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Effects of fast charge on a lithium-ion battery system

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Outline of the presentation

ENEA's activity and experience on battery testing

Definition of fast charge

Fast charging test at cell level

Battery module for fast charging test

Response of the battery module to fast charge

Fast charging life cycle test on battery module

Mission for Local Public Transportation

Implementation on a minibus

Conclusions

Realized by



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Supported by the Italian Ministry of Economic Development in the framework of the Program Agreement for the Research on Electric System



ENEA's activity and experience on battery testing (1^)

Battery lab

Cyclers

E-8325	ELTRA	0 ÷ 12 V	150 A
E-8094	ELTRA	2 ÷ 60 V	280 A
BNT_50-080-8_BDBT	Digatron	0 ÷ 80 V	8x50 A
E-8135	ELTRA	48 ÷ 110 V	600 A
E-8376	ELTRA	0 ÷ 330 V	400 A
E-8304	ELTRA	48 ÷ 360 V	350 A
E-8619	ELTRA	0 ÷ 560 V	250 A
E-Storage System 250 kW	AVL	0 ÷ 800 V	600 A

Climatic chambers

Angelantoni	¼ m³	-75 ÷ +180 °C	10 ÷ 98% R.H.
Angelantoni	1 m³	-40 ÷ +180 °C	15 ÷ 98% R.H.
Angelantoni	2 m³	-40 ÷ +180 °C	15 ÷ 98% R.H.
Angelantoni	1 m³	-50 ÷ +150°C	10 ÷ 98% R.H.



ENEA's activity and experience on battery testing (2^)

Battery testing

Characterization

Life cycles

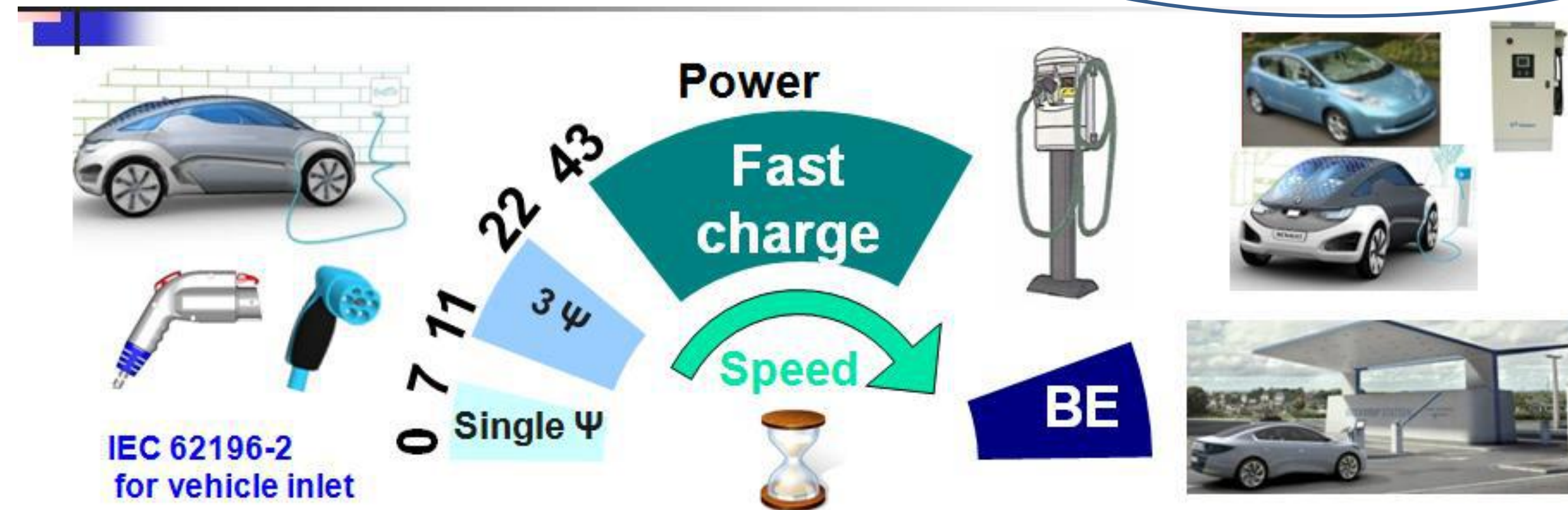
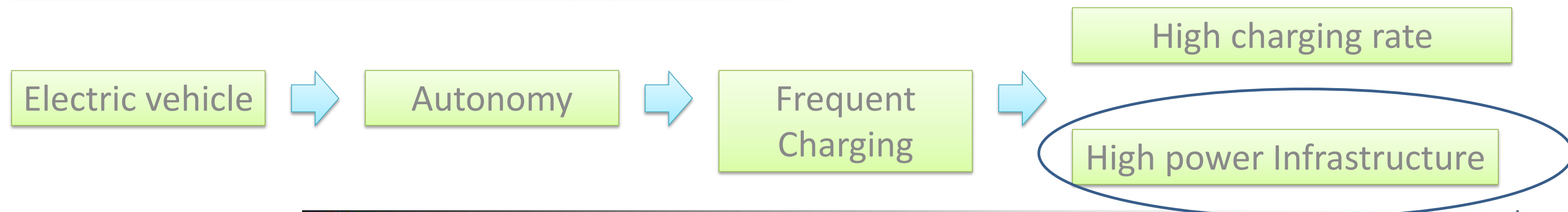
Abuse

ISO 12405-1 “Electrically propelled road vehicles – Test specification for lithium-ion traction battery packs and systems – Part 1: High power application”
 ISO 12405-2 “Electrically propelled road vehicles – Test specification for lithium-ion traction battery packs and systems – Part 1: High energy application”
 ISO 12405-3 “Electrically propelled road vehicles — Test specification for Lithium-ion traction battery packs and systems — Part 3: Safety performance requirements”
 EUCAR Traction Battery Working Group “Specification of test procedures for Hybrid Electric Vehicle Traction Batteries”
 IEC 62660-1 “Secondary batteries for the propulsion of electric road vehicles – Part 1: Performance testing for lithium-ion cells”
 IEC 62660-2 “Secondary batteries for the propulsion of electric road vehicles – Part 2: Reliability and abuse testing for lithium-ion cells”

Customized test plan - Tests based on real working conditions

Fast charge – current definition

Importance of fast charge

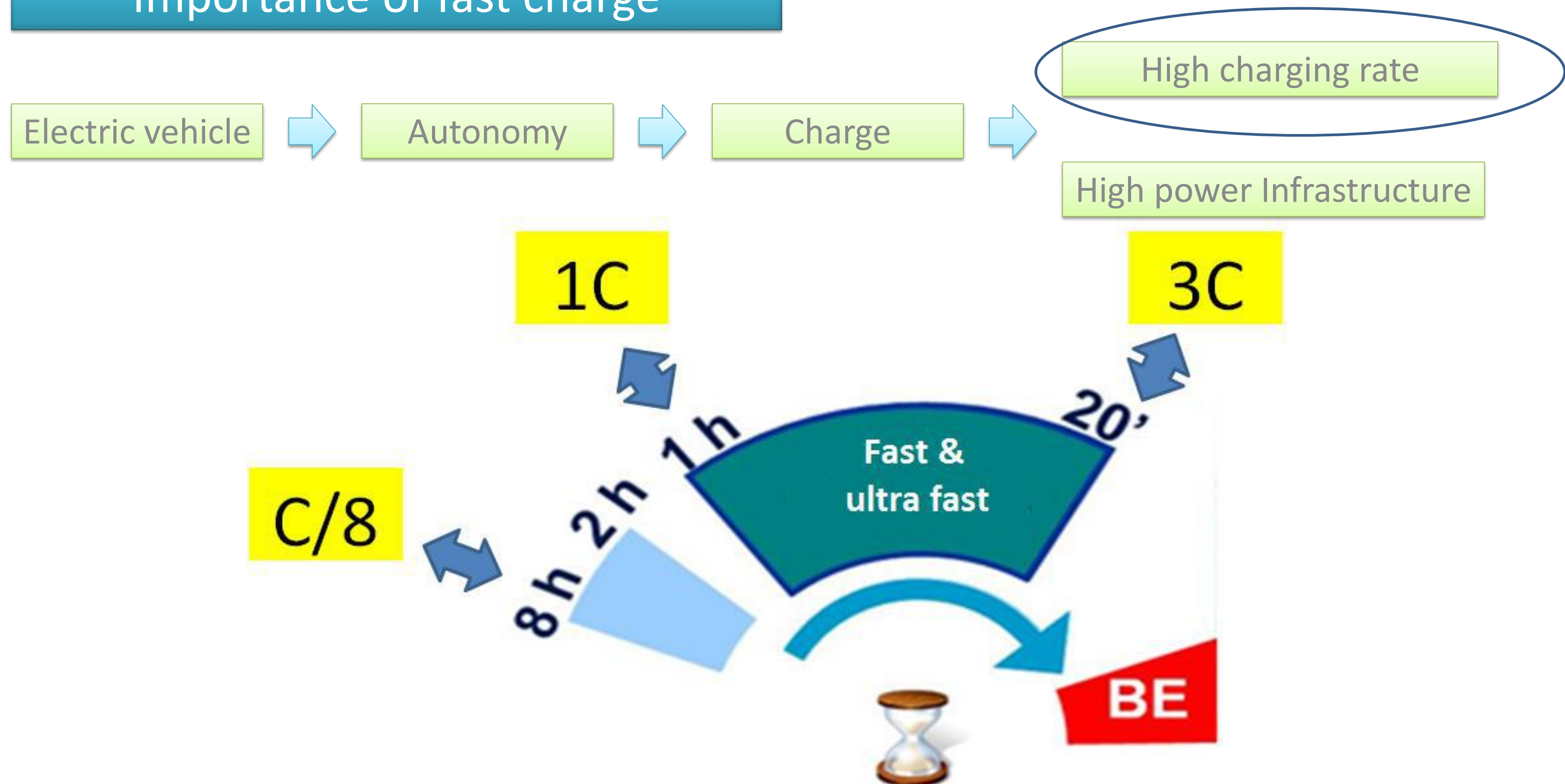


	Standard charge (AC)	→ 1ph: between 4 an 8 hours 3ph: between 1 an 2 hours
	Fast charge (AC or DC)	→ 1 hour or less
	Battery exchange	→ in a few minutes !



Fast charge – definition based on C-rate

Importance of fast charge



Absence of specific literature about life-cycle testing with Fast Charge !

Need of life-cycle testing with Fast Charge !

Fast charge – Test at cell level (1[^])

Cell's main characteristics

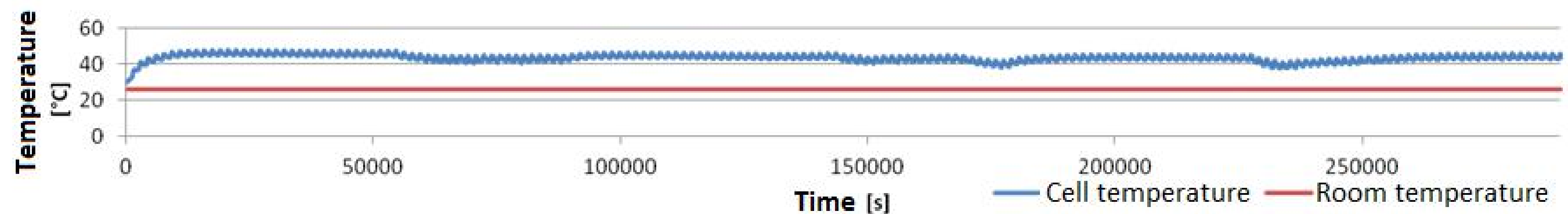
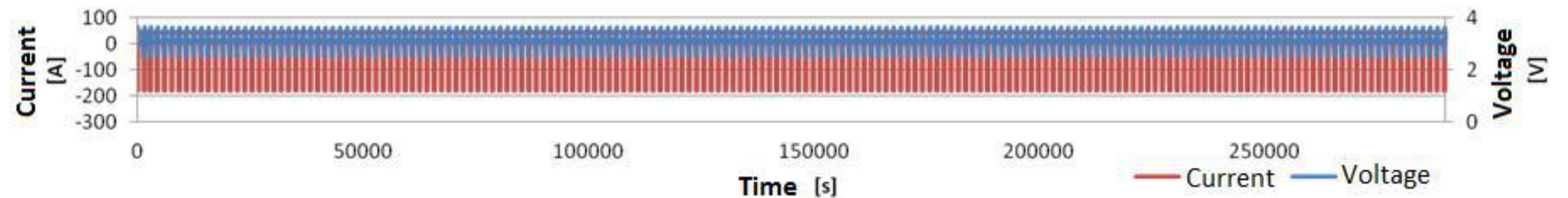
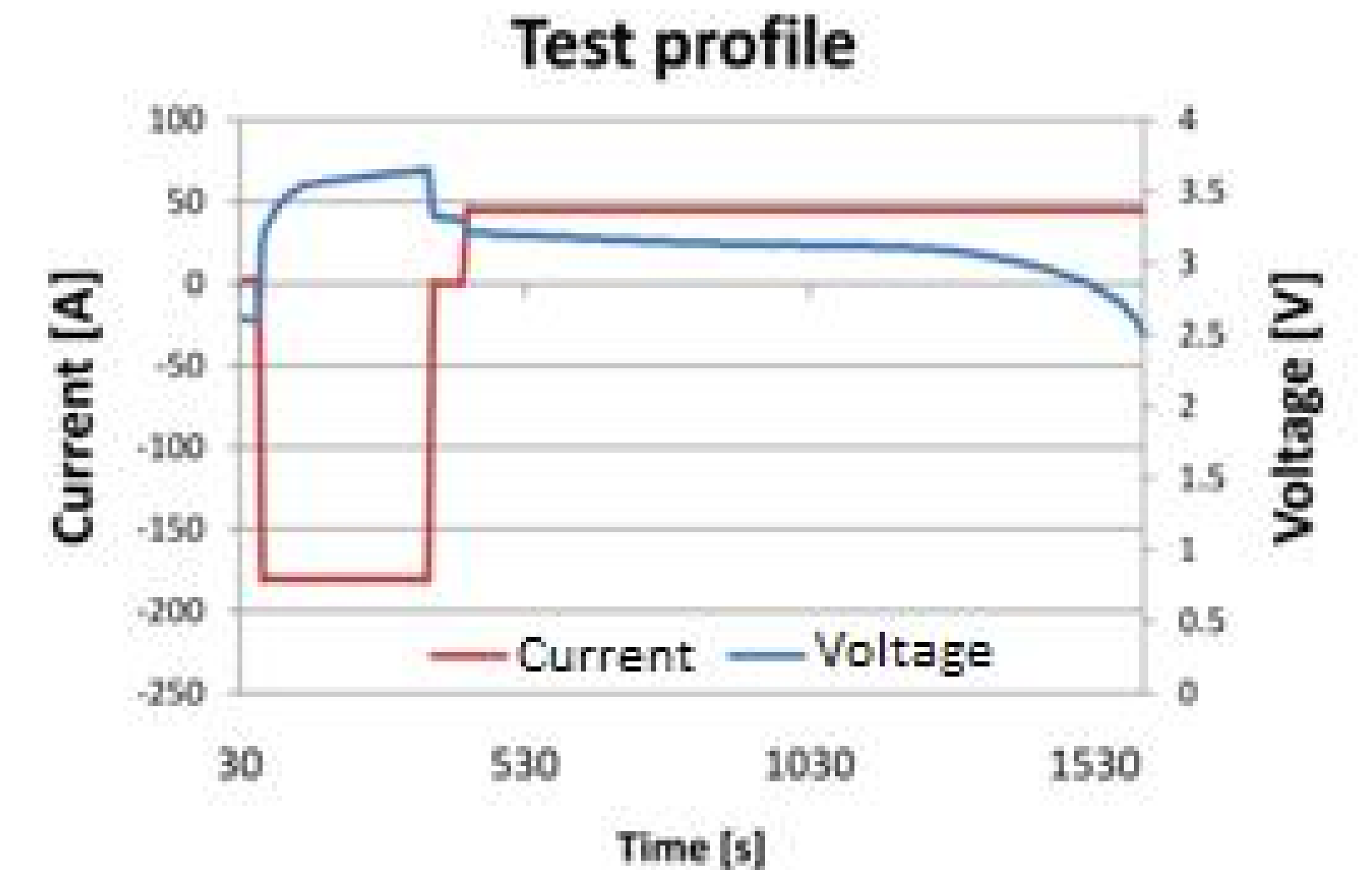
LITHIUM-ION CELL 3.2 V – 60 Ah		
Type	Lithium Iron Posphate	
Capacity	60 Ah	
Voltage	nominal	3.20 V
	minimum	2.50 V
	maximum	3.65 V
Maximum continuative current	discharge	180 A = 3C
	charge	60 A = 1C
Working temperature	discharge	-20 ÷ +60° C
	charge	0 ÷ +45° C



Fast charge – Test at cell level (2[^])

Test profile

Step	C-rate	Time
discharge	2/3	1200 s
rest		60 s
charge	3	300 s
rest		60 s
Total time		1620 (about 2cycles per hour)



Fast charge – Test at cell level (3[^])

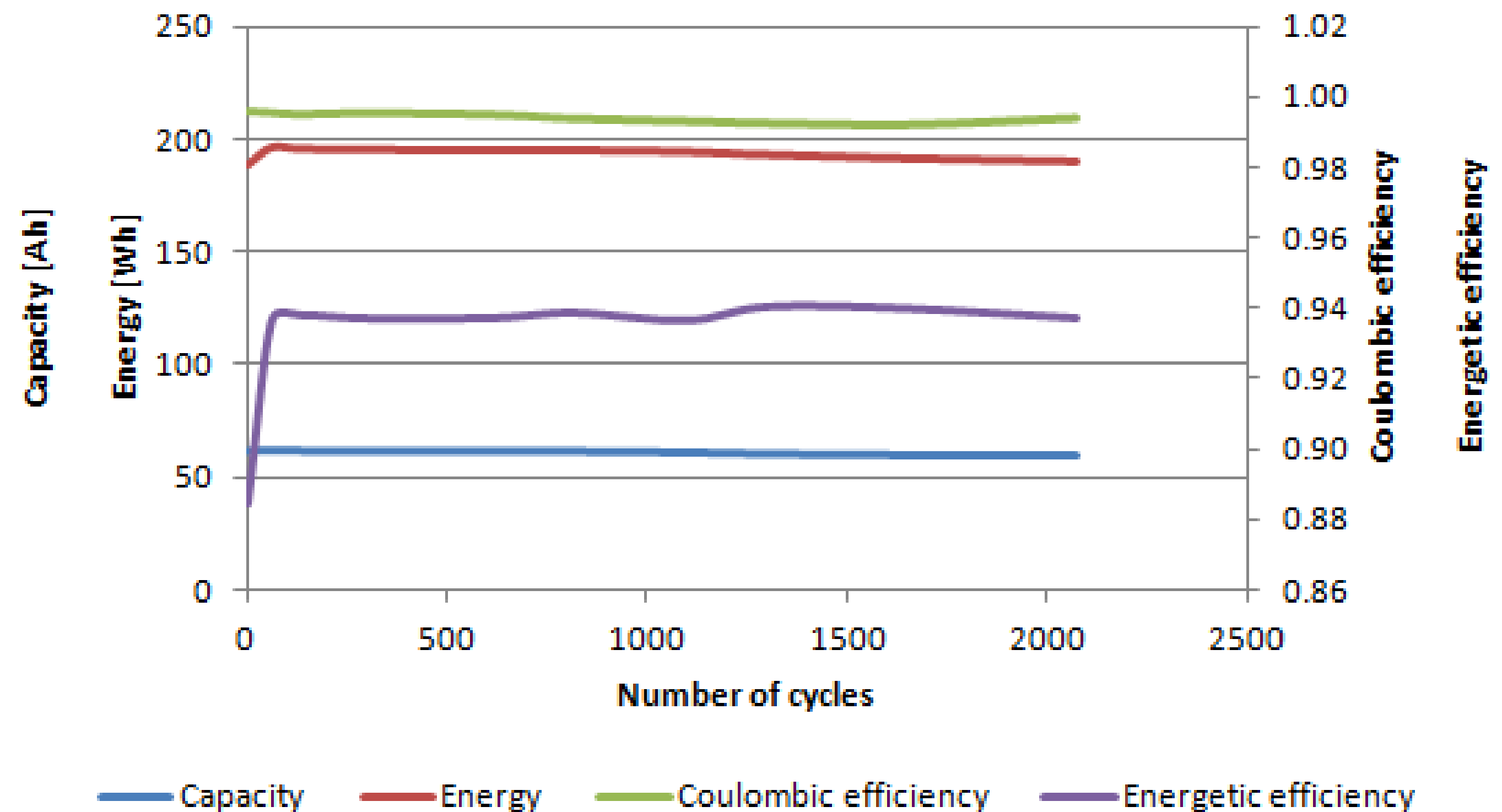
Results

*More than
2000 (900 h)
cycles
executed*

*No relevant
reduction of
performances*

**Encouraged
repetition of
test at
module level**

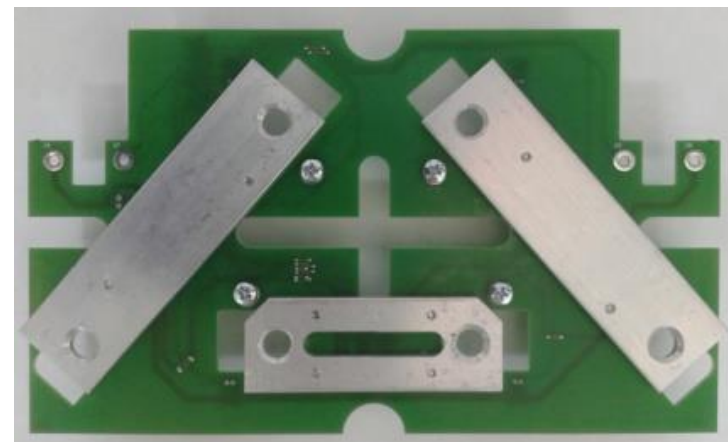
Periodic check of performances



Battery module (developed in ENEA)

Cells

Connection board



BMS board & cooling system

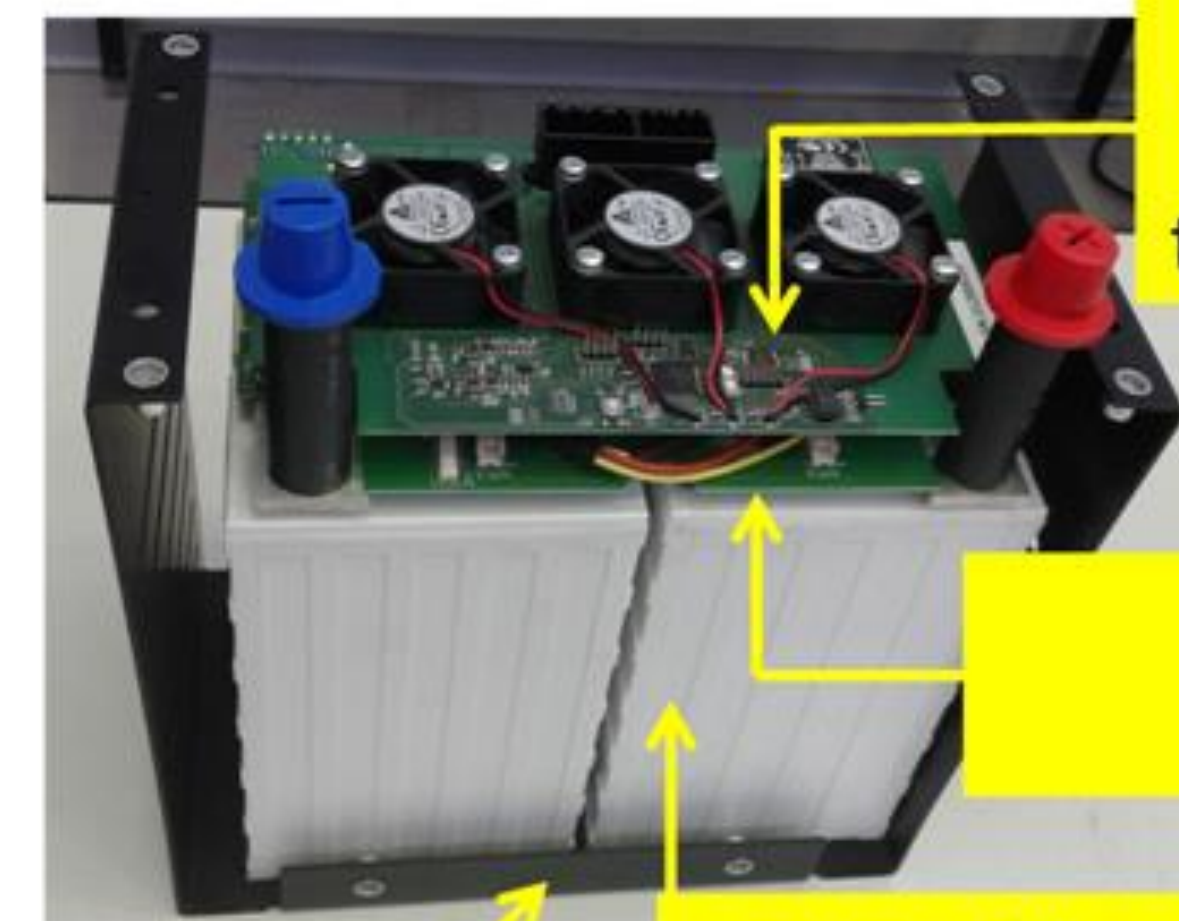
Monitoring

Protection

Active
balancing



3 fans 12 V – 30 Nm³/h managed by BMS



BMS board with
active balancing and
thermal management

connection
board

case bottom

series of 4 cells

Fast charge – Response of the battery module

Behavior of a battery module to fast charge at CC 3C for 5 min

High charging currents quickly move working voltage towards the maximum cell voltage

The alarm system stops the charge before completing the programmed charging time

The cells in the module are nominally equal but really all different

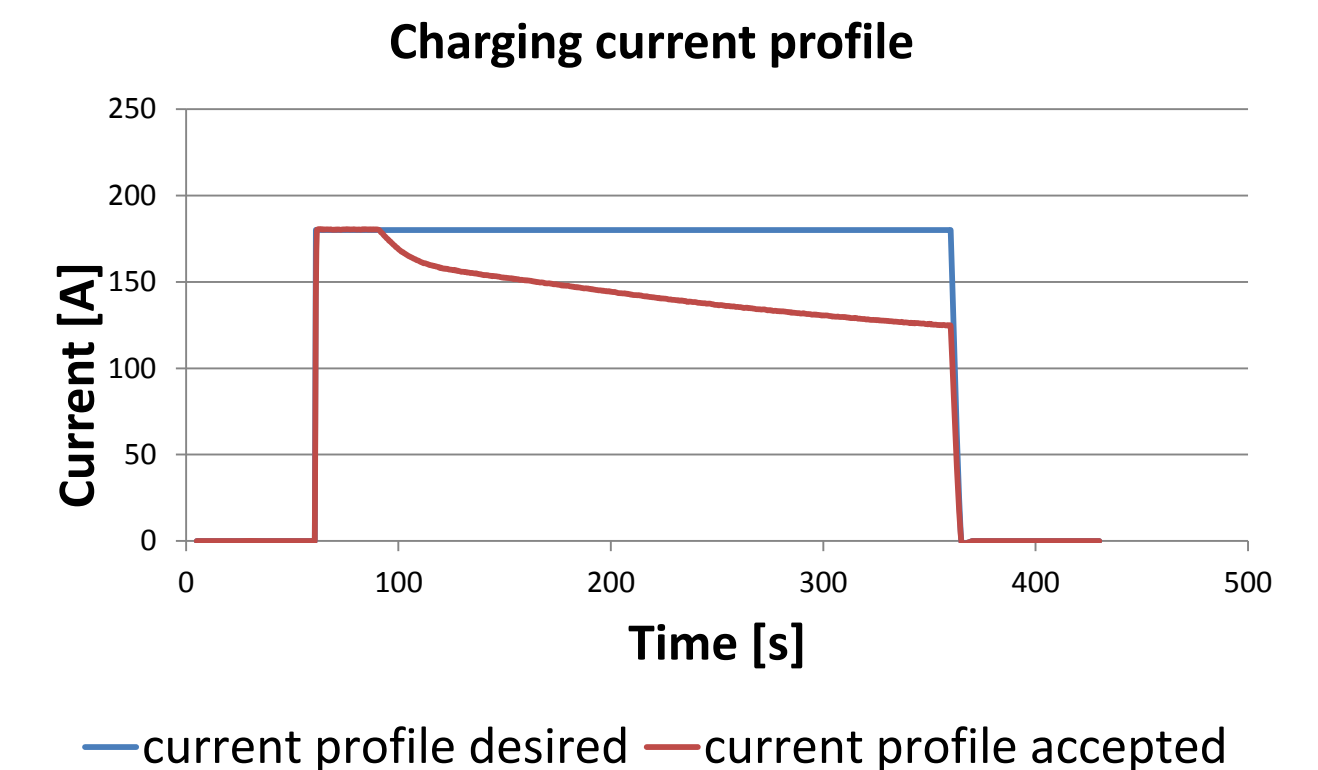
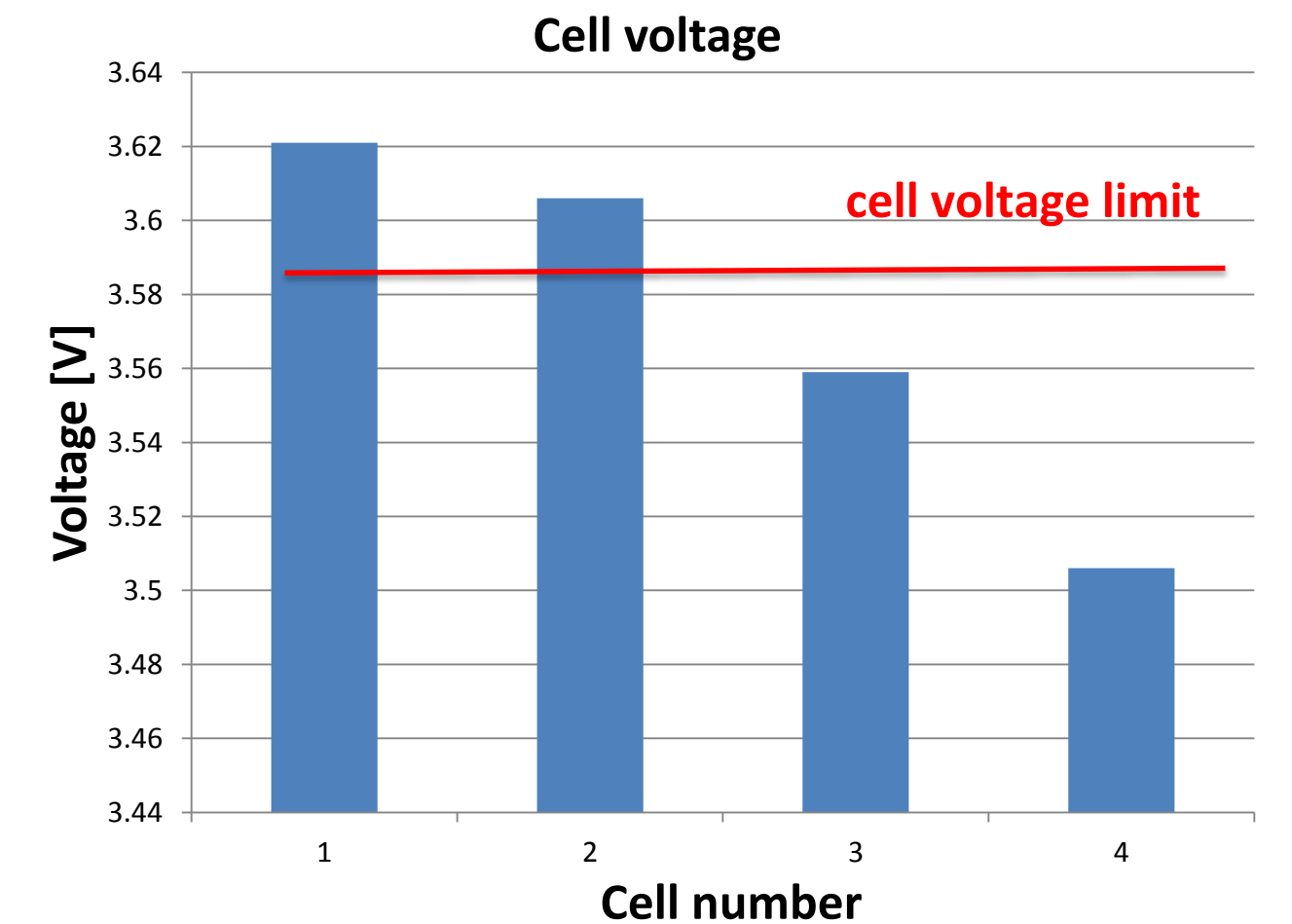
This situation is emphasized by the unbalancing of cells

Also the contact resistance plays an important role

Attempt repeated at different SOC level: 75%, 50%, 25%

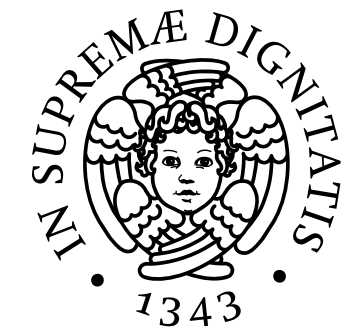
The negative effect of fast charge is as bigger as the SOC is higher

- 1) Well selected cells (before)
- 2) Cells well balanced (during the night, standard charge)
- 3) Change the type of charge from CC to CC/CV



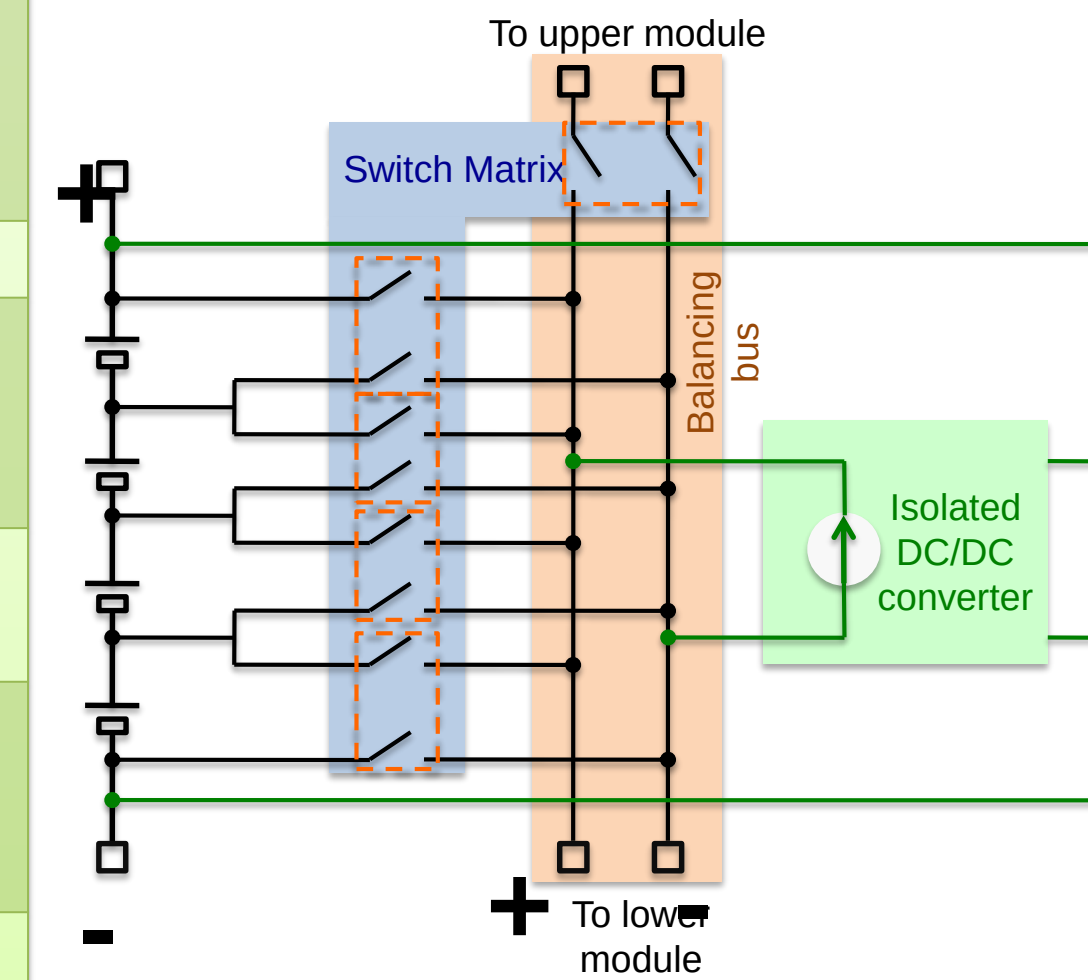
Fast charge – Life cycle test on battery module (1[^])

Test procedure



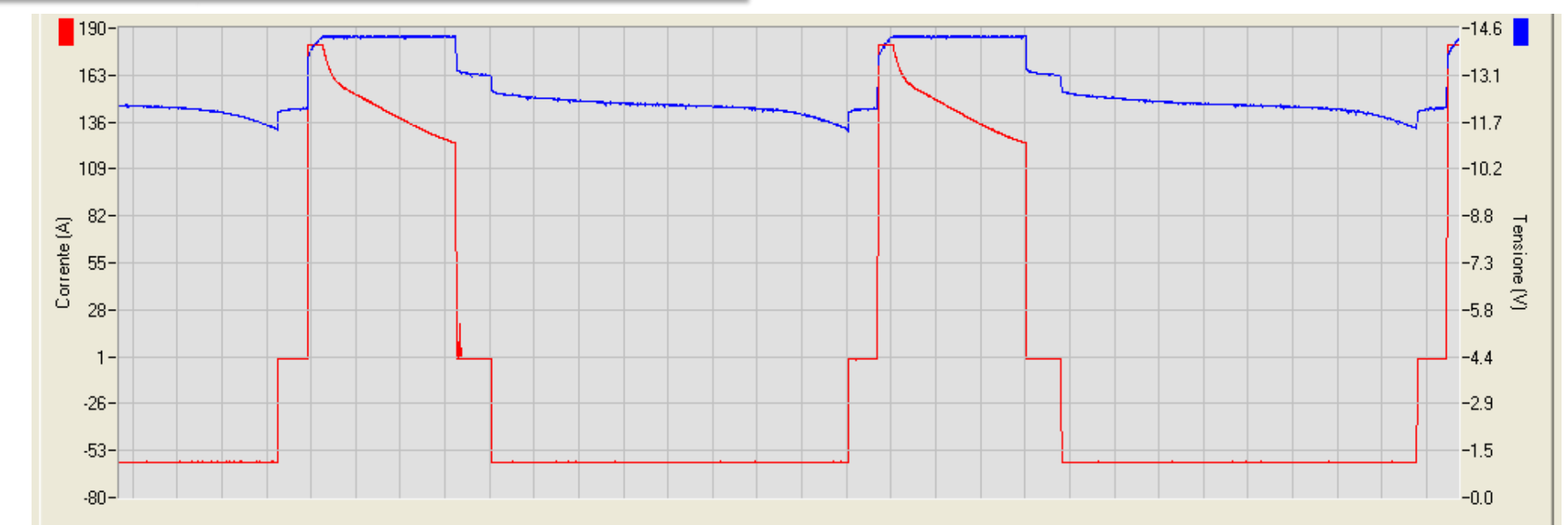
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Step number	Step type	Step characteristics	Step end conditions	Comment	Correspondence with TPL mission
01	Rest		60 s	Life cycle profile with fast charge	Stop at end of line Disconnection from charging station
02	Discharge	CC @ 1C	900 s or Vmin		Travel
03	Rest		60 s		Stop at end of line Connection to charging station
04	Charge	CC/CV – I _{max} = 3C	300 s		Stop at end of line Fast charge
05		Go to step 1 and do the loop from step 1 to step 4 for 30 times		Loop	Operation for 10 h without interruption
06	Rest		7200 s	Slow charge	Slow charge and balancing during night at the garage
07	Charge	CC/CV – I _{max} = C/3	Complete charge		
08	Rest	Rest while the BMS provides the balancing function		Balancing	



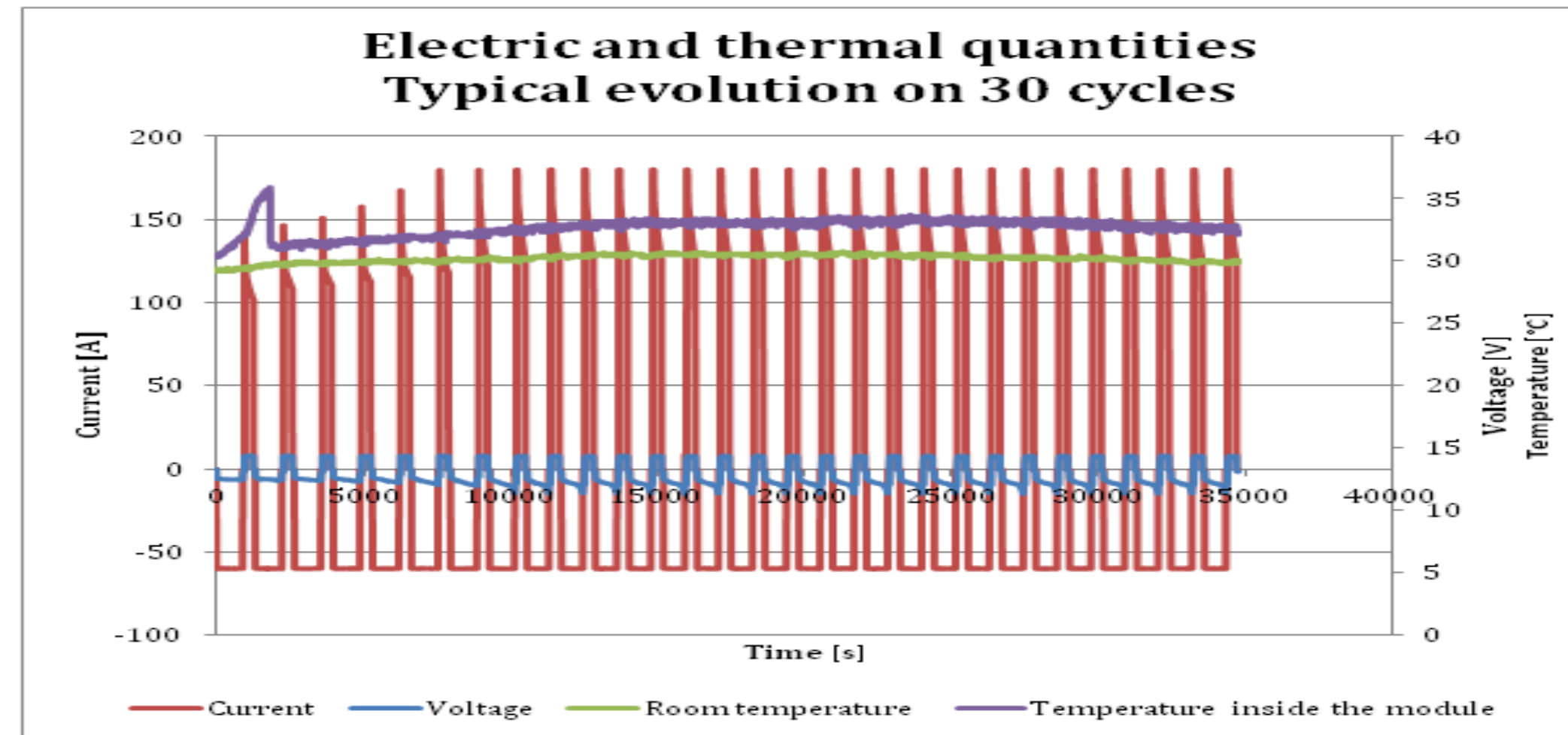
Schematic of the balancing function provided by the BMS

The test procedure is consistent with a typical mission required by the local public transportation

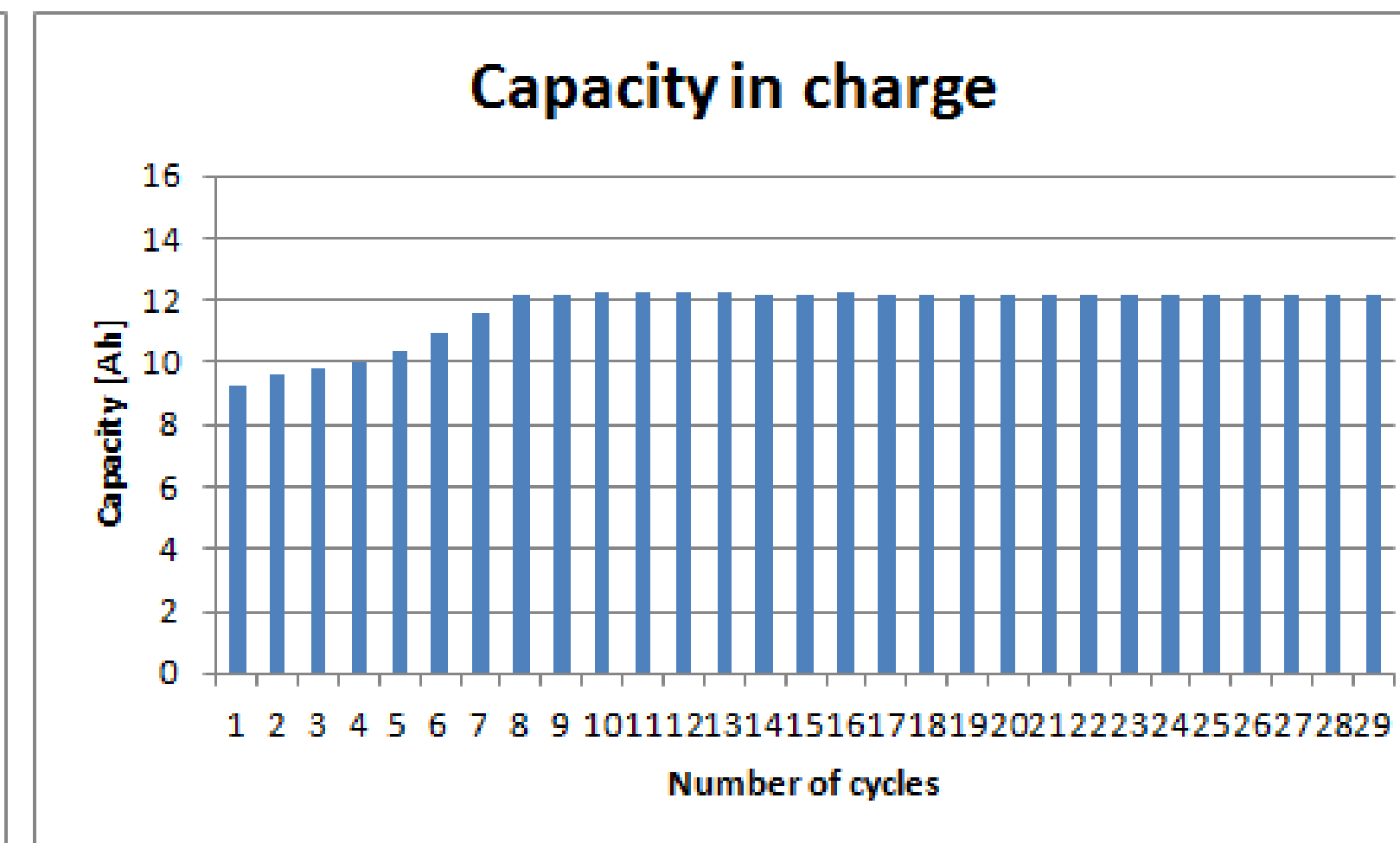
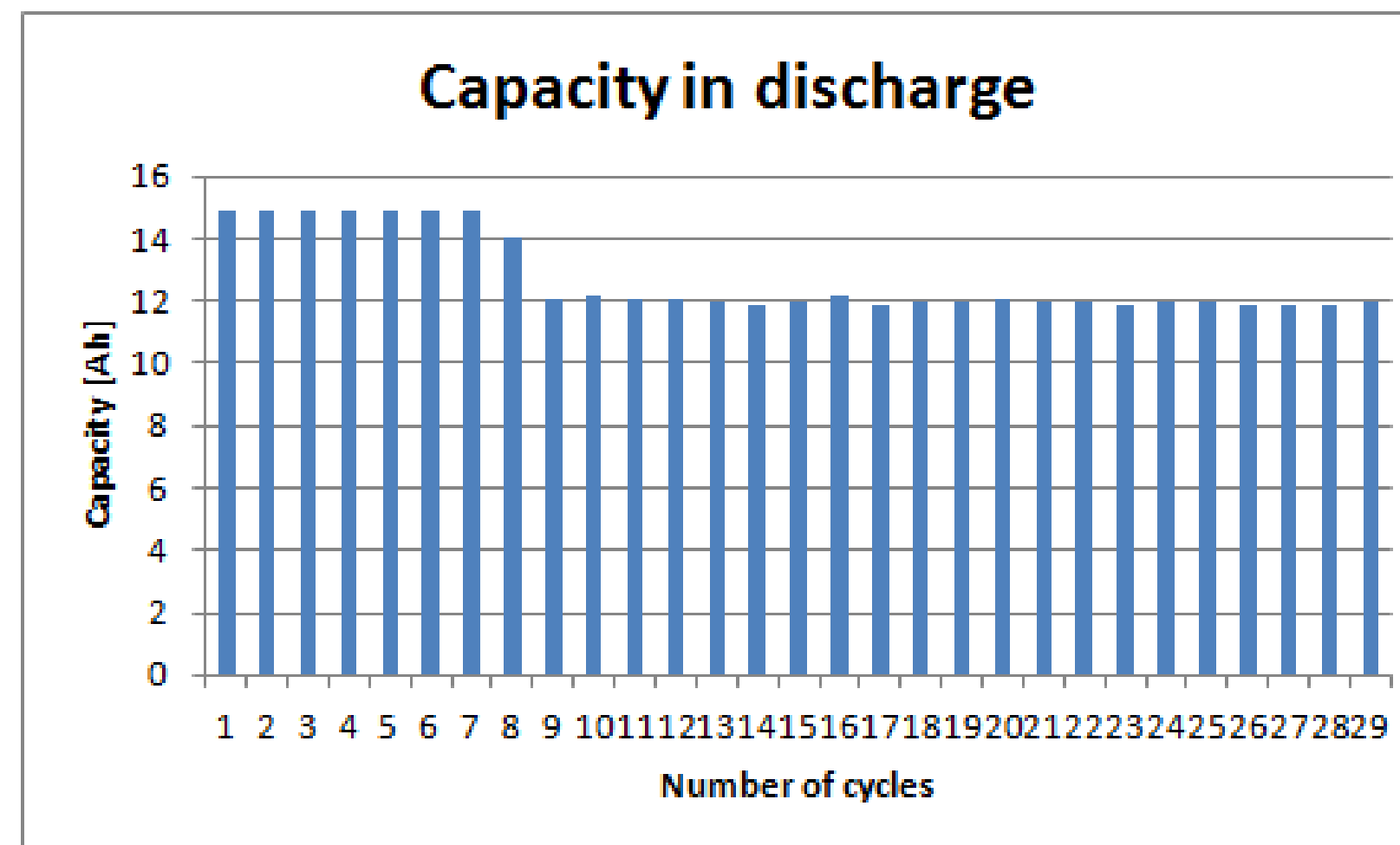


Fast charge – Life cycle test on battery module (2^)

Behavior of the battery module



Typical evolution of the battery module's electric quantities during the life cycle test (30 cycles in a day)



Equilibrium of the quantity of electric charge

Fast charge – Life cycle test on battery module (3^)

Gestione ciclatore per prove su batterie

File Profili Speciali Info!



Laboratorio di Casaccia (RM)

Capacità		Energia	
Carica	279.128 Ah	Carica	3994.6 Wh
Scarica	282.584 Ah	Scarica	3442.6 Wh
Totale	-3.456 Ah	Totale	552.0 Wh

Aggiorna

Bilancio energetico

Identificativi Sicurezza Dati prova **In corso** Log

Profilo Modulo_12V-60Ah_ric_rap_3C

Ciclo
24
di 24

Fase 4

CARICA A V/I COSTANTE

Corrente massima: 180.0 A

Tensione massima: 14.3 V

Termine: 300 sec o 15.0 Ah max

Corrente min ammessa: 1.0 A

Durata 25.1 s



Misure sulla batteria

14.26 V

180.32 A

PT-100

27.5 °C

Temperatura

29.2 °C

Valori calcolati

Potenza

2.573 kW

Capacità

1.207 Ah

Energia

16.9 Wh

In funzione

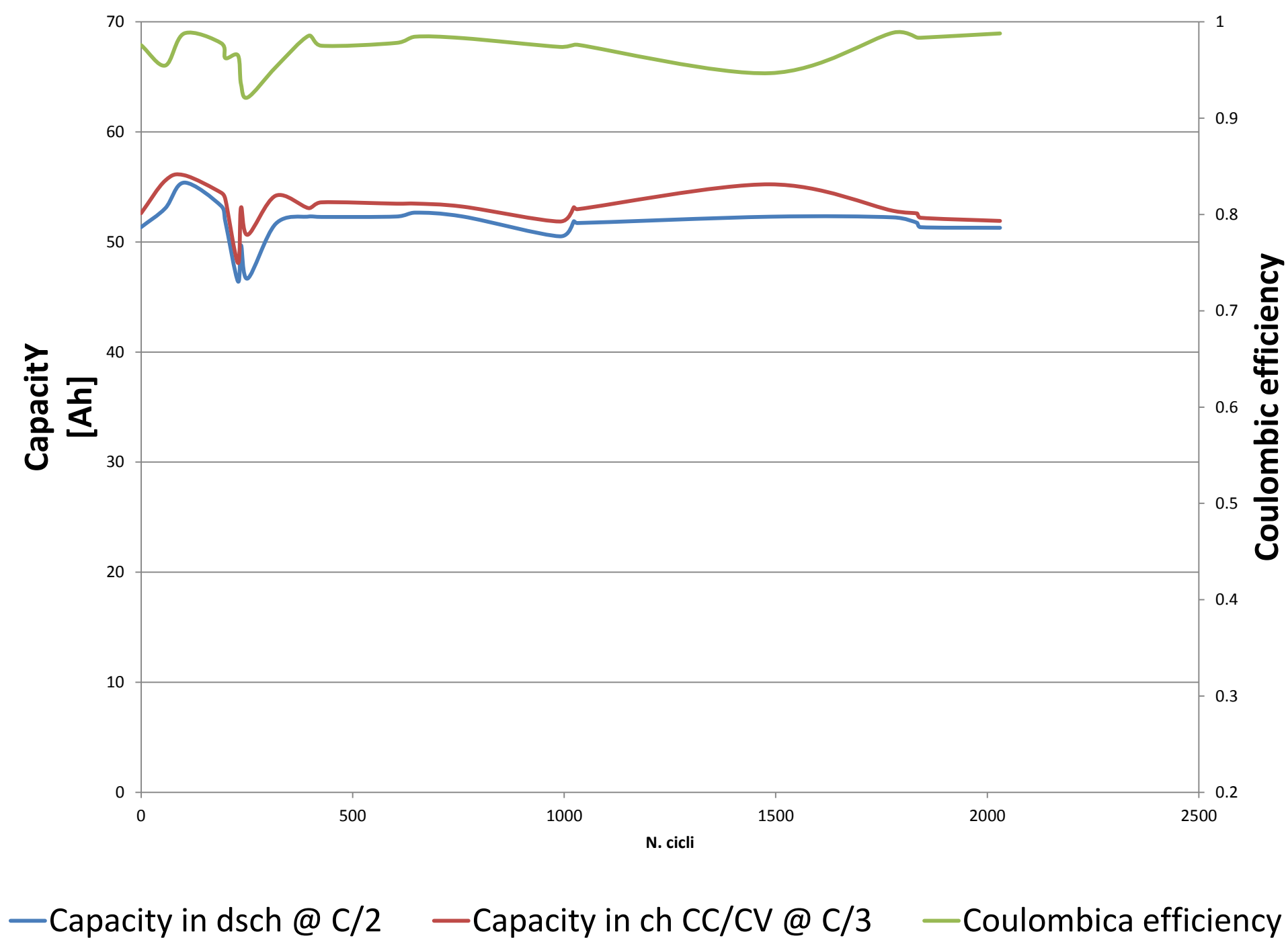


Imposta...



Fast charge – Life cycle test on battery module (3[^])

Performance check – Capacity (standard cycle)

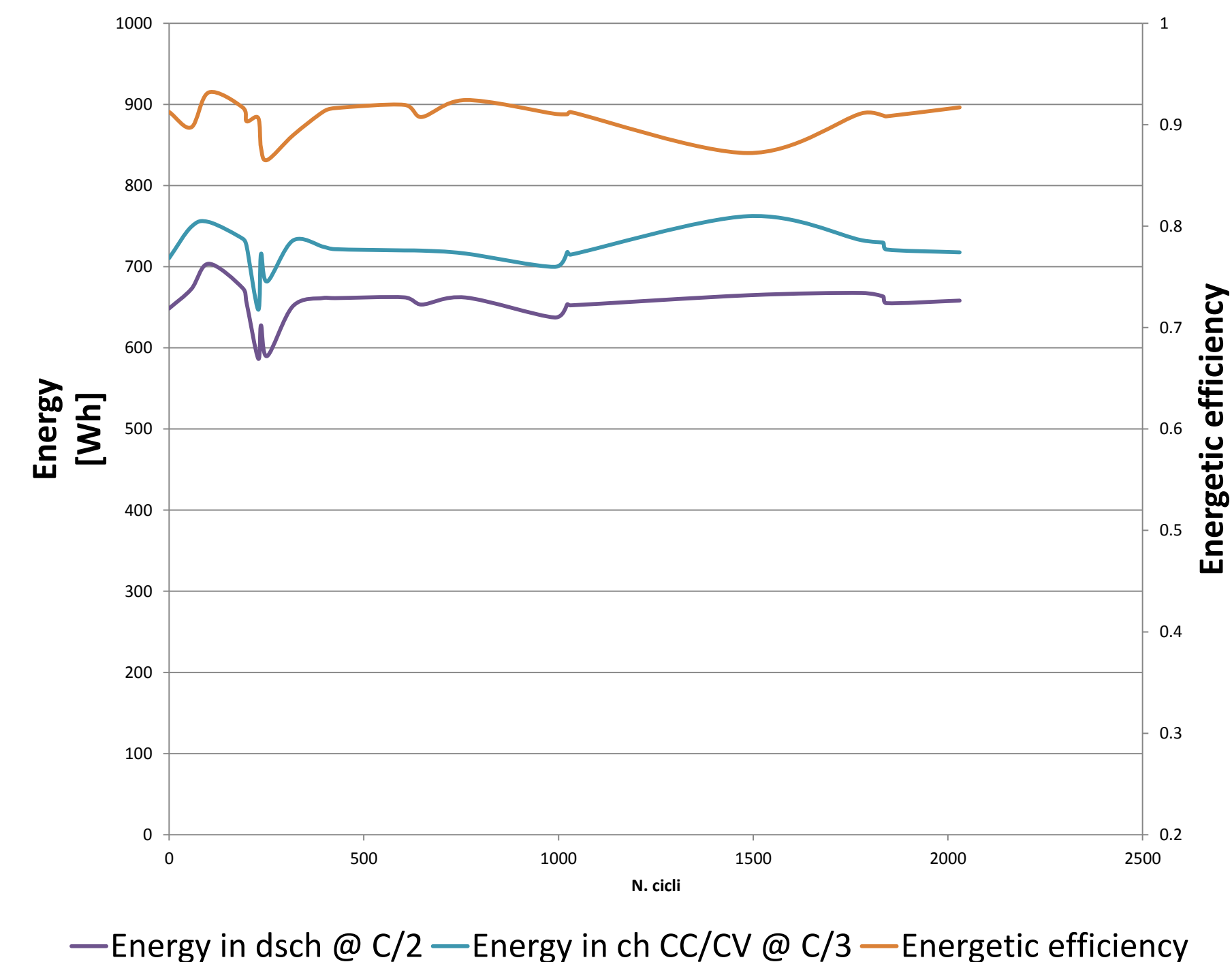


More than 2000 cycles performed

Test in progress

No relevant reduction of performances

Performance check – Energy (standard cycle)



A typical mission (Local Public Transport): the problem

Test procedure is consistent with a typical mission required by the LPT

Equation of “total time”: $T_d + T_s = 1$

Equation of “energy balance”: $C \times V \times T_d = P \times T_s \times \eta$

Parameters: C = kilometric consumption, V = mean speed, P = charging power, η = drive train efficiency

Td = driving time, Ts = stop time

Solving the system, using the values:

C = 600 Wh/km typical value for a minibus like “Gulliver” Tecnobus

V = 20 km/h typical value for a minibus like “Gulliver” Tecnobus

η = 0.8 typical value for a minibus like “Gulliver” Tecnobus

P = 55 kW typical value for DC charging stations



Minibus “Gulliver” Tecnobus

Solving the system of 2 equations in 2 unknowns,

Td = 0.79; Ts = 0.21

Possible LPT missions

Test procedure is consistent with a typical mission required by the LPT

$$T_d = 0.79; T_s = 0.21$$

Number of travels in an hour	Total time	Stop time	Driving time	Travel's length
1	3600 s	756 s	2844 s	15.73 km
2	1800 s	378 s	1422 s	7.87 km
3	1200 s	252 s	948 s	5.24 km
4	900 s	189 s	711 s	3.93 km

Implementation on a minibus “Gulliver” Tecnobus

Complete battery system

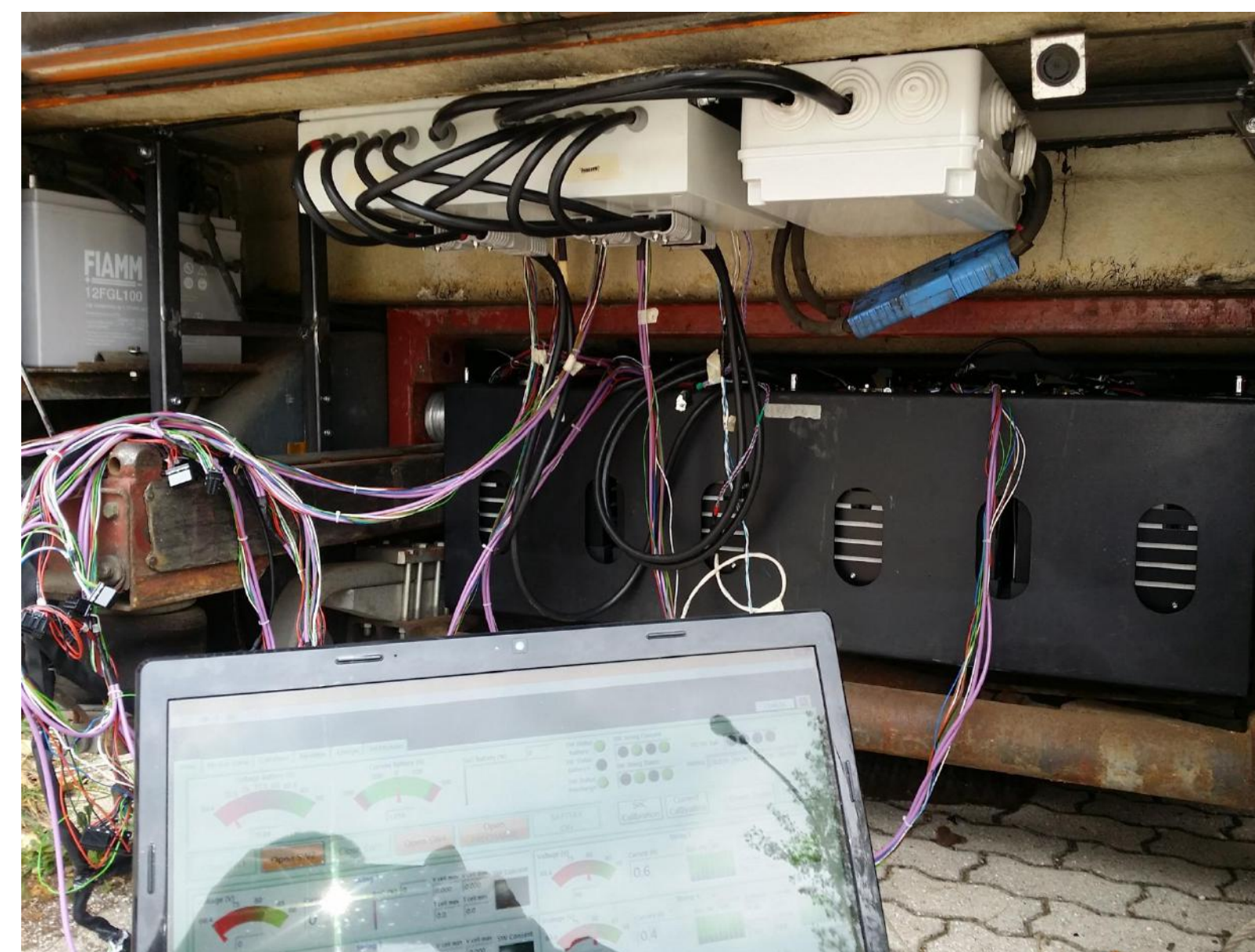
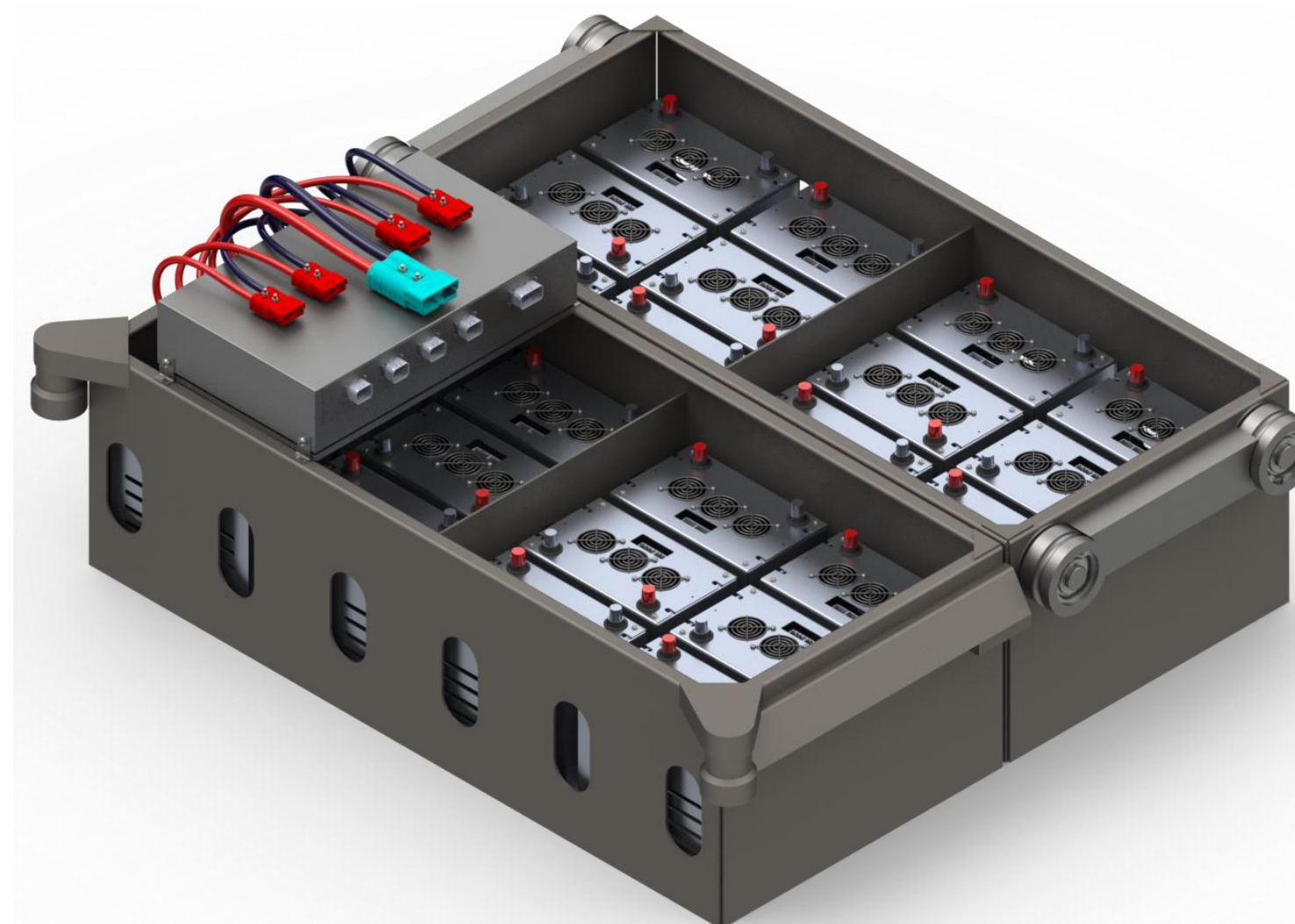
String

6 modules 12 V – 60 Ah in series,
string total: 72 V – 60 Ah

System

4 strings 72 V – 60 Ah in parallel,
system total: 72 V – 240 Ah

Housed in the original container



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Fast charging

Charging power 55 kW ↔ C-rate = 3

ENEA is starting the tests
on the bus

Conclusions (1[^])

The dispositive (cell, module) used for the test (according to the manufacturer's prescriptions, charge: 1C) is particularly suitable to emphasize the effects of fast charge (F.C. = 3C)

Our suggestions to better withstand fast charge

Cells well selected

Cells well balanced

Cells well managed
by BMS (cooling)

Contact quality

Charge type

Low SOC

Characteristics of the fast charge examined

Partial charge
 $\Delta\text{SOC}_{\text{max}} = 25\%$

Shallow cycle
DOD = 25%

Spaced out with a
complete and slow charge

Voltage and temperature of
each cell managed by BMS

Balancing function
performed by BMS

Effects on long term ↔ life cycle test (3C in charge)

More than 2000 cycles (700 hours) executed at cell and module level, no relevant reduction of performances at the moment

Conclusions (2[^])

No contradiction with the common opinion on fast charge

Life cycle test on battery module still in progress until the EOL condition

Life cycle test on complete battery system on board the minibus is waiting to start

Benefits of fast charge

No service
interruption

Reduce
battery size

Fast charge + battery + vehicle mission
seems to be the right connection



Thank you!

For further information:

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