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# Development and realization of lithium-ion battery modules for starting applications and traction of off-road electric vehicles

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# Structure of the presentation

- Definition of standard battery modules
- Previous studies
  - starting batteries
  - off road electric vehicles
- Standard modules
- Design of battery modules
  - test on cells
    - capacity
    - fast charge
    - internal resistance
    - CCA
  - thermal mng
    - thermal analysis on single cell
    - cooling plant by air
    - cooling plant by water
    - cooling tests
  - Battery Management System
- Realization of functional prototypes
- Conclusions

# Definition of standard battery module

development and realization of standard battery modules

- definition of battery module

  *cells, electronic board BMS, thermal management, connections, mechanical case*

- definition of “standard” battery modules

  *same modules for more applications*

  *same components for more module*

  *help for businessmen (especially little)*

# Previous studies - 1

## ❑ Starting batteries

*voltage 12V, chemistry LFP*

| Chemistry | Cell voltage [V] (min-nom-max) | Number of cells | Battery voltage [V] (min-nom-max) |
|---|---|---|---|
| LCO | 2,7-3,7-4,2 | 4 | 10,8-14,8-16,8 |
| LMO | 2,75-3,7-4,2 | 4 | 11,0-14,8-16,8 |
| NMC | 3,0-3,6-4,2 | 4 | 10,8-14,4-16,8 |
| NCA | 3,0-3,6-4,2 | 4 | 10,8-14,4-16,8 |
| **LFP** | **2,5-3,2-3,65** | **4** | **10,0-12,8-14,6** |
| LTO | NA-2,4-NA | 5 | NA-12-NA |

*Request: motor on 13,5÷15V – motor off 9,9÷14,1V – motor starting 8V or 6V*

# Previous studies - 2

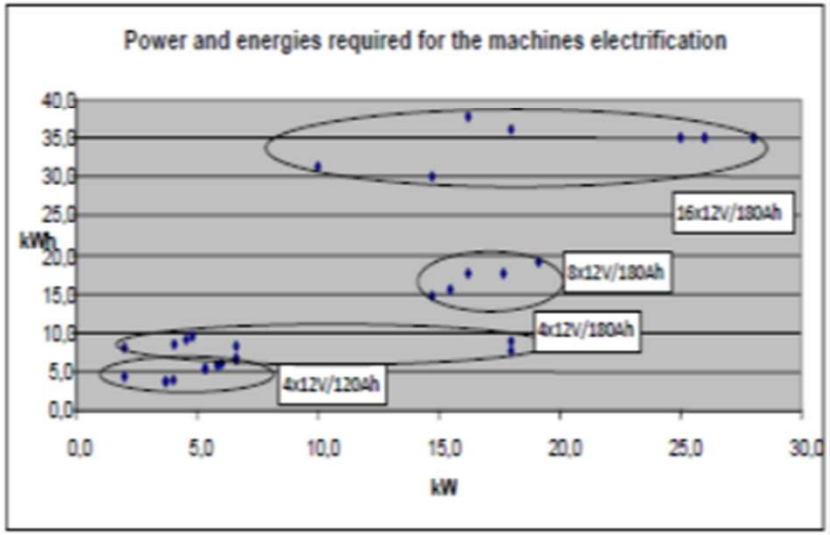
- Electrification of off-road vehicles
- *Italian market at 2020*

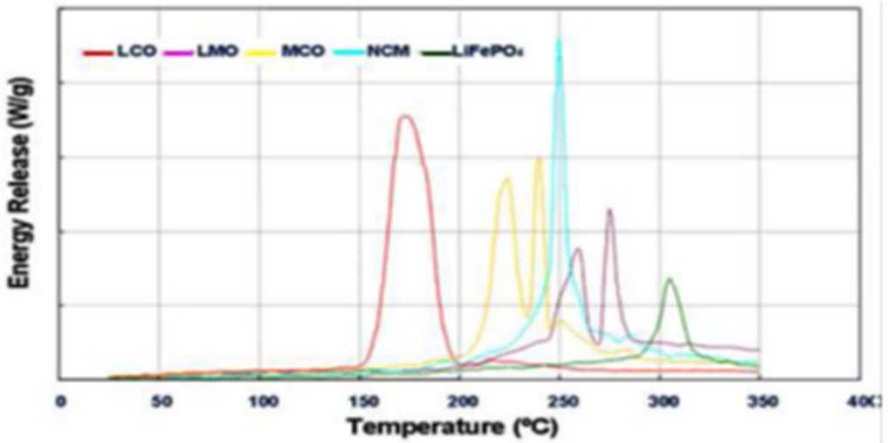
  *25% of the battery market for electric cars*
- *voltages and capacities*

  *48, 96, 192V → 12V*

  *120, 180Ah → 30,60,90Ah*
- *LFP chemistry*

  *suitability, safety and economy*



# Standard modules

- 3 standard modules
  - *12Vn-30Ah (little size)*
  - *12Vn-60Ah (medium size)*
  - *12Vn-100Ah (large size)*
  - *four cells $LiFePO_4$ series connected*

# Design of battery modules

## ❑ Design of battery modules

- *test on cells*
  - *capacity*
  - *fast charge*
  - *internal resistance*
  - *CCA*
- *thermal management*
  - *thermal analysis on single cell*
  - *cooling plant by air*
  - *cooling plant by water*
  - *cooling tests*
- *Battery Management System*

# Design of battery modules: test on cells - 1

- Verify performances and suitability
- EUCAR procedures
  - *energy and capacity at different C-rates and temperatures*
  - *fast charge*
  - *internal resistance*
  - *cold cranking test (CEI EN 50342-1)*

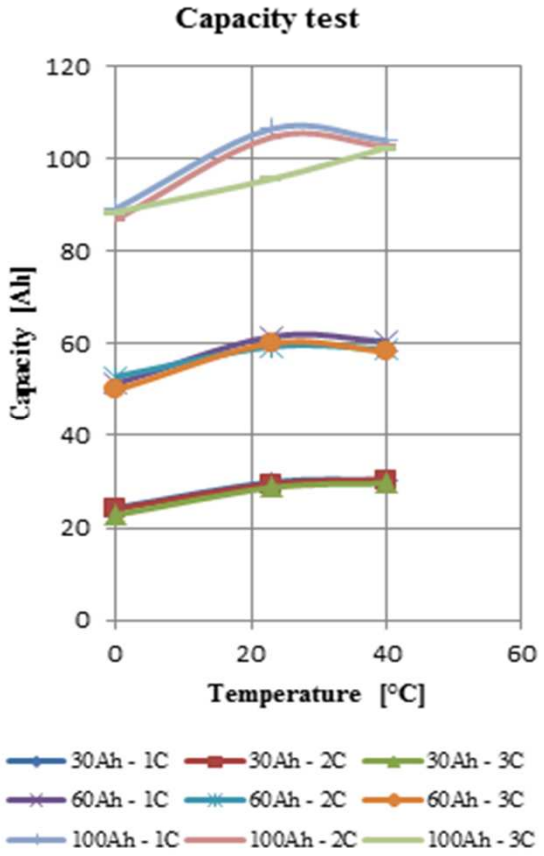
# Design of battery modules: test on cells - 2

- Capacity @ different C-rates and temperatures
  - *discharge @ 1C, 2C, 3C*
  - *temperature 0, +23, +40°C*
  - *results:*

    *capacity @ a given temperature*

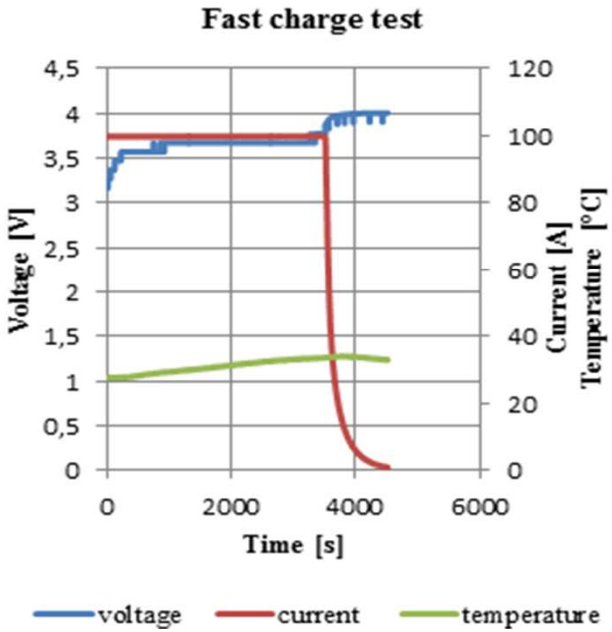
    *capacity @ a given C-rate*

    *best performances*



# Design of battery modules: test on cells - 3

- Fast charge
  - *charge type CC/CV @ 1C according to the specifications of the manufacturer*
  - *voltage, current and temperature were monitored and registered during the test*
  - *results temperature within limits*

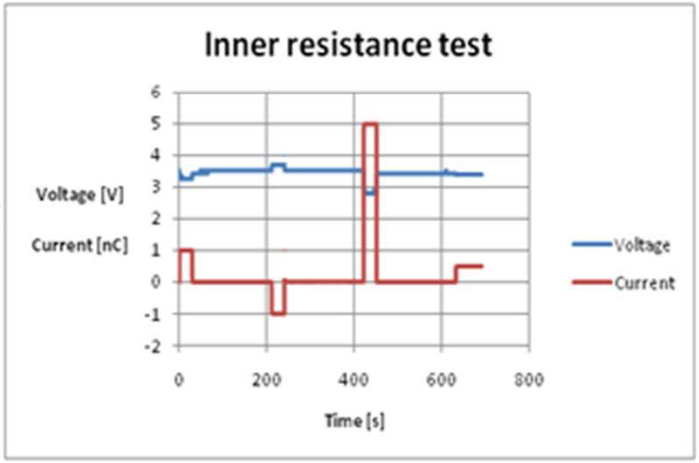


# Design of battery modules: test on cells - 4

## Internal resistance

- *important factor affecting heating and efficiency of the cell*
- *three current pulses*
- *results*

  *the values obtained agree with the specification of the manufacturer*




| Values of internal resistance | |
|---|---|
| $R_{\Omega,dch}$ | 1.66 mΩ |
| $R_{1C,dch}$ | 2.66 mΩ |
| $R_{\Omega,cha}$ | 1.64 mΩ |
| $R_{1C,cha}$ | 1.6 5 mΩ |
| $R_{HC,dch}$ | 1.26 mΩ |

# Design of battery modules: test on cells - 5

## Cold cranking test

- *standard CEI EN 50342-1 for lead batteries*

  *cooling @ -18°C, 10s dsch @ $I_{cc}$,*

  *verify voltage, dsch @ 0,6$I_{cc}$ until $V_{min}$*

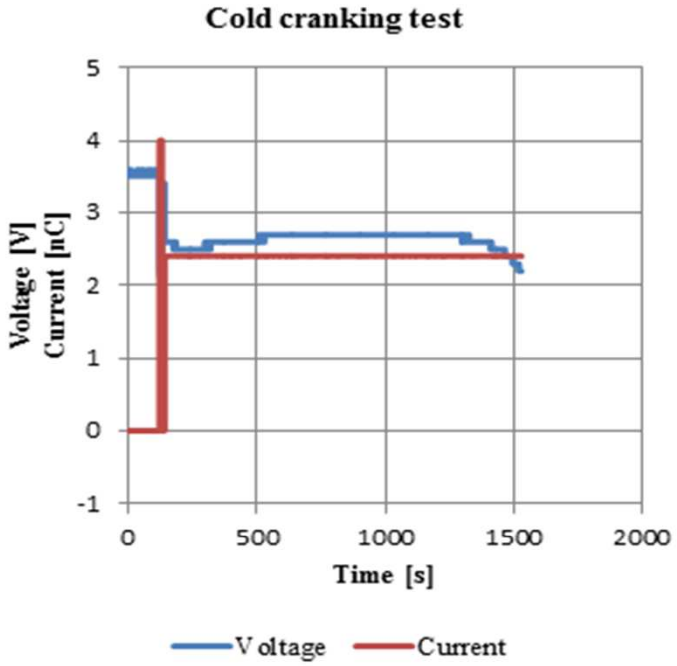
- *adaptation for lithium batteries*

  *cooling @ -10°C, $I_{cc}$ = 4C*

  *(lead acid 44Ah – $I_{cc}$ = 170A) $V_{min}$ = 2,5V*

- *results*

  *voltage over $V_{min}$*



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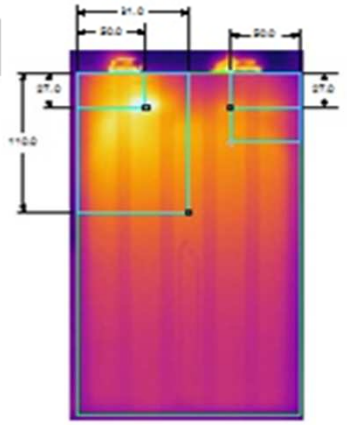
# Design of battery modules: thermal management - 1

- **Thermal analysis on single cell**

  *without thermal conditioning*

  *thermocouples + thermo camera*

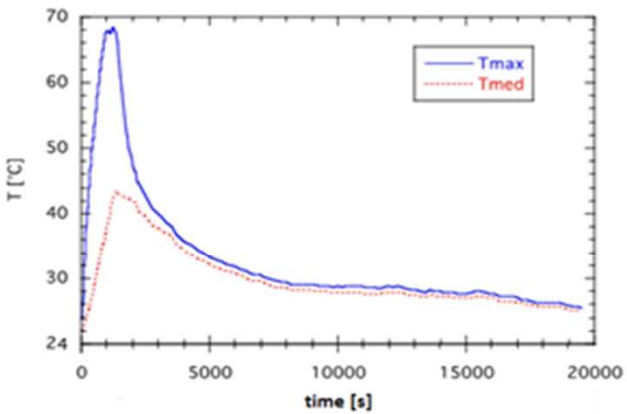


- *tests at low temperatures*

  *heating not needed*

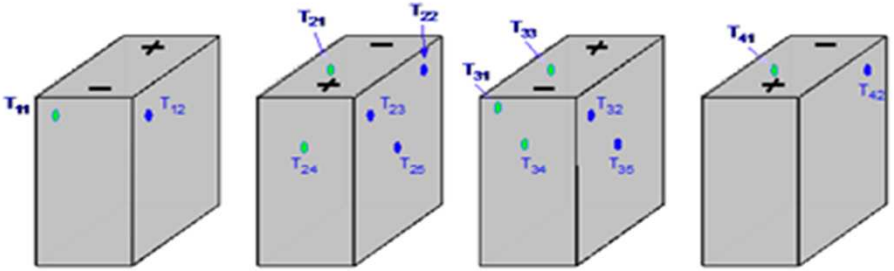
- *tests to evaluate if cooling is needed*

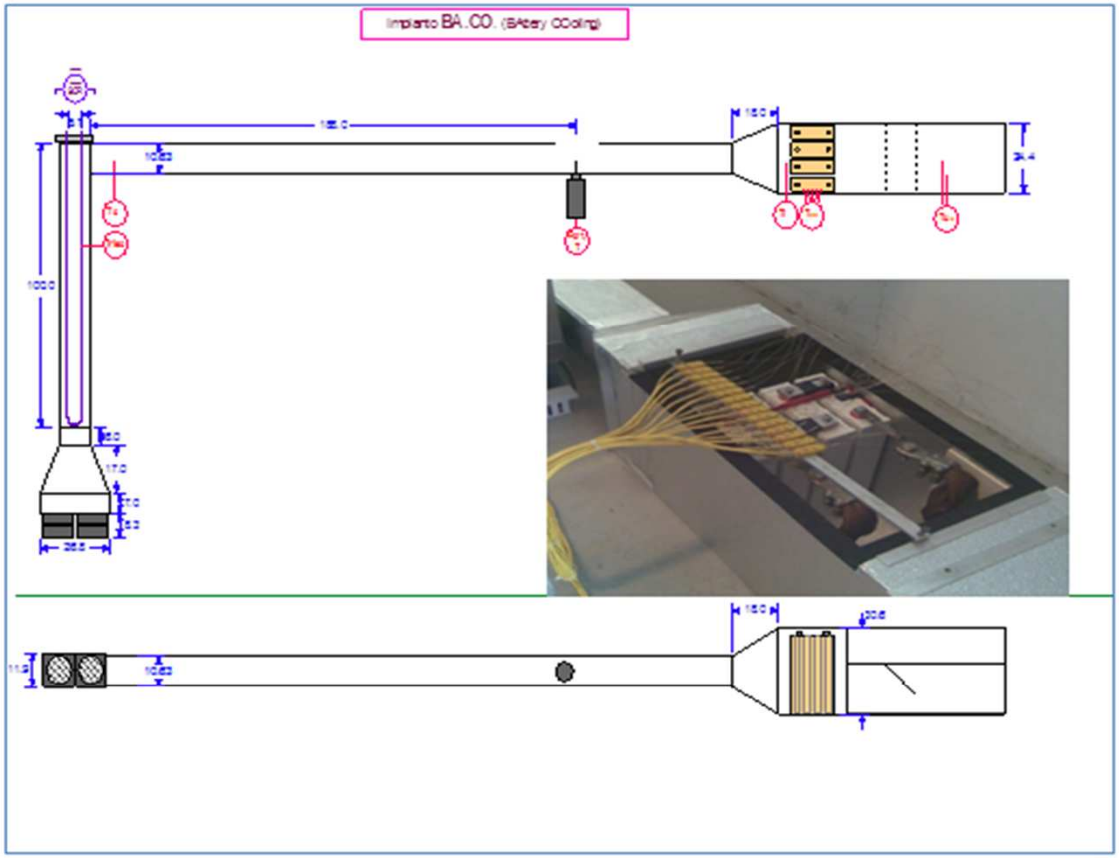
  *hot point detected - indication to place the sensor used for thermal monitoring; critical temperatures reached only at the end of discharge at the maximum C-rate*



# Design of battery modules: thermal management - 2

- Cooling plant by air
  - *BA.CO. plant*
  - *test section*
  - *position of thermal sensors*



# Design of battery modules: thermal management - 3

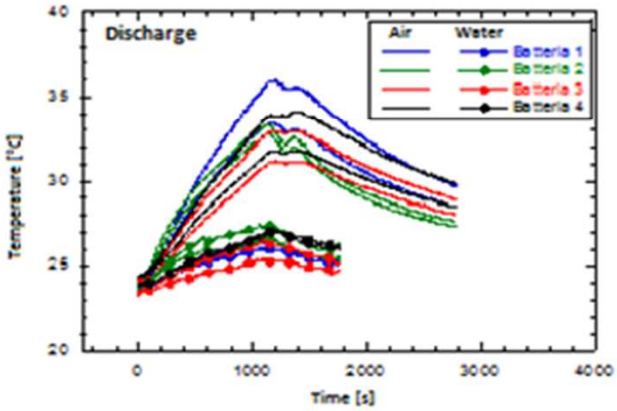
- Cooling plant by water
  - *simple cooling circuit type "pool boiling"*
  - *position of thermal sensors*
  - *data acquisition system*

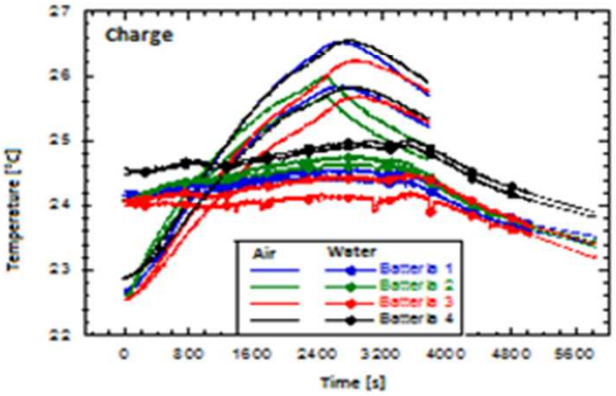
# Design of battery modules: thermal management - 4

- Cooling tests
  - *cooling tests realized at the most critical operating conditions*

    *discharge @ 3C, charge @ 1C*
  - *air flow 100Nm³/h - little fans*
  - *water flow 100l/h - little pump*
  - *results*

    *both cooling systems efficient, comparison in favour of water but air was chosen – efficiency, simplicity, economy*

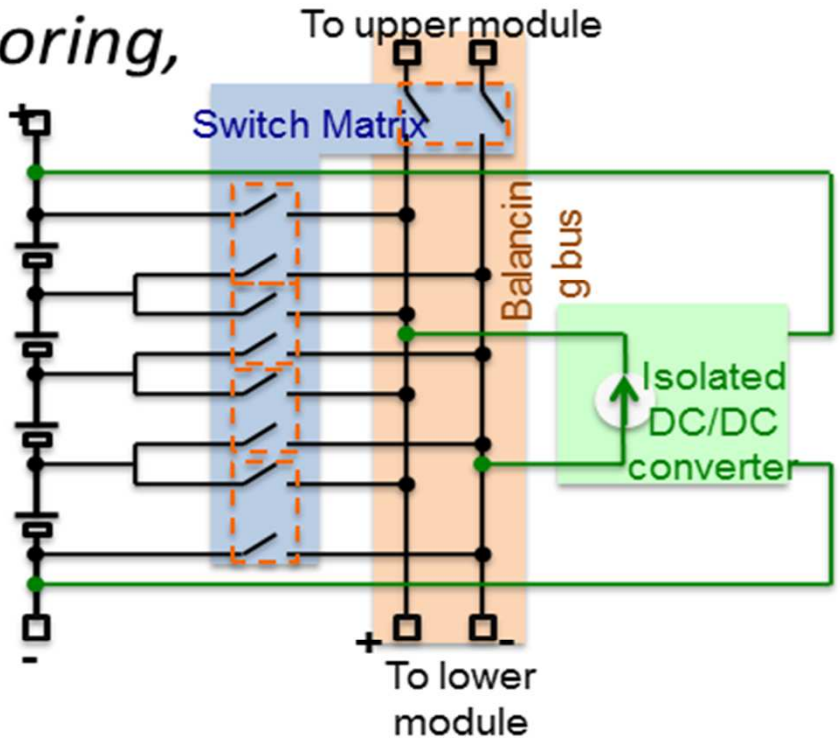


# Design of battery modules: BMS - 1

## Battery Management System

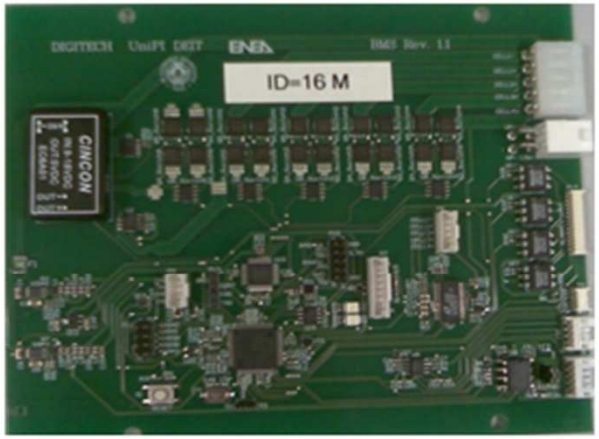
- *functions of protection, monitoring, data acquisition, active balancing*
- *architecture*
  *DC/DC converter +switch matrix*
- *current level can reach 2 A*
- *balancing intra-extra module*

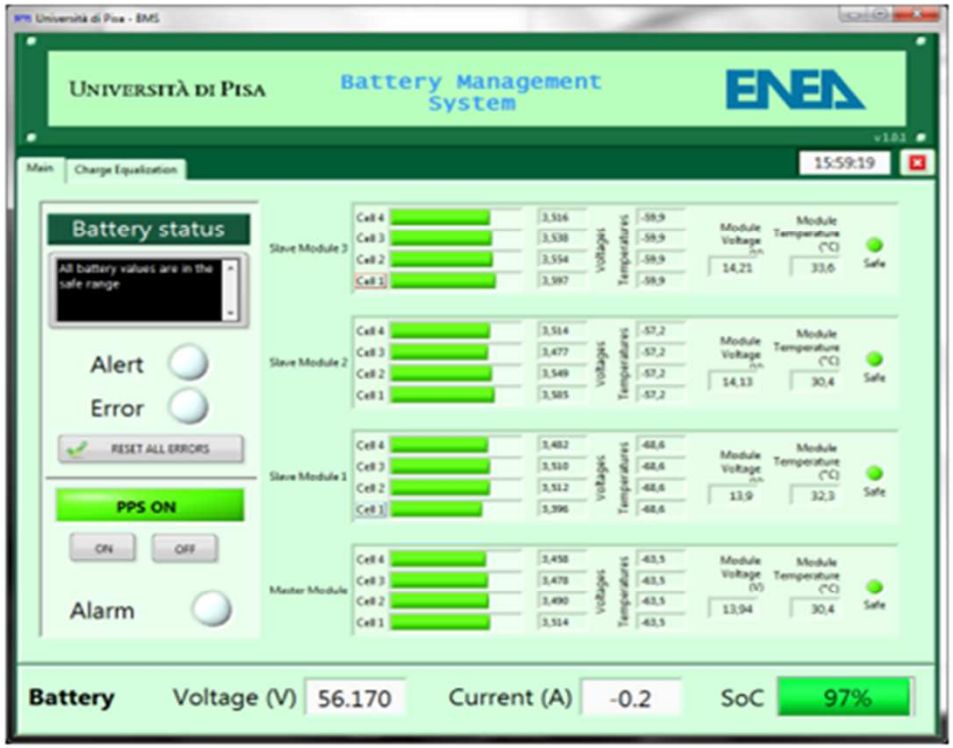


# Design of battery modules: BMS - 2

- *only one type of electronic board is required*

  *set of capacity and function – master or slave*
- *manage battery cooling*
- *user friendly interface*
- *electronic board*



# Realization - 1

## ❑ Realization of functional prototypes

- *geometric configuration*

  *best ratio performances/volume*

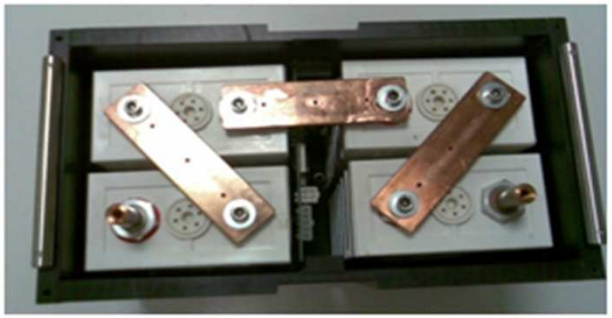
- *thermal management*

  *ventilation channels, NTC sensor*

  *three fans 34.5Nm$^3$/h, 75.5Pa @ 7000rpm*

  *start @ +45°C (settable)*

- *same cooling system and BMS*



# Realization - 2

- Final characteristics of the modules

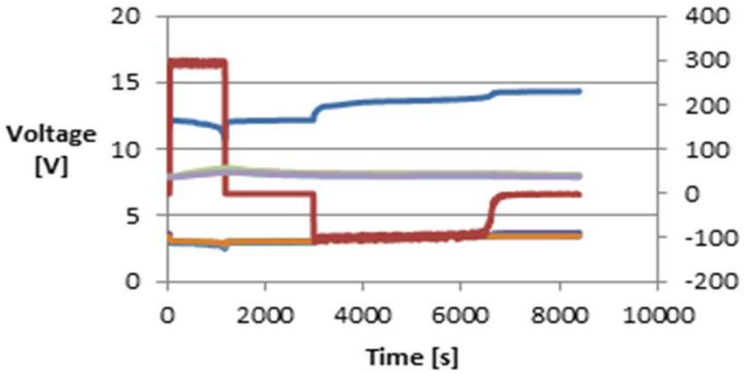
| Main characteristics of the battery modules | | | | | | | |
|---|---|---|---|---|---|---|---|
| Module size | Capacity [Ah] | Dimensions LxWxH [mm] | Weight [kg] | Energy density [Wh/dm$^3$] | Power density [W/dm$^3$] | Specific energy [Wh/kg] | Specific power [W/kg] |
| small | 30 | 277x160x208 | 8.3 | 42 | 125 | 47 | 139 |
| medium | 60 | 297x166x236 | 12.3 | 66 | 198 | 63 | 188 |
| large | 100 | 310x186x318 | 19.1 | 70 | 210 | 67 | 201 |

# Conclusions - 1

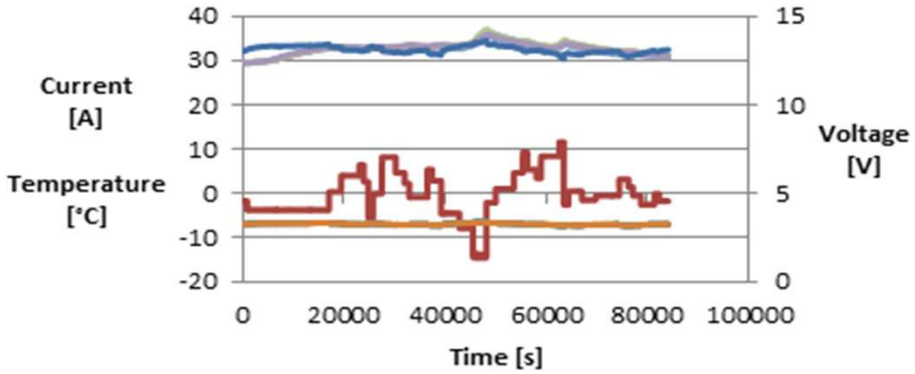
- Tests are going on
  - *confirm geometry and performances*

    *dsch 3C + ch 1C, fast charge @ 3C, stationary applications*

**Module 100 Ah**
**Dsch 3C - Ch 1C @ +40°C**



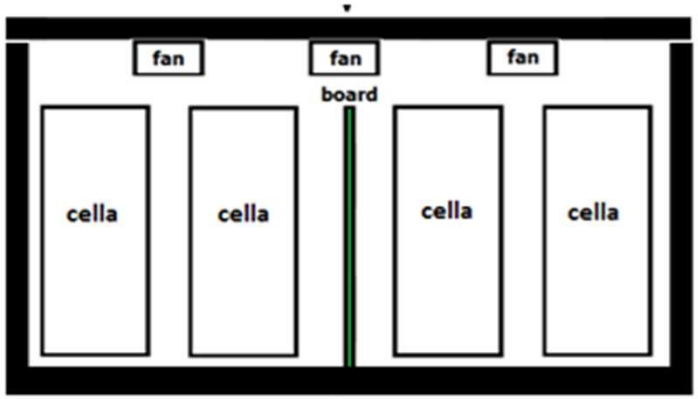

**Module 30Ah**
**Power balancing**



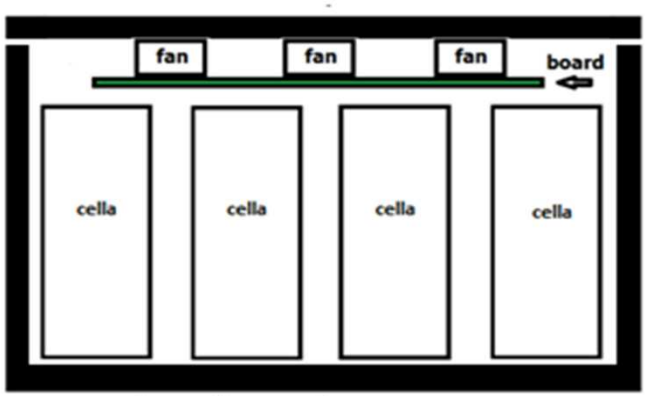
# Conclusions - 2

- *suggest optimization*

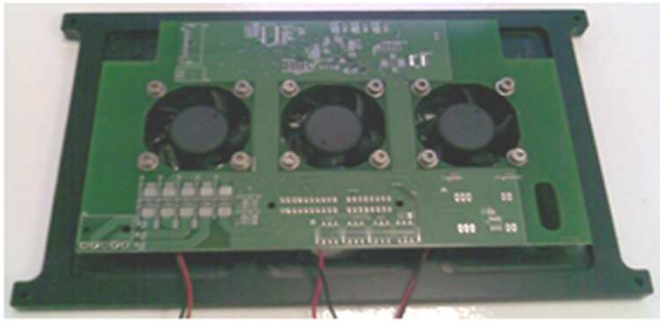
  *move BMS board*




*actual version*




*idea for new version*



*realization*

- *final engineering with industrial partners*

  *(campers, overhead cranes)*

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# Thanks

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***Thank you very much!***

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