (battery) [mΩ]	Internal Resistance (Cell) [mΩ]	Batt. Temperature at time of measurement [°C]
2 to 4A	32.0	16.0	10.3
4 to 6A	28.4	14.2	11
6 to 4A	24.1	12.1	13.5

Charge / Discharge Limit Test

Both batteries allow charging and discharging at the rate specified by the "datasheets". The voltage of the LiFePO4 battery does however drop significantly under heavy load duo to the higher internal resistance, this will limit the effective capacity of the final system as the BMS may interrupt operation prematurely if heavy acceleration is performed.

Destructive Test

Purpose of this test is to compare safety risks and gain knowledge about the behavior in the event of overcharging. Both batteries were charged by applying a constant current of the rated max charging current (5C = 15A), no upper voltage threshold was set, as the purpose was to provoke overcharging. Both batteries expanded dramatically and eventually released the overpressure by splitting, in doing so the Li-PO burst into flames, while the LiFePO4 remained calm. See pictures below.

Figur 11 - Test setup at start of test Li-PO

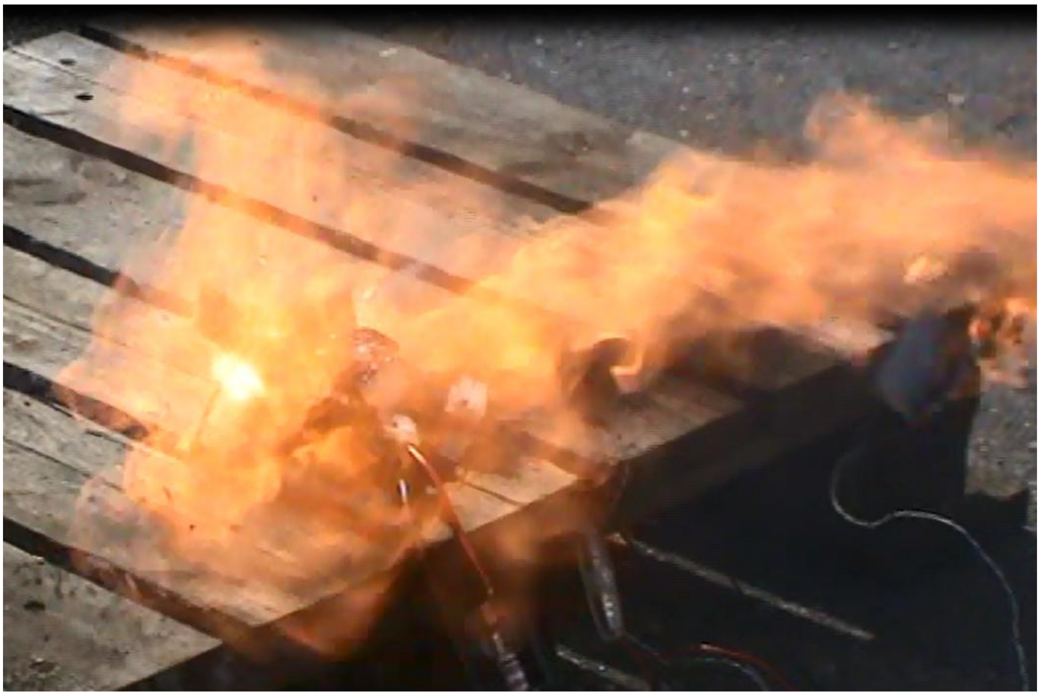


Figure 12 - Reaction at overcharge Li-PO

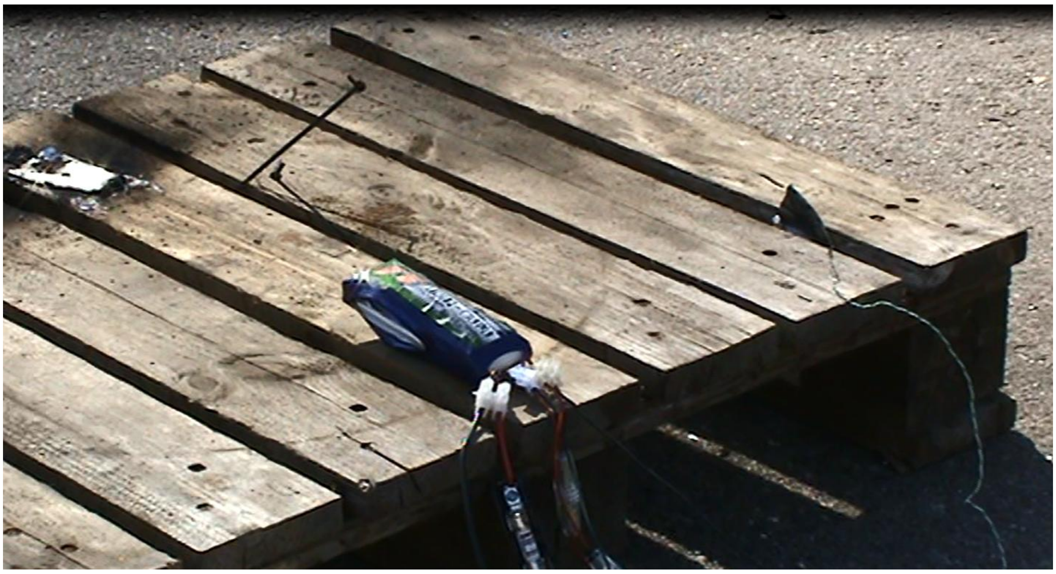


Figure 13 - Reaction at overcharge LiFePO4