Battery technology and QUB EV lab

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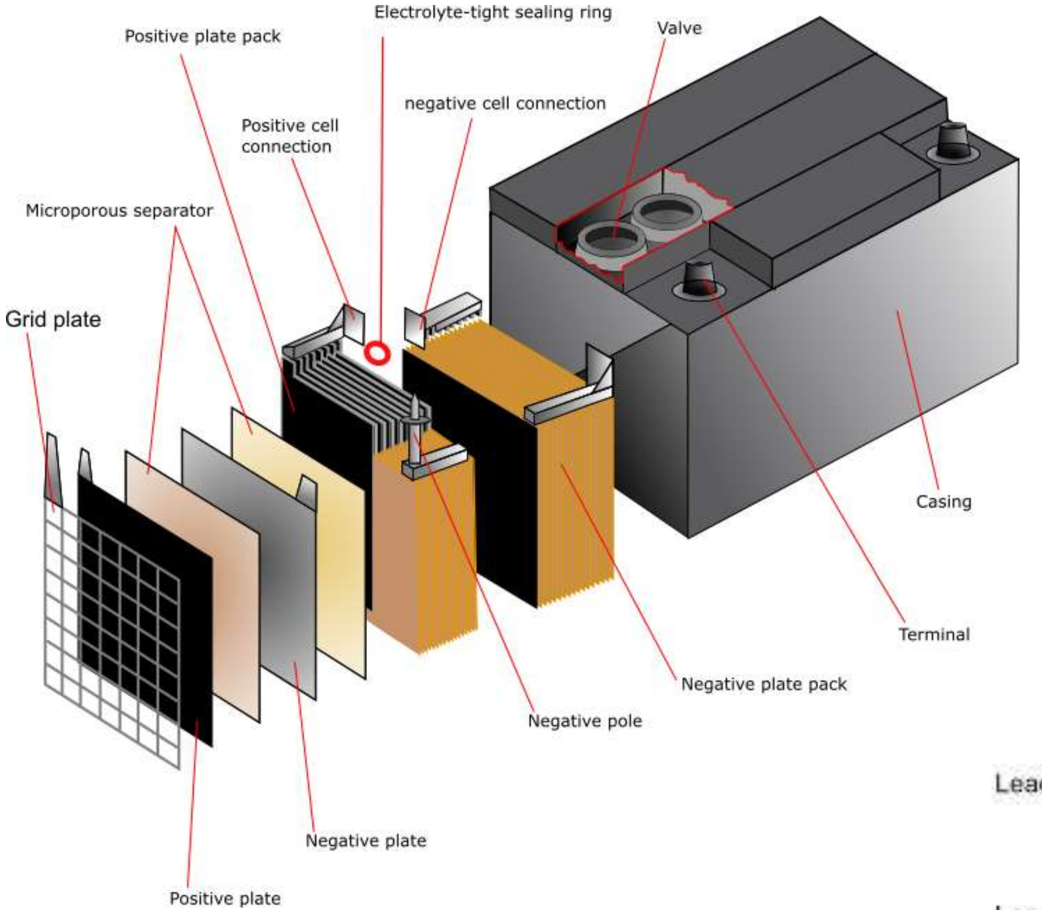
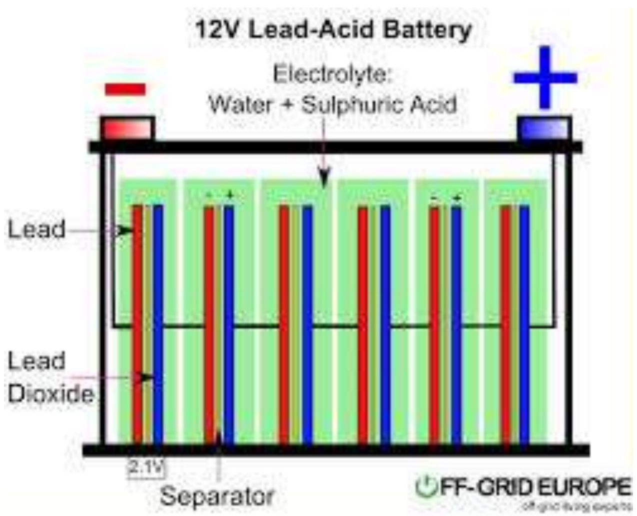
energy, power
& intelligent control

Content

- Lead Acid Battery
  - Mechanism
  - Category
  - Characterization
  - Life cycle
- Other Batteries
  - Advanced Lead Acid
  - Li-Ion
  - Lead Acid + Supercapacitor
- QUB EV lab
- Our research

Machnism

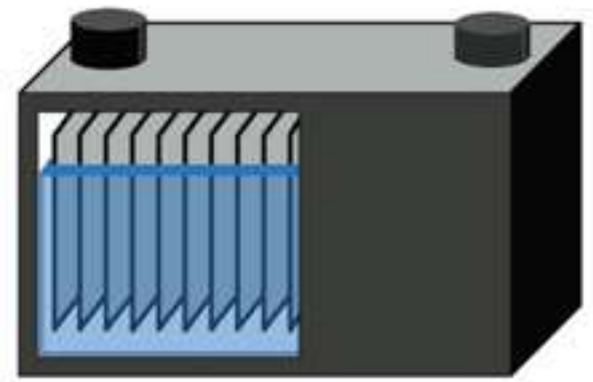

Electrolyte-tight sealing ring
Valve
Positive plate pack
negative cell connection
Positive cell connection
Microporous separator
Grid plate
Casing
Terminal
Negative plate pack
Negative pole
Negative plate
Positive plate


12V Lead-Acid Battery
Electrolyte:
Water + Sulphuric Acid
Lead
Lead
Dioxide
2.1V
Separator
OFF-GRID EUROPE

Lead-Acid Reactions

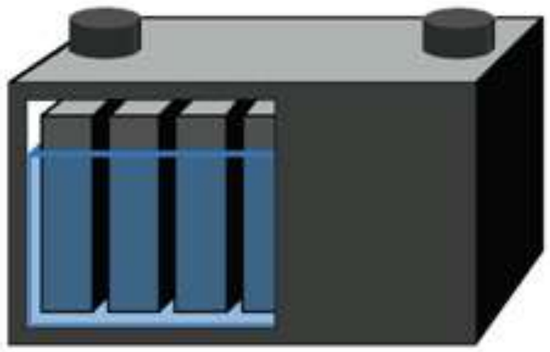
Equation 1 Electrolyte	H_2SO_4	$\rightleftharpoons$	$H^+ + HSO_4^-$
Equation 2 Negative Electrode	$Pb_{(metal)} + HSO_4^-$	$\underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}}$	$PbSO_4 + H^+ + 2e^-$
Equation 3 Positive Electrode	$PbO_2 + 3H^+ + HSO_4^- + 2e^-$	$\underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}}$	$PbSO_4 + 2H_2O$
Equation 4 Total Reaction	$Pb_{(metal)} + PbO_2 + 2H_2SO_4$	$\underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}}$	$2PbSO_4 + 2H_2O$

Background of lead acid battery



Starter battery

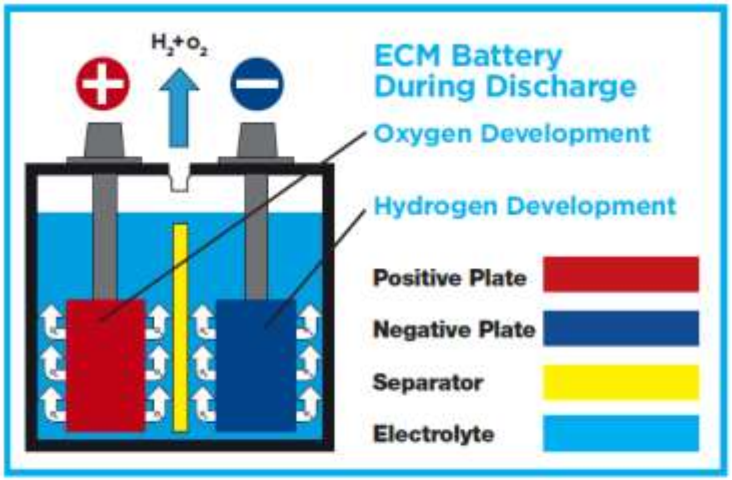
- Low internal resistance
- High power

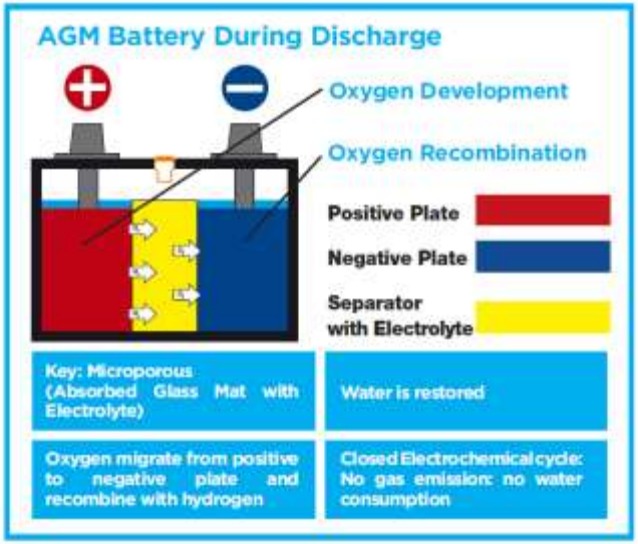


Deep-cycle battery

- Designed for cycling
- Small continuous power

Lead Acid Battery Categories





ECM (Enhanced Cyclic Mat)
AFB (Advanced Flooded Battery)
EFB (Enhanced Flooded Battery)

AGM (Absorbed Glass Mat)

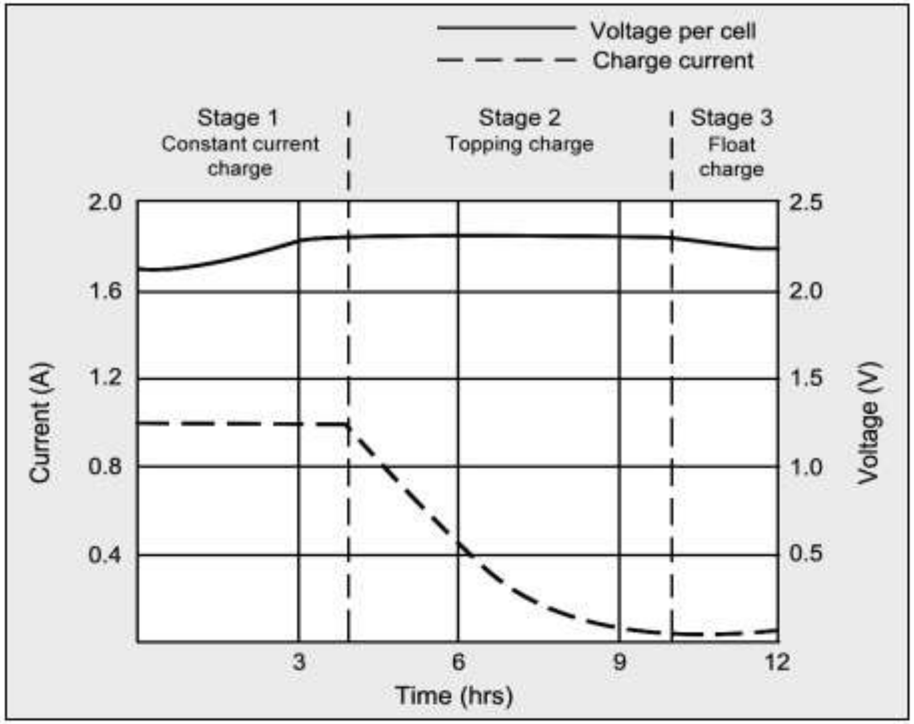
Good for Brake Energy Regeneration

Background of lead acid battery

Standard	EFB	AGM
		
Bosch S4 Car Battery Type 096	Bosch S5 Car Battery Type 100	Bosch S6 Car Battery Type 096
Amp Hours (Ah): 74Ah Cold Cranking Amp (CCA): 680cca	Amp Hours (Ah): 74Ah Cold Cranking Amp (CCA): 750cca	Amp Hours (Ah): 70Ah Cold Cranking Amp (CCA): 760cca
£71.49	£84.95	£123.32

Price from http://www.europeanbatterysupplies.co.uk/

Standard Charging



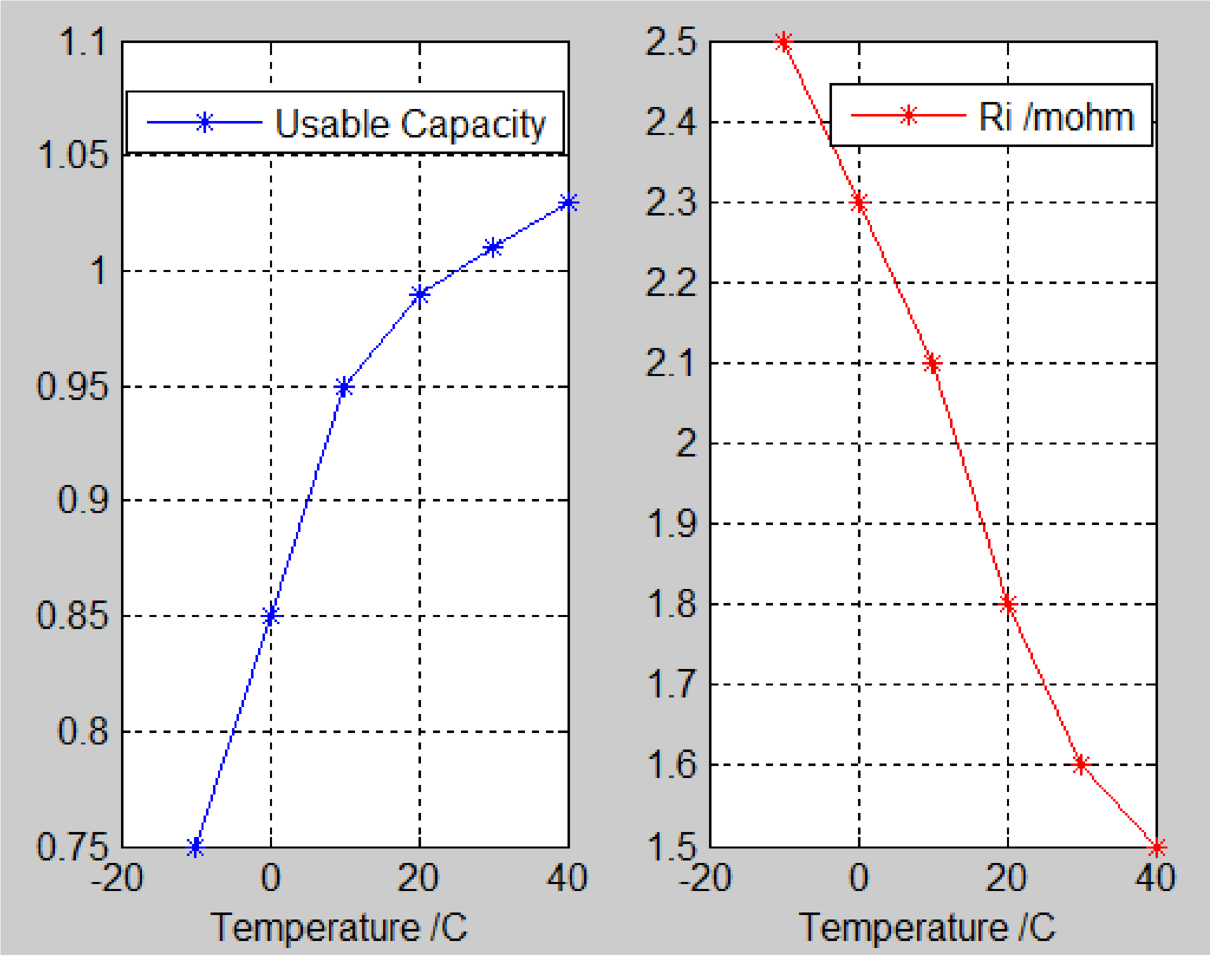
Stage 1: Voltage rises at constant current to V-peak.

Stage 2: Current drops; full charge is reached when current levels off

Stage 3: Voltage is lowered to float charge level

Charging Lead Acid

Lead Acid Performance vs Temperature

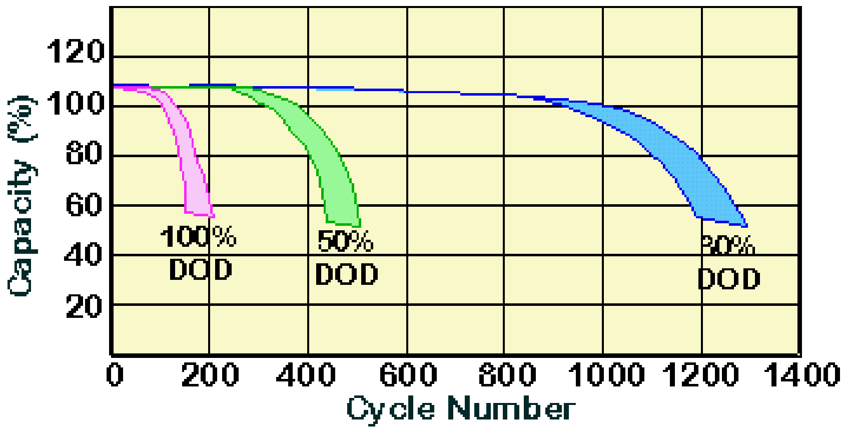


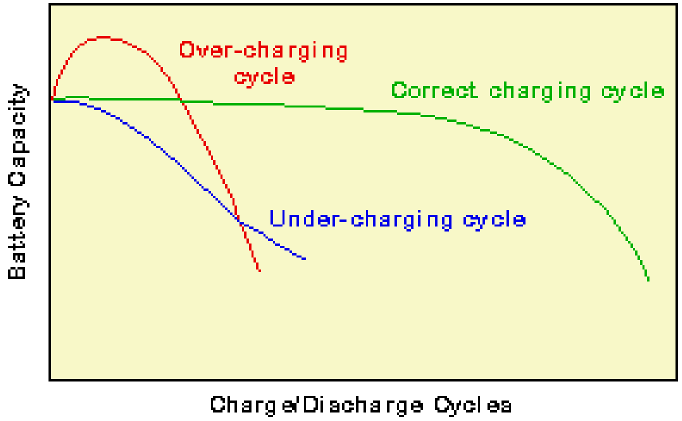
Cycle life versus DoD

Battery life

Depth of Discharge	Starter Battery	Deep-cycle Battery
100%	12–15 cycles	150–200 cycles
50%	100–120 cycles	400–500 cycles
30%	130–150 cycles	1,000 and more cycles

From http://batteryuniversity.com/

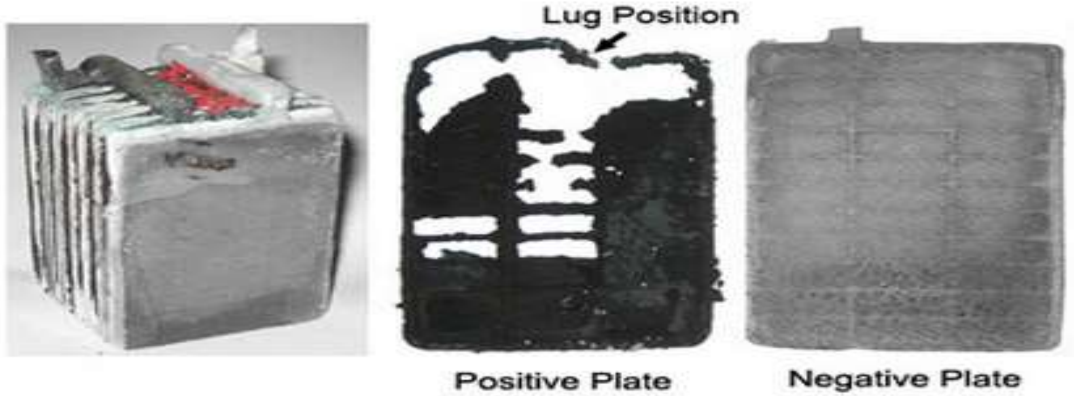


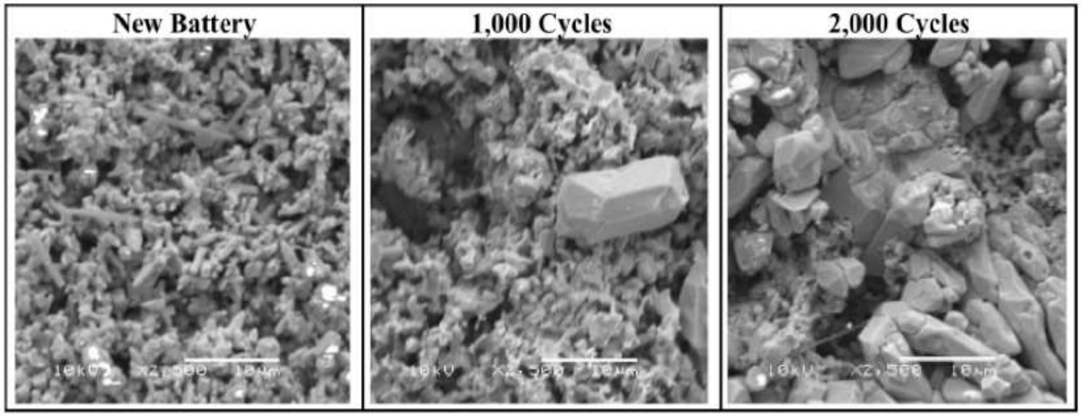


http://pvcdrom.pveducation.org/BATTERY/charlead.htm

lead acid battery aging

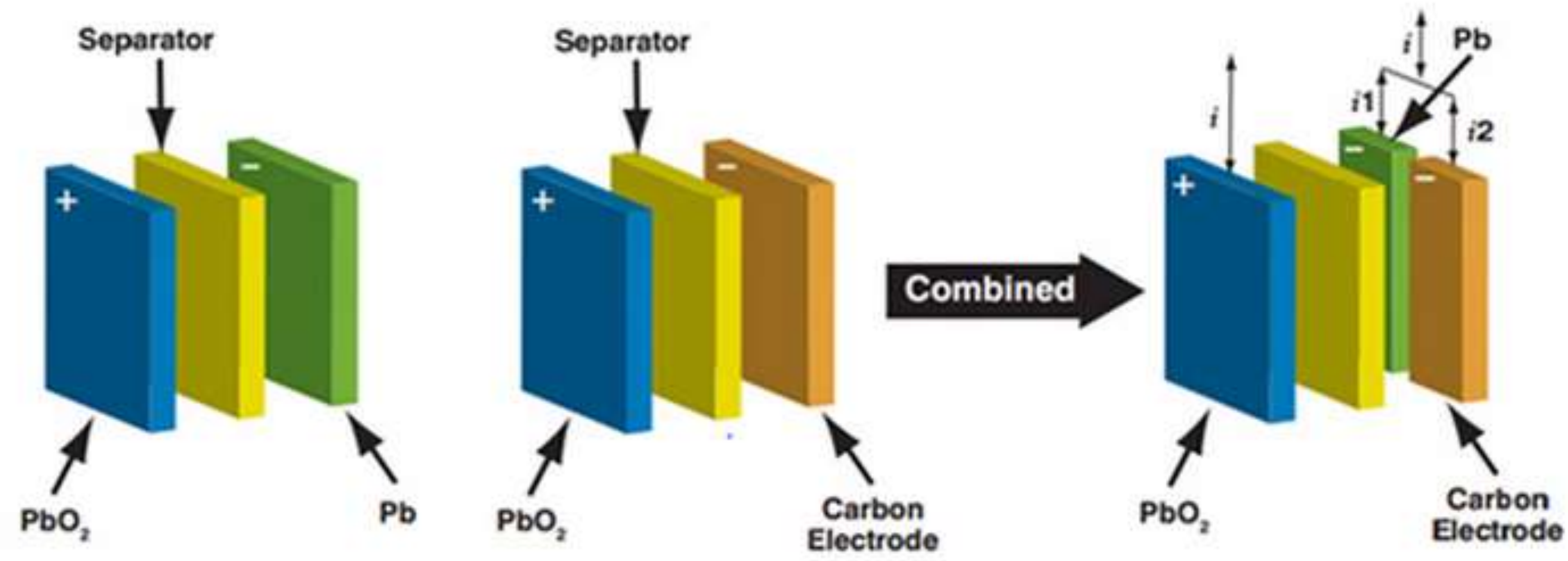
Over charge	→	Grid corrosion (+)
Lower charge	→	Sulphation build-up (−)



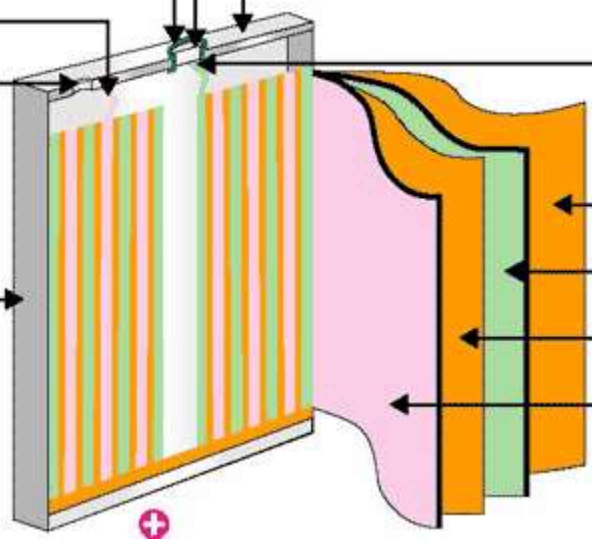


Advanced Lead Acid Battery

Advanced Lead-Carbon



Li ion Battery



Anode $$LiFePO_4 \rightarrow FePO_4 + Li^+ + e^-$$

Cathode $$Li^+ + e^- + C_6 \rightarrow LiC_6$$

Li ion Battery Characterization

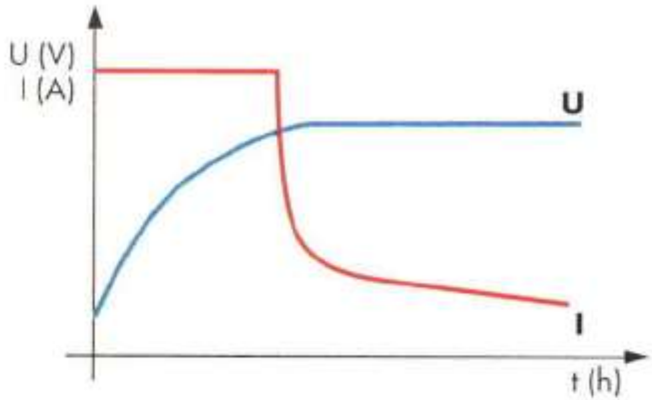


Fig 1. Typical Charging Profile

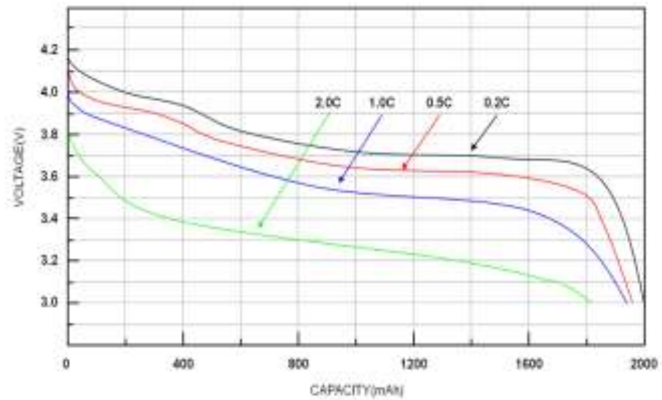


Fig 2. usable capacity versus discharging current

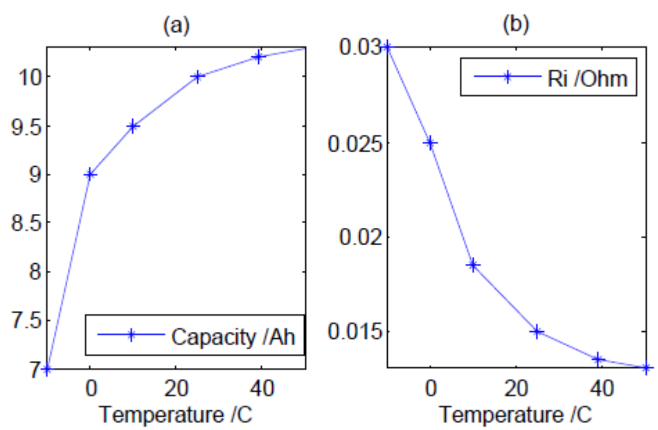


Fig 3. Temperature effect on usable capacity and internal resistance

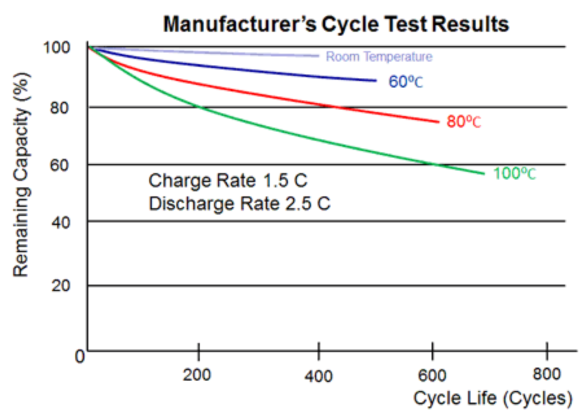


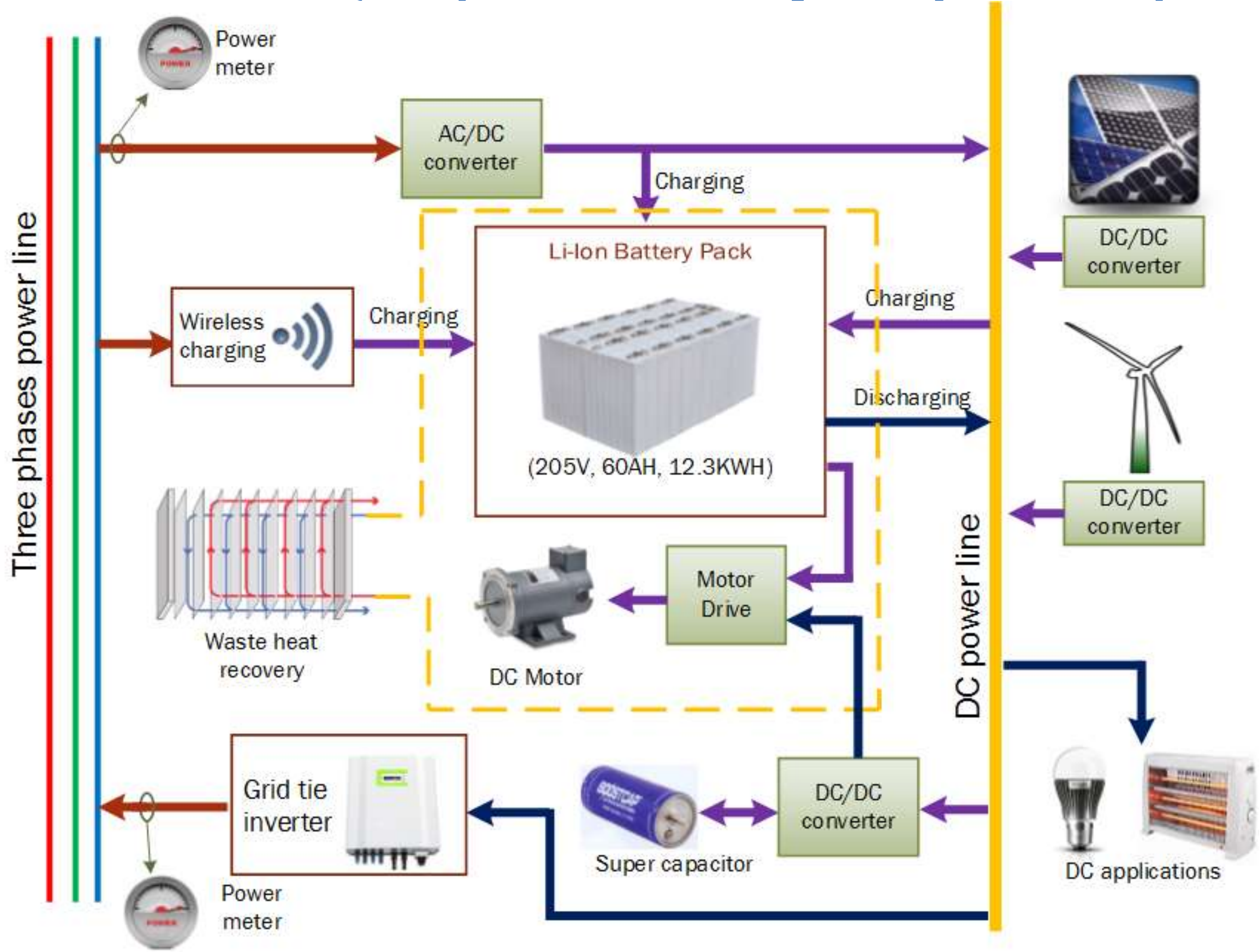
Fig 4. Battery aging process vs temperature & Cycle number

Aging is also affected by discharging current level, discharging depth,

Lead Acid vs Li-ion

Specification	Lead-acid	Li-ion
Energy Density (Wh/L)	60-110	300 - 700
Specific Energy (Wh/kg)	40	100 - 260
Energy Density (W/kg)	180	250 - 350
Cycle life	800 @ 50% DoD	2000 @ 80% DoD
Temperature Sensitivity	Degrades significantly above 25°C	Degrades significantly above 45°C
Efficiency	100% @ 0.05 C-rate 80% @ 0.25 C-rate 60% @1 C-rate	100% @ 0.05 C-rate 99% @ 0.25 C-rate 92% @1 C-rate
Cost ($/kWh)	100	400
Maintenance	free	BMS

EV lab at QUB (EPSRC-NSFC jointly funded)



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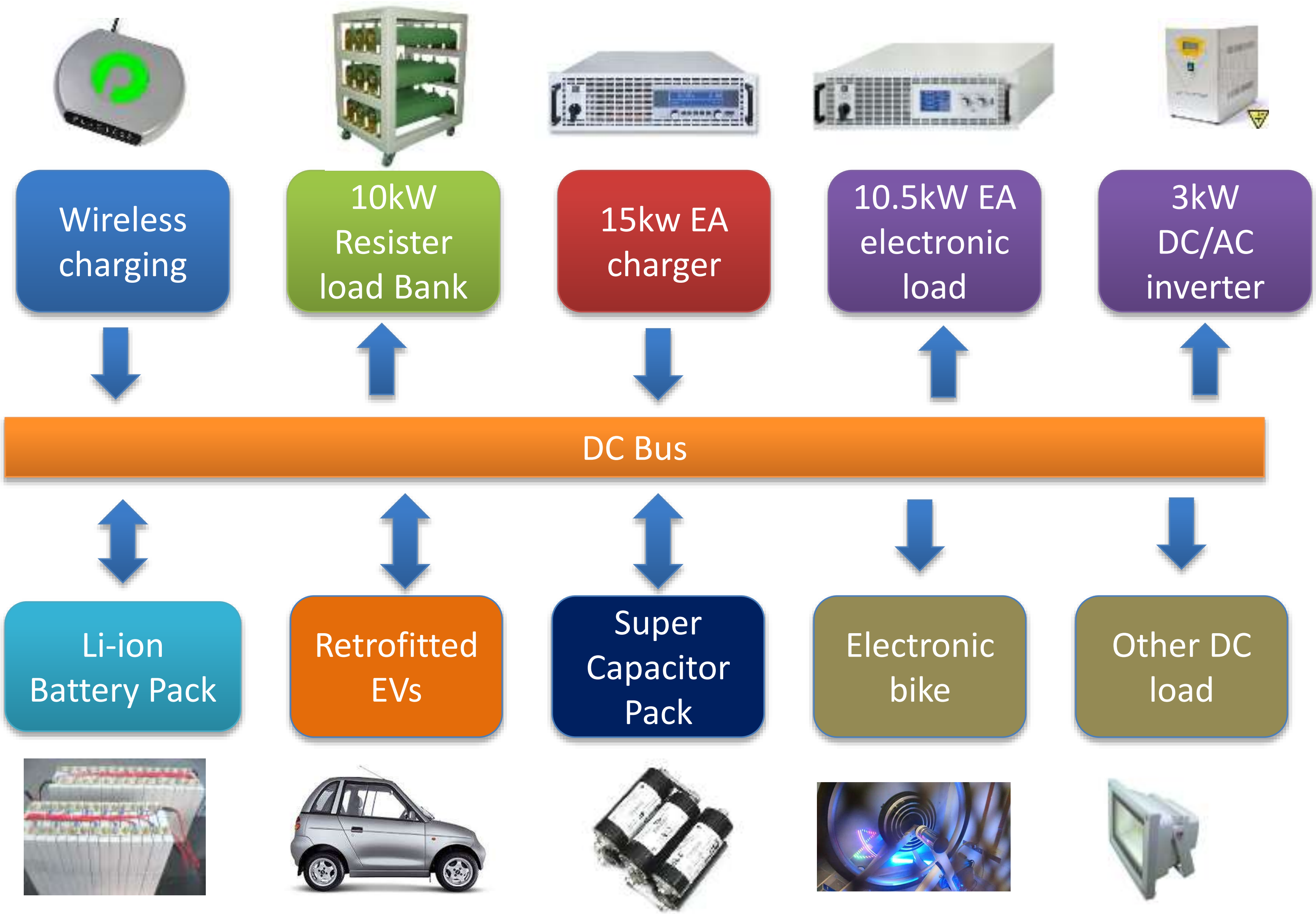
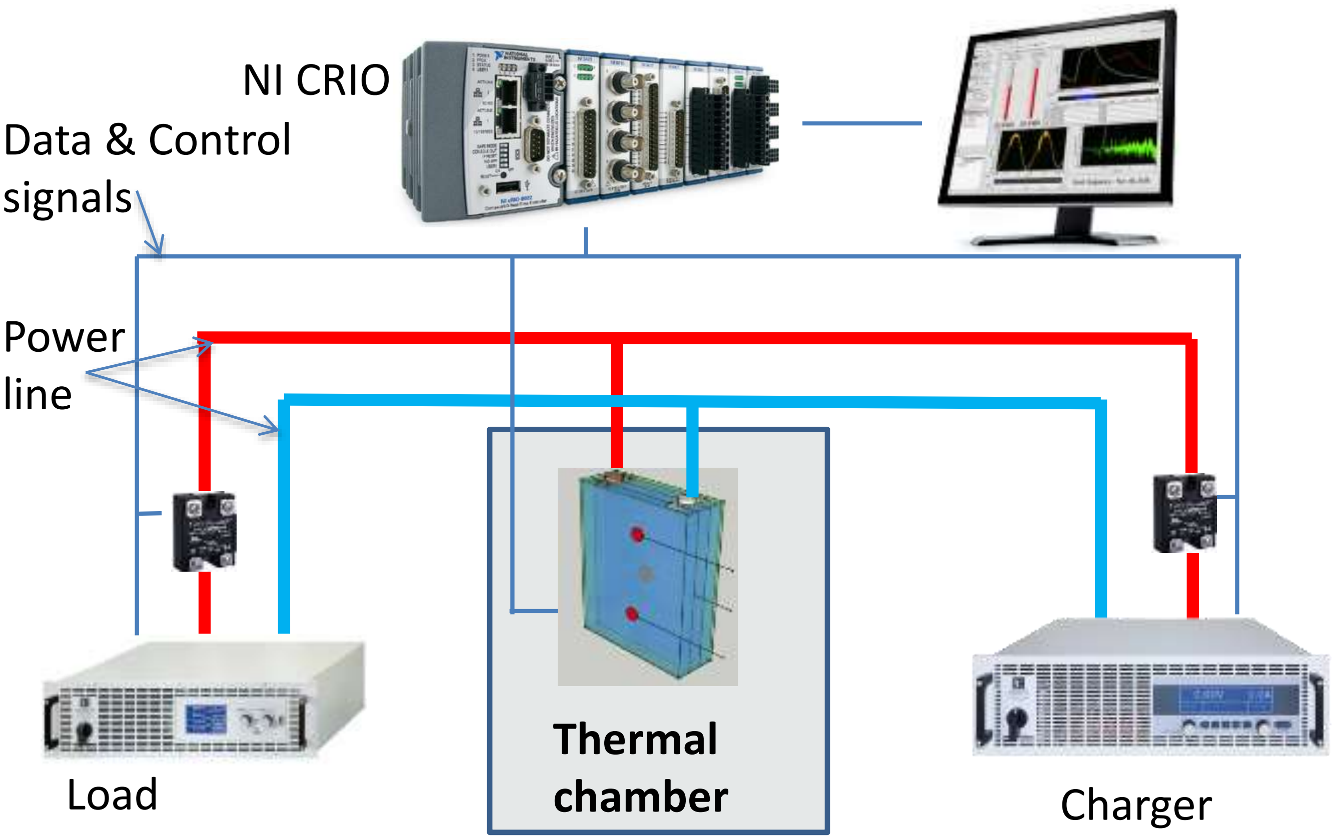

Wireless charging
10kW Resister load Bank
15kw EA charger
10.5kW EA electronic load
3kW DC/AC inverter
DC Bus
Li-ion Battery Pack
Retrofitted EVs
Super Capacitor Pack
Electronic bike
Other DC load

EV Lab

1. Battery testing system



Functionality:

1. ***Fully automatic charging/discharging test***
2. ***Temperature control***
3. ***User-defined VIP test sequence*** *(within charger / load capacity limit)*
4. ***Expandable***
5. ***User interface*** *(Labview)*

EV Lab

NATIONAL INSTRUMENTS™ LabVIEW™

NI CRIO 9022 test controller

- *Embedded controller runs LabVIEW Real-Time for deterministic control, data logging, and analysis*
- *533 MHz processor, 2 GB non-volatile storage, 256 MB DDR2 memory*
- *Dual Ethernet ports with embedded web and file servers for remote user interfacing*
- *Hi-Speed USB host port for connection to USB flash and memory devices*
- *RS232 serial port for connection to peripherals; dual 9 to 35 VDC supply inputs*

EV lab

➢ Electronic Load

EA-ELR 9250-210 ELECTRONIC LOAD with recovery function

- Output power: 10.5kw
- Output voltage: 0 – 250v
- Output current: 0 - 210A
- Program interface: USB, Ethernet, CAN, RS-232

➢ Charger

EA Elektro-Automatik EA-PS 500-90 3U

- Output power: 15kw
- Output voltage: 0-500v
- Output current: 0-90A
- Program interface: USB, Ethernet, CAN, RS-232

EV lab

➢ Electronic Load 2

EA-ELR 9080-170 ELECTRONIC LOAD with recovery function

- Output power: 3.5 kw
- Output voltage: 0 - 80v
- Output current: 0 - 170A
- Program interface: USB, Ethernet, CAN, RS-232

➢ Charger 2

EA-PSI 9080-120 1 phase

- Output power: 3kw
- Output voltage: 0-80v
- Output current: 0-120A
- Program interface: USB, Ethernet, CAN, RS-232

EV lab

Temperature range: -20°C to +80°C

Temperature accuracy: ∓2°C

Cold test environment

Hot test environment

Automatic Temperature controller

➢ Li ion Battery

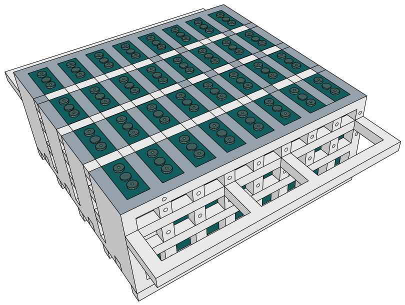
- LiFePO4
- 3.2 V
- 10 Ah
- 3C discharge
- 1C charge

- LiFePO4
- 3.2 V
- 100 Ah
- 1C discharge
- 1C charge

➢ Super capacitor

- Capacitance: 2000 Farad
- Voltage: 2.7V
- Continuous current: 130A
- Peak current: 1800A

EV lab



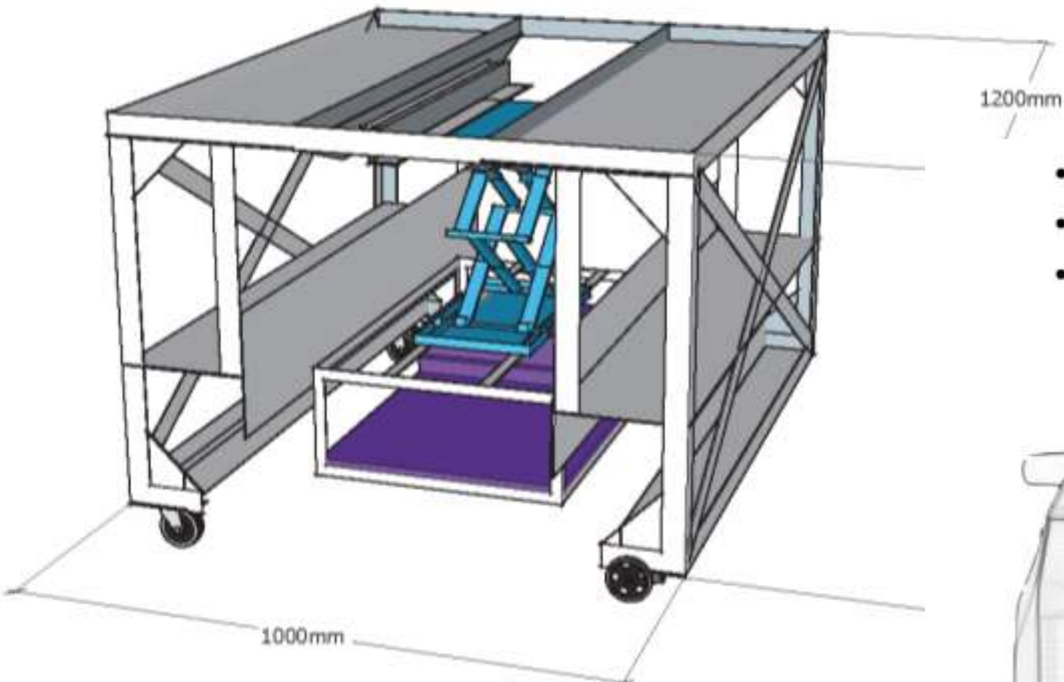
Battery holder with waste heat recovery

G-Wiz electric car

- DimensionsL 2.6m, W 1.3m, H 1.6m
- Motor power: 6kW continuous
- Weight: 400 kg excl batteries
- Battery: 200AH, 48V, Lead-acid
- Range: 48 miles

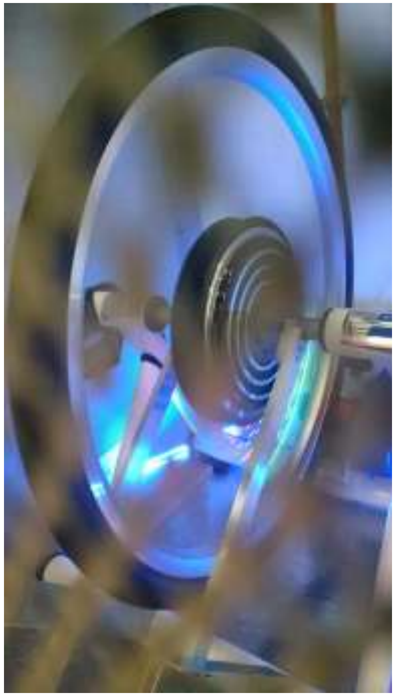
Retrofit: Li-ion battery, BMS, wireless communication, standard charging plug

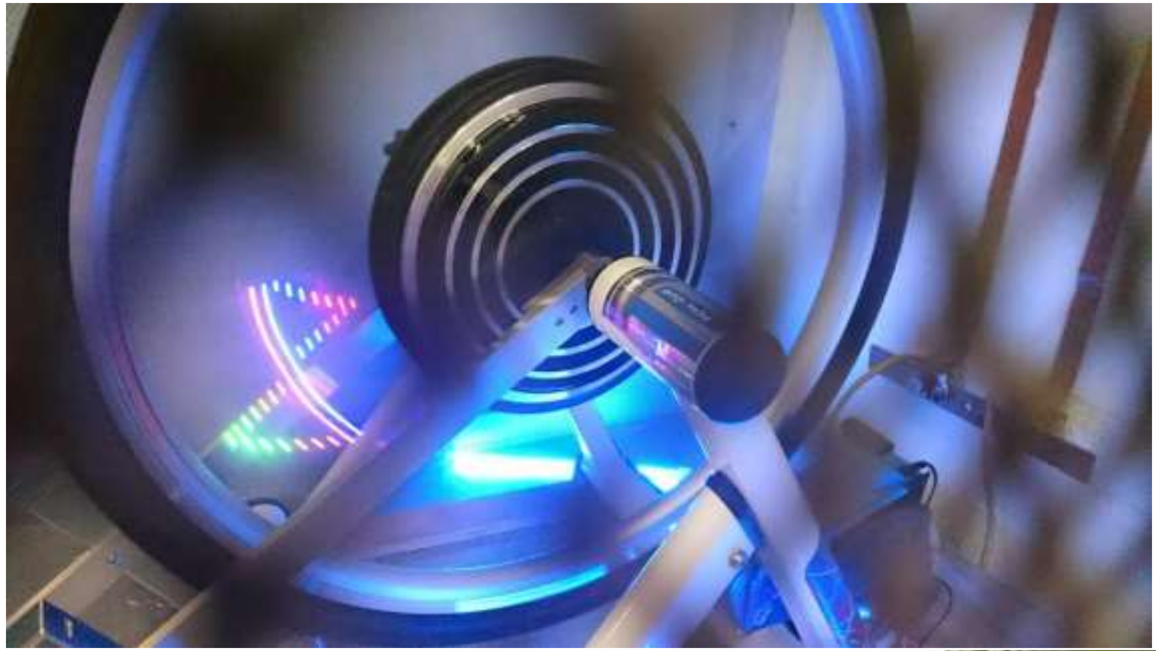
Wireless charging

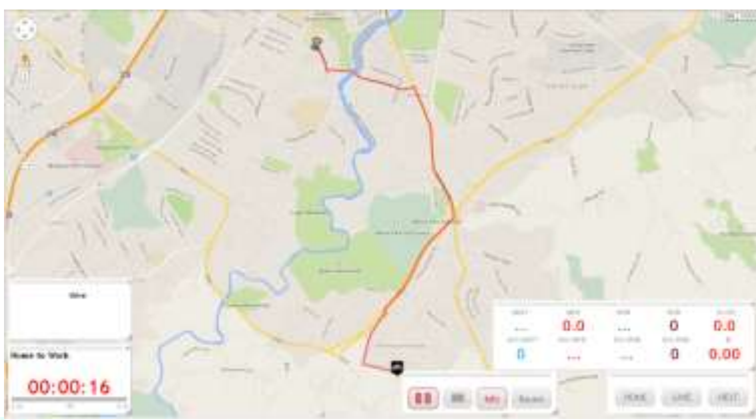


- Control Panel
- Vehicle Adapter
- Parking Pad

Driving style simulation platform to mimic city bus driving







Battery pack monitoring and control

Analog input module

Communication module

Voltage and current module

Relay signal module

Digital input/output module

Temperature module

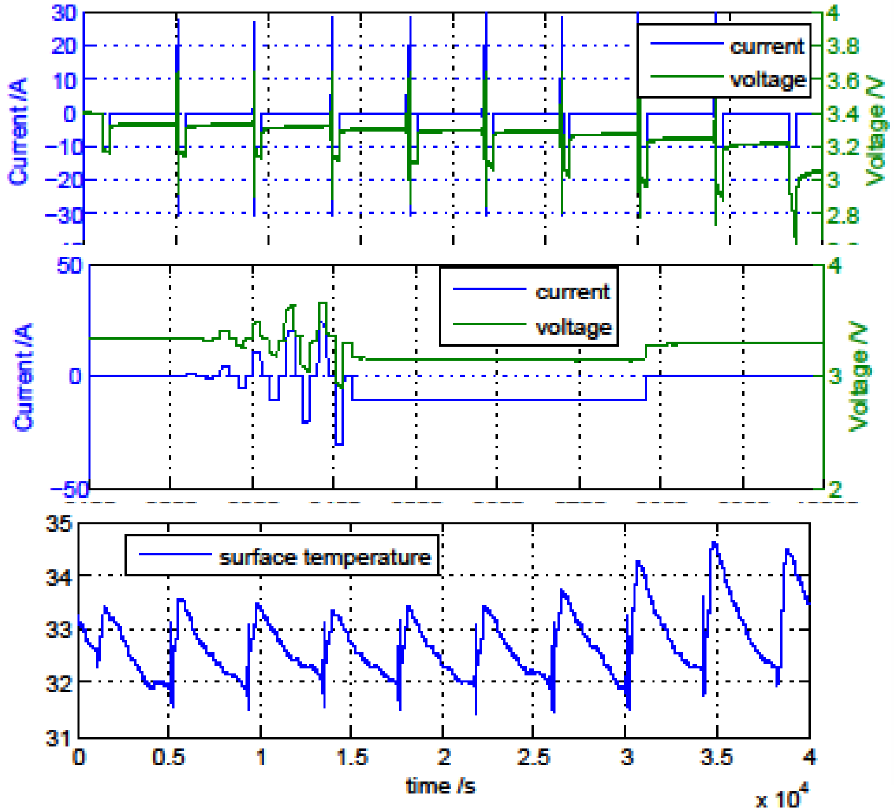
BMS module

Protocol converter module

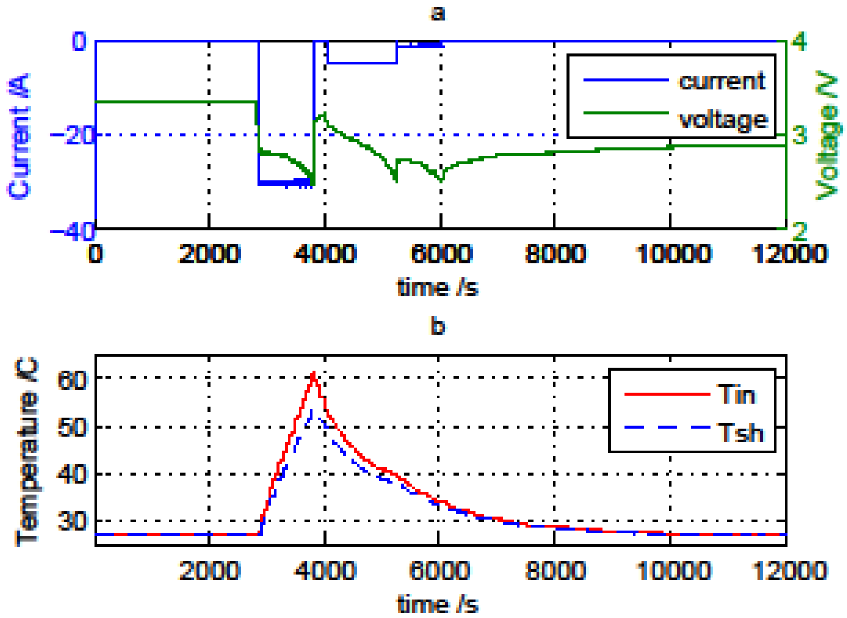
Interface card for main controller

Test data

HPPC tests at different temperatures:
[0, 10, 23, 32, 39, 52]°C



Thermal test



Our Research

1. Battery modelling

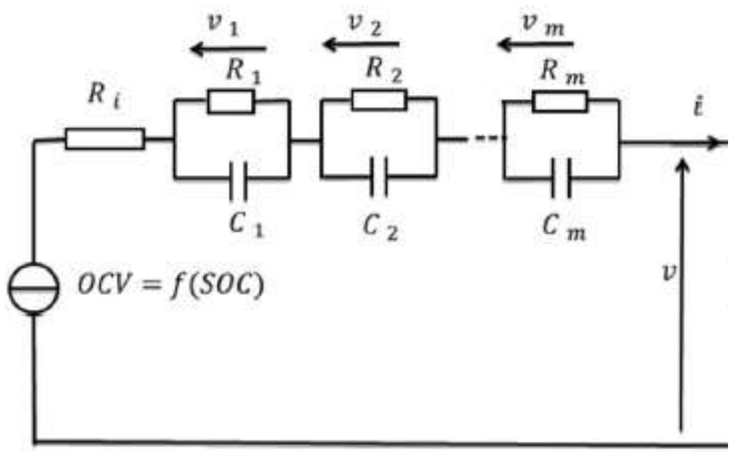


Fig 1: Li ion battery model

Modelling procedure

1. Select model structure
2. Test data collection
3. Model parameter optimization
4. Model validation
5. Model application

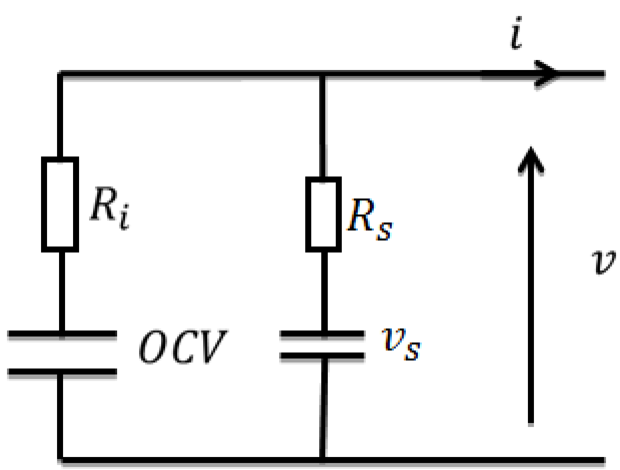


Fig 2: Lead-Acid battery model

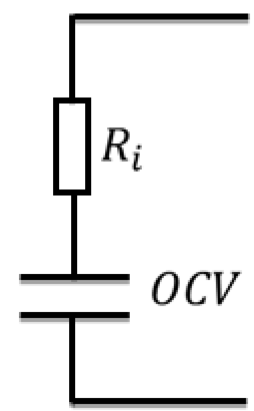


Fig 3: Supercapacitor model

Our Research

2. Battery State estimation

1. State-of-charge (SOC) estimation

   Current methods:

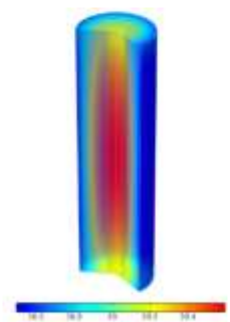
   a) Hydrometer, battery impedance (drawbacks: not suitable for online application)

   b) OCV measurement (drawbacks: long relaxation process)

   c) Current integration method (drawbacks: open loop method; current measurement error build up)

   We proposed ***model-based method using Extended Kalman Filter algorithm***

2. Internal temperature estimation



   Battery thermal model based internal temperature estimation using surface temperature measurements and advanced state estimation algorithm

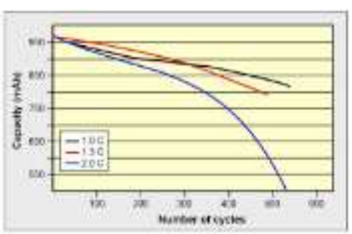
3. Battery State-of-health estimation

   By battery internal resistance estimation and usable capacity estimation

   How fast battery ages with different load condition? (e.g., peak load)

   How to prolong battery life?

4. Other applications



   Battery internal resistance estimation,
   battery power capacity prediction

   …

Our Research

3. Battery control

1. Battery charging/discharging control

Based on the developed battery model and state estimation methods

1. Prevent over-charging, over-discharging
2. Prevent over-current
3. Prevent over-temperature

2. Battery temperature control

based on developed battery thermal model

1. Battery temperature estimation
2. Battery warming/cooling
3. Reduce battery thermal management parasitic energy consumption

3. Battery balancing

QUB support

How can we contribute?

1. Battery test
    a) Charging/discharging, regenerative break; deep recycling, …
    b) Different temperature settings
    c) ***Any** user defined VIP test sequence*
2. Data analysis
    a) Load analysis
    b) Battery life analysis
3. System design improvement
4. Charging/discharging control
    a) Model, state estimation, control
    b) *To prolong battery life*

Questions ?

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