Universidad del País Vasco
Euskal Herriko Unibertsitatea
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KLAIPĖDOS UNIVERSITETAS

INNOVATIVE EUROPEAN STUDIES ON RENEWABLE ENERGY SYSTEMS (IESRES)

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BATTERY TECHNOLOGIES AND BATTERY MODELS

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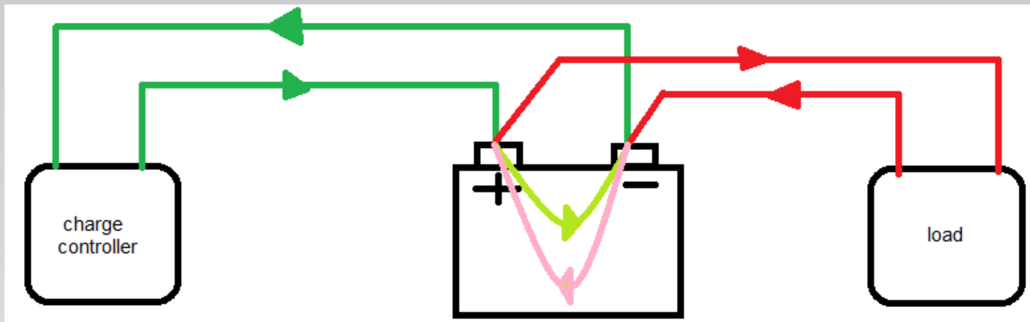
OUTLINE

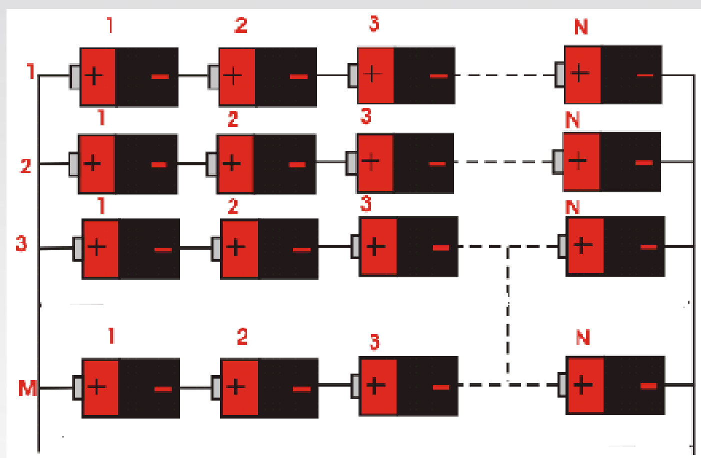
- Main technologies used for batteries
- Their advantages and limitation
- Battery parameters
- Tests for determining parameters
- Battery models
- Case study – developing a model for a battery

BATTERIES AS POWER SOURCES

- An electrochemical converter

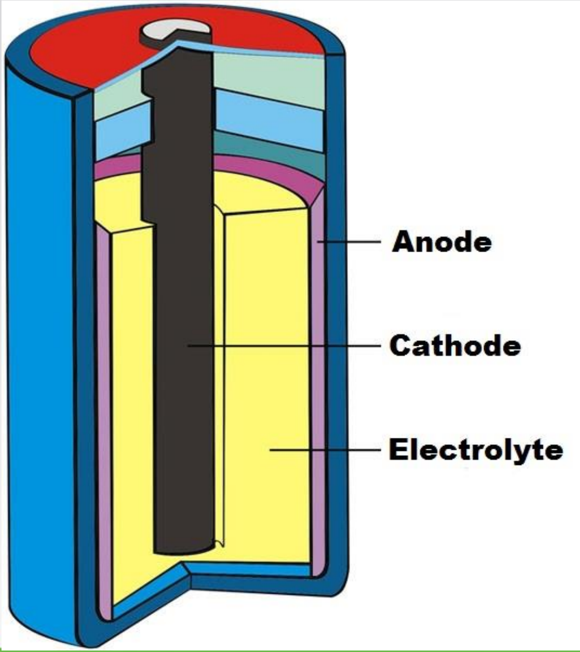


- Battery = a series of interconnected cells



BATTERIES AS POWER SOURCES

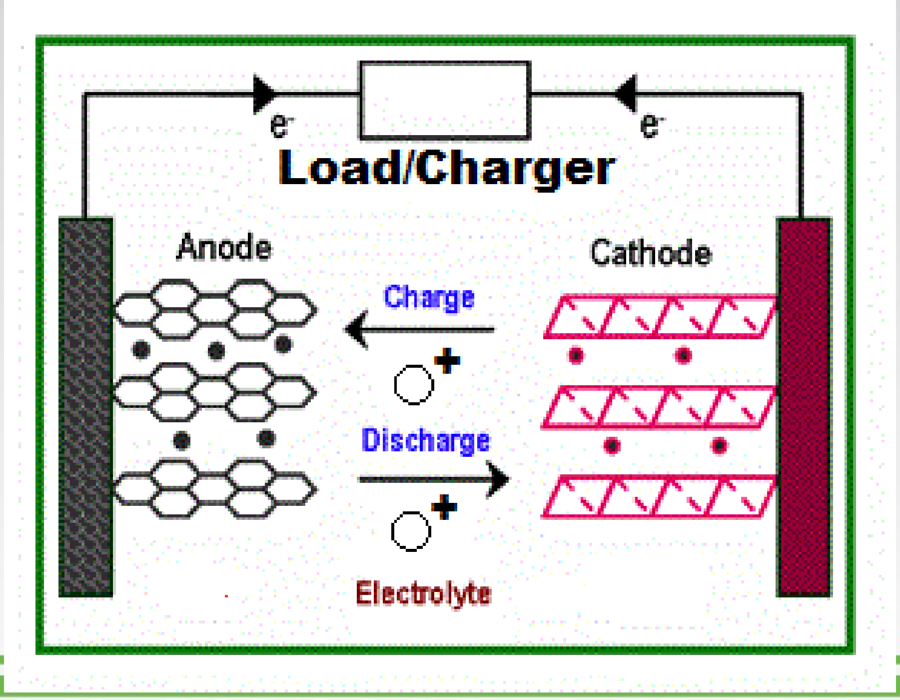
- A cell contains: electrodes (anode -, cathode +), electrolyte, separators



BATTERIES AS POWER SOURCES

- Anode – oxidation $A \rightarrow A^{z+} + ze\_$
- Cathode – reduction $C + ze\_ \rightarrow C^{z-}$

$$A^{z+} + C^{z-} \rightarrow AC$$



BATTERY TECHNOLOGIES

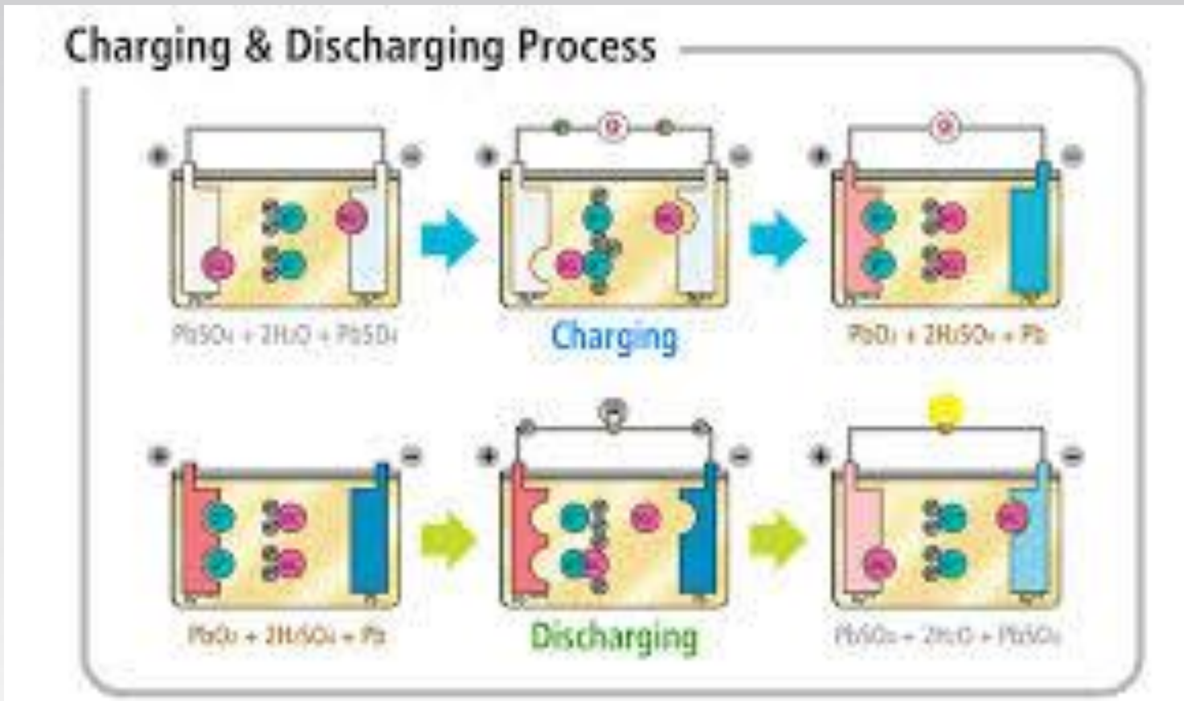
- Lead-acid
- Ni batteries
  - Ni-Cd
  - Ni-MH
- Li-Ion batteries
  - Li-polymer
  - LiCoO2
  - LiMn2O4
  - LiFePO4

LEAD-ACID BATTERIES

- Sponge lead as active material at the anode
- Lead dioxide (PbO_2) as active material at the cathode
- Electrolyte made up of a diluted solution of sulphuric acid (H_2SO_4)

LEAD-ACID BATTERIES

$$Pb + PbO_2 + 2H_2SO_4 \leftrightarrow 2PbSO_4 + 2H_2O$$



LEAD-ACID BATTERIES

Parameter	Value
Specific energy [Wh/kg]	20-35
Energy density [Wh/l]	54-95
Specific power [W/kg]	250
Nominal voltage [V]	2
Internal impedance [Ω]	0.022
Lifespan [no. of cycles]	800
Self-discharging [%/day]	2
Temperature [°C]	10-55
Charging time [h]	8

Ni BATTERIES

- Technologies: Ni-Fe, Ni-Zn, **Ni-Cd** and **Ni-MH**
- **Ni-Cd batteries**
- Cadmium at anode
- Nickel oxy-hydroxide (NiOOH) at cathode
- Electrolyte made up of potassium hydroxide (KOH)

$$2NiOOH + 2H_2O + Cd \leftrightarrow 2Ni(OH)_2 + Cd(OH)_2$$

Ni-Cd batteries

Parameter	Value
Specific energy [Wh/kg]	40-55
Energy density [Wh/l]	70-90
Specific power [W/kg]	125
Nominal voltage [V]	1.2
Internal impedance [Ω]	0.06
Lifespan [no. of cycles]	2000
Self-discharging [%/day]	0.5
Temperature [°C]	-40–80
Charging time [h]	1

Ni-MH BATTERIES

- Similar construction to the Ni-Cd
- Anode uses hydrogen instead of cadmium, which is absorbed in a metal alloy MH.
- Cathode nickel oxy-hydroxide

$$\mathrm{MH} + \mathrm{NiOOH} \leftrightarrow \mathrm{M} + \mathrm{Ni}\left(\mathrm{OH}\right)_2$$

- Alloy is manufacturer specific

Ni-MH batteries

Parameter	Value
Specific energy [Wh/kg]	65
Energy density [Wh/l]	150
Specific power [W/kg]	200
Nominal voltage [V]	1.2
Internal impedance [Ω]	0.06
Lifespan [no. of cycles]	1000
Self-discharging [%/day]	5
Temperature [°C]	-40–80
Charging time [h]	1

Li BATTERIES

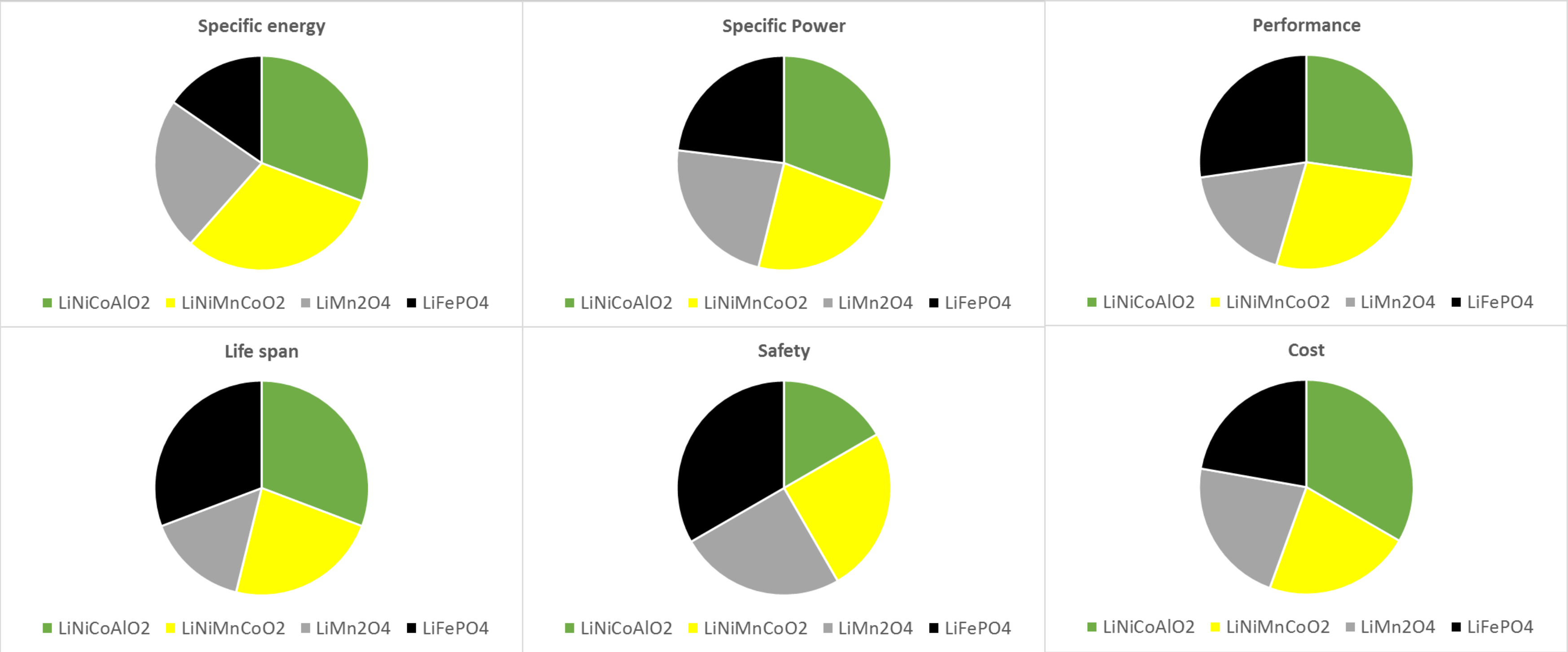
- Two major technologies based on lithium: lithium polymer (Li-P), lithium-ion (Li-ion)
- **Li-P**
- Li at the anode
- An oxide of a transition metal at the cathode
- Electrolyte a solid polymer (SPE)

$$xLi + M_yO_z \leftrightarrow Li_xM_yO_z$$

Li-Ion BATTERIES

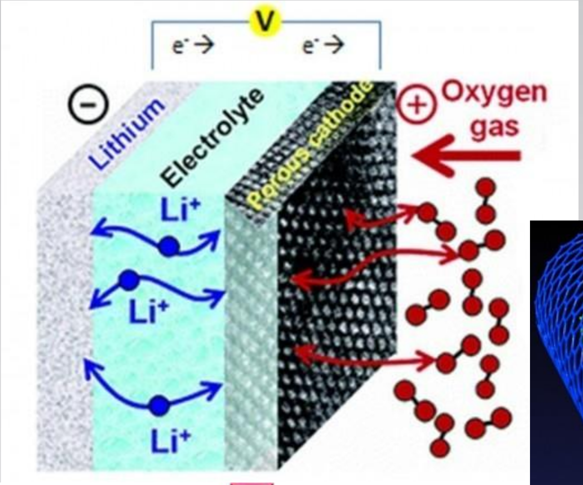
- Li-ion is an entire family of batteries
- Manufacturer specific
- $LiCoO_2$, $LiMn_2O_4$, $LiNiO_2$, $LiNiMnCoO_2$, $LiNiCoAlO_2$, $LiFePO_4$

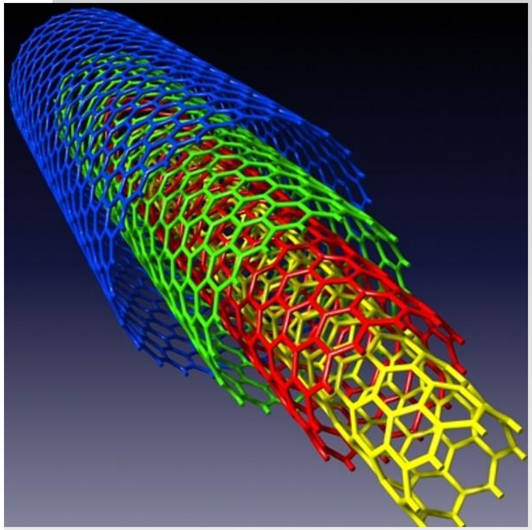
Li-Ion BATTERIES

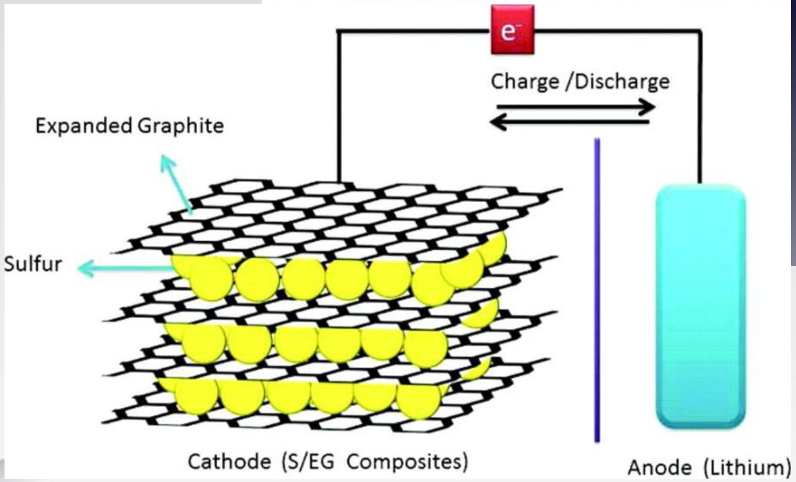


NEW TYPES OF BATTERIES

- Li-air
- Nano-rods
- Sulphur







BATTERY PARAMETERS

- Specifications
  - Nominal voltage
  - Nominal capacity
  - Discharge current
  - Cut-off voltage
  - Temperature operation range

- Parameters
  - State of Charge (SoC)
  - Open Circuit Voltage (OCV)
  - Internal resistance (Ri)

BATTERY PARAMETERS

- SOC – remaining charge in the battery

$$SOC = \frac{C(t)}{C_n}$$

- OCV – output voltage without load or charger
- Ri – internal resistance

$$R_i = \frac{\Delta V}{I}$$

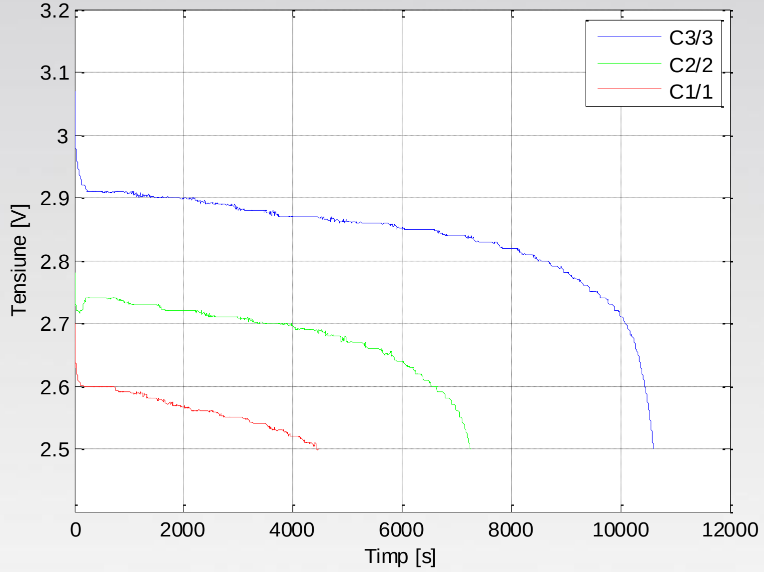
TESTS FOR DETERMINING THE BATTERY PARAMETERS

- Constant current discharge test – SoC, OCV

- Hybrid Pulse Power Characterization Test – OCV, Ri

CONSTANT CURRENT DISCHARGE TEST

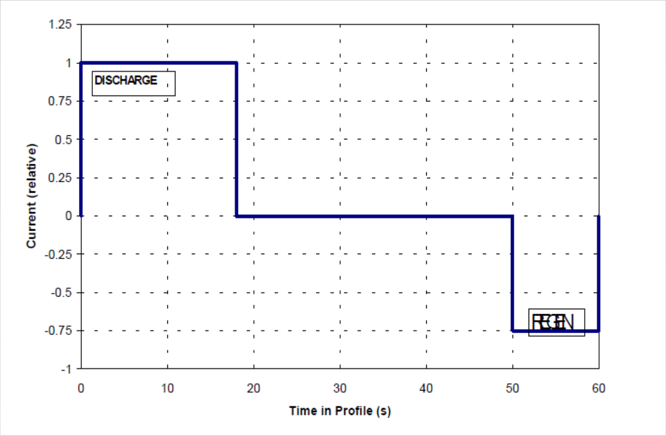
- Three currents: $C_3/3$, $C_2/2$ și $C_1/1$
- $C_3/3$ – is the capacity for 3 h

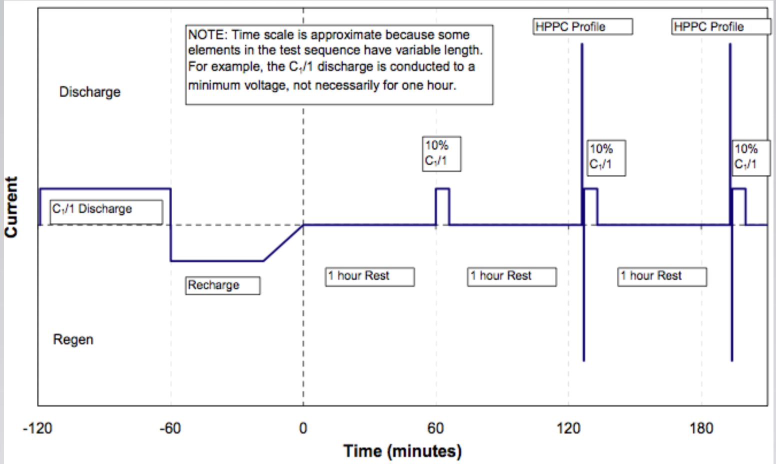


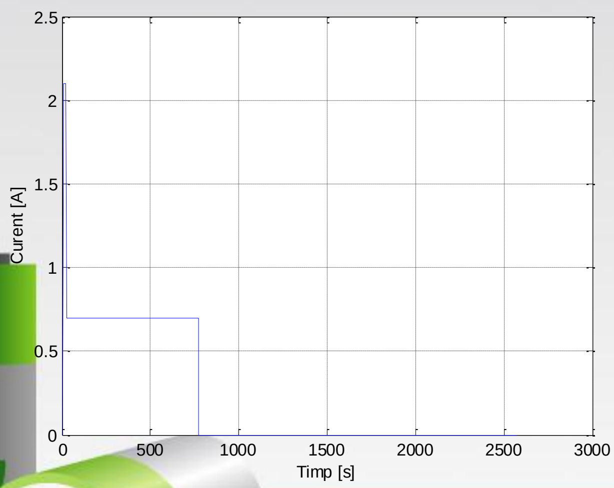
HYBRID PULSE POWER CHARACTERIZATION TEST

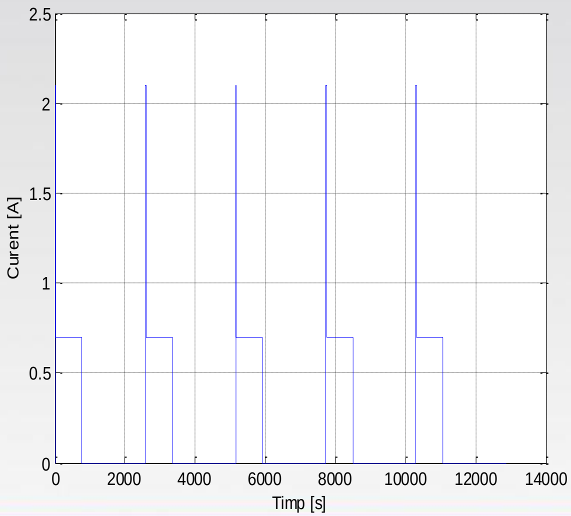
- 10 SoC
- ID = 75% max discharge current
- ID = 25% max discharge current
- IC = $C_1/1$
- 18 s discharge, 32 s rest 10 s charge

HYBRID PULSE POWER CHARACTERIZATION TEST







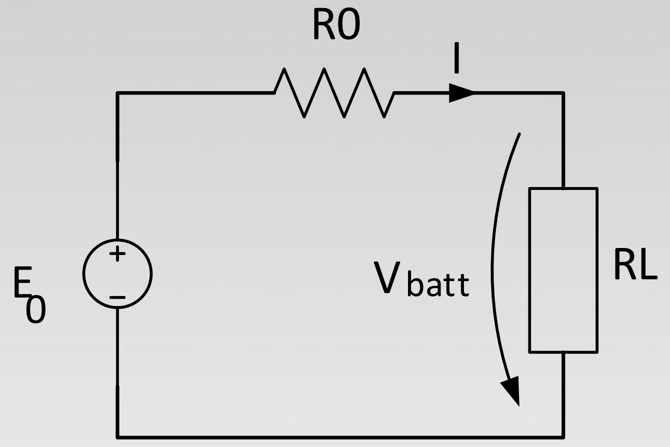


BATTERY MODELS

- Electrochemical used by battery developers involve a system of nonlinear equations
- Analytical simplify the electrochemical models use only a few non linear equations
- Circuit based reproduce the behaviour of the battery using electrical components

CIRCUIT BASED MODELS

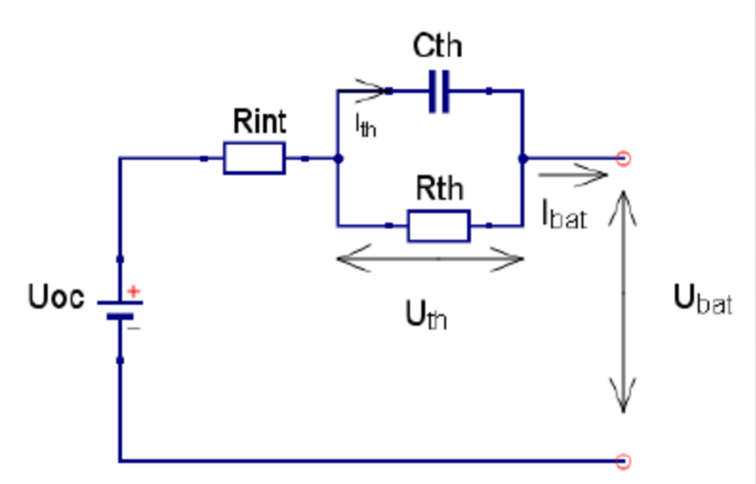
- Elementary model (R_{int})



$$I = \frac{E_0 - V_{batt}}{R_0 + R_L}$$

CIRCUIT BASED MODELS

- Thevenin model

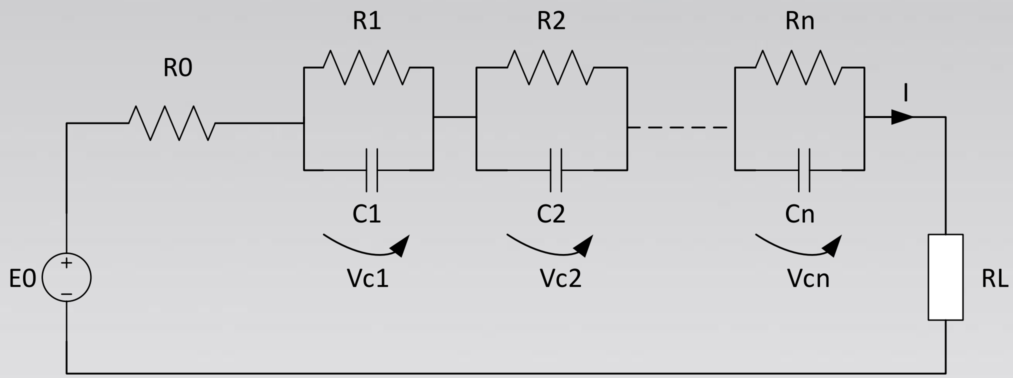


$$V_{batt} = E_0 - R_0 \cdot I - R_p \cdot I_p$$

$$\frac{dI_p}{dt} = \frac{(I - I_p)}{\tau}$$

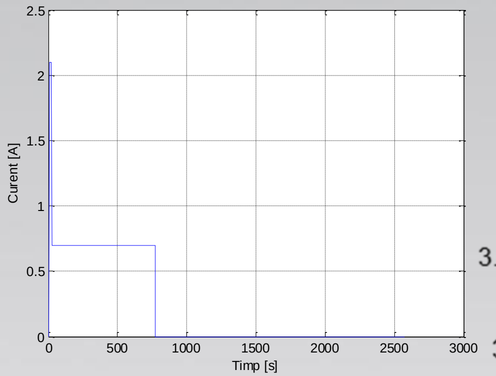
CIRCUIT BASED MODELS

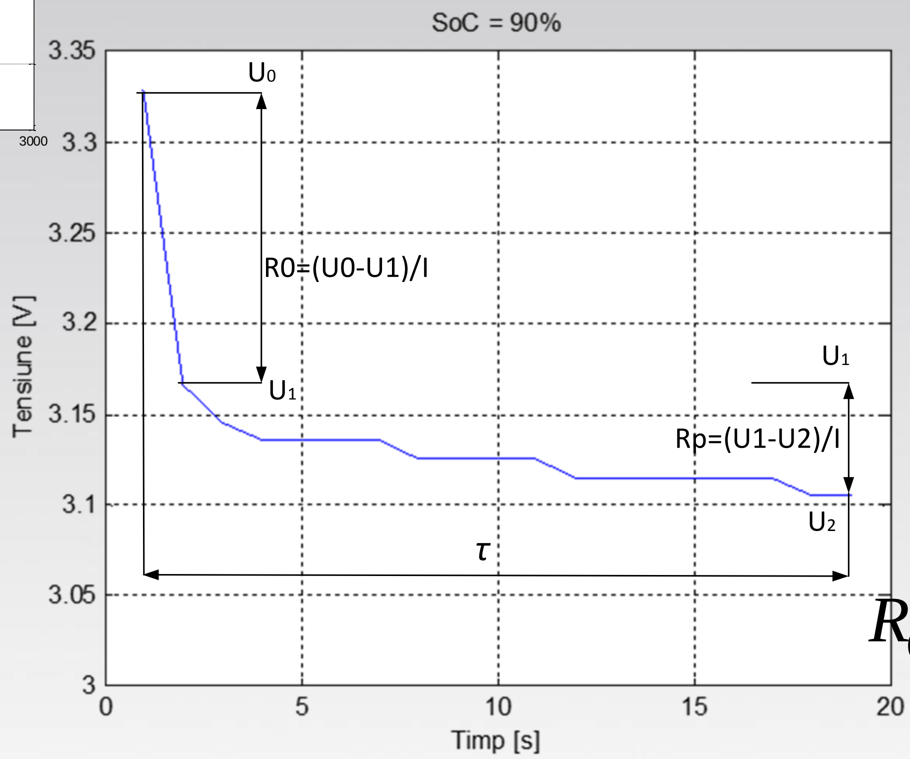
- R-C network models



$$\begin{bmatrix}\dot{V}_{C1}\\ \dot{V}_{C2}\\ \vdots\\ \dot{V}_{Cn}\end{bmatrix} = \begin{bmatrix} -\frac{1}{R_1C_1} & 0 & \cdots & 0\\ 0 & -\frac{1}{R_2C_2} & \cdots & 0 \\ 0 & 0 & \cdots & -\frac{1}{R_nC_n}\end{bmatrix}\cdot\begin{bmatrix}V_{C1}\\ V_{C2}\\ \vdots \\ V_{Cn}\end{bmatrix} + \begin{bmatrix}\frac{1}{C_1}\\ \frac{1}{C_2}\\ \vdots\\ \frac{1}{C_n}\end{bmatrix}\cdot i$$

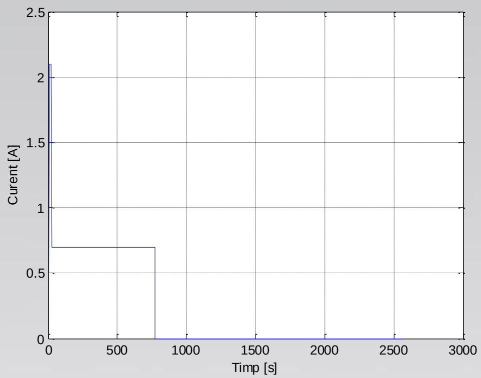
Extracting the parameters

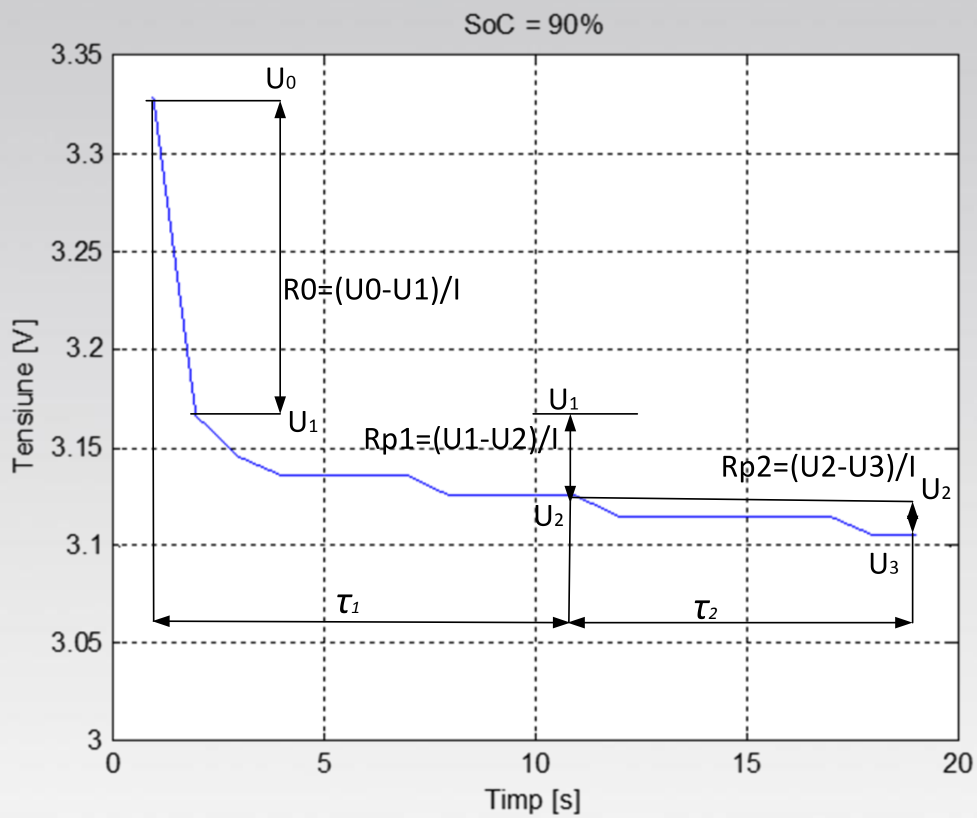




$$R_0 = \frac{\Delta U}{I} = \frac{U_1 - U_0}{I}$$

Extracting the parameters





Case study Thevenin model

- A $LiFePO_4$ 1400 mAh 3.2 V
- Specific capacity C = 1470 mAh
- Determined parameters:

SoC	100%	90%	80%	70%	60%
E_0 [V]	3,4254	3,3337	3,3337	3,3133	3,2929
R_0 [Ω]	0,1698	0,1358	0,1504	0,1310	0,1407
R_p [Ω]	0,0291	0,0533	0,0291	0,0533	0,0242
C_p [F]	618,111	337,150	618,111	337,153	741,743

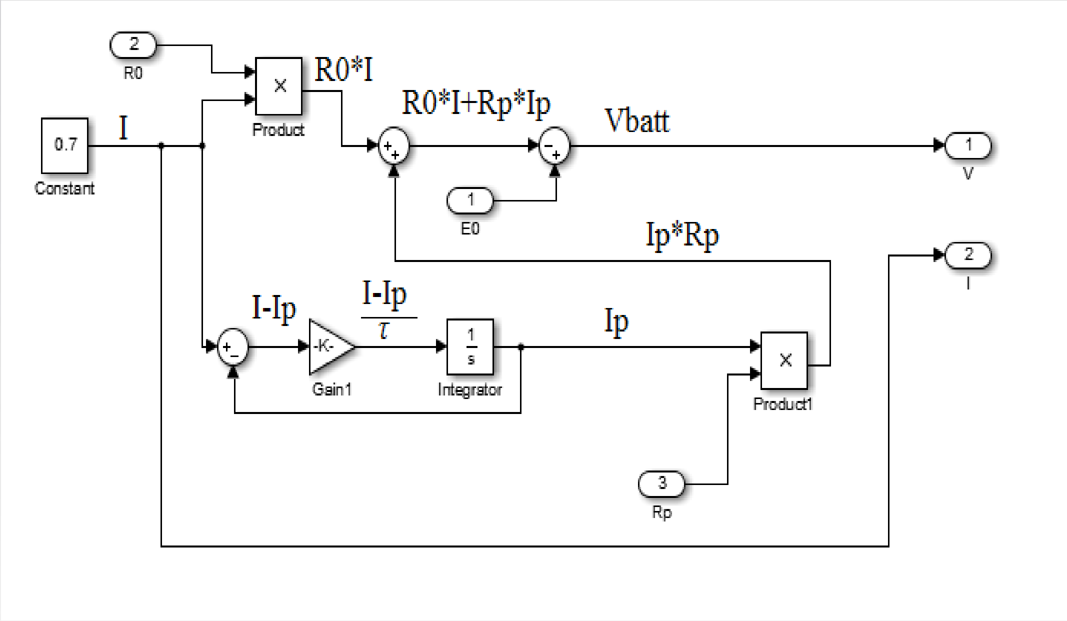
SoC	50%	40%	30%	20%	10%
E_0 [V]	3,2929	3,2929	3,2725	3,2419	3,2012
R_0 [Ω]	0,1553	0,1456	0,1456	0,1358	0,1553
R_p [Ω]	0,0145	0,0388	0,0630	0,0533	0,0485
C_p [F]	1236,22	463,587	285,285	337,153	370,868

Case study Thevenin model

Matlab model

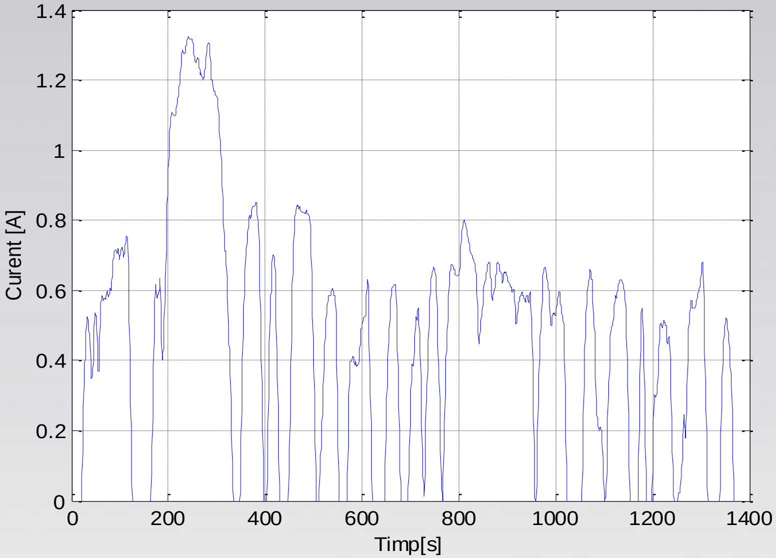
$$V_{batt} = E_0 - R_0 \cdot I - R_p \cdot I_p$$

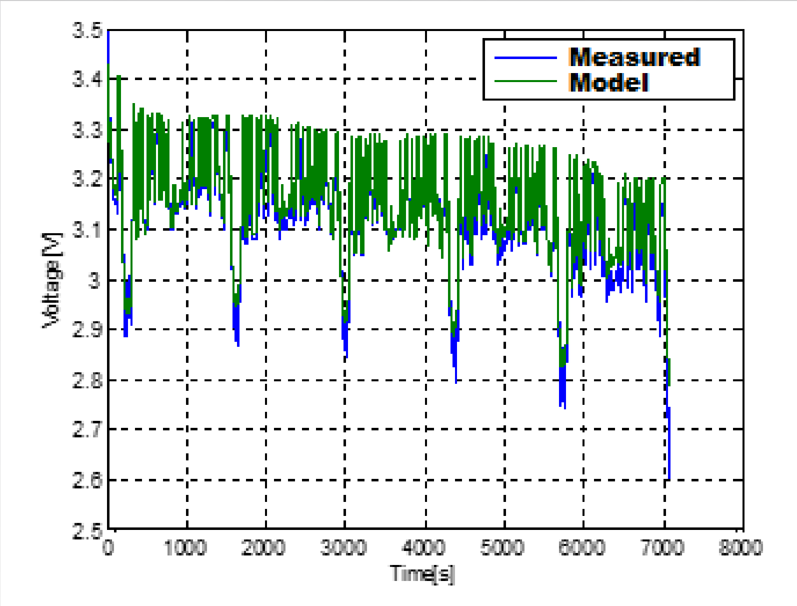
$$\frac{dI_p}{dt} = \frac{(I - I_p)}{\tau}$$



Case study Thevenin model

Validation





Discharge profile Output voltage

Max absolute error = 5.95%

Conclusions

- Batteries are in a continuous evolution
- Improving models
- Reduce cost for developing
- Model more parameters

Teşekkür ederim!

Vă mulțumesc!

Thank you!

Grazie!

Gracias!

Ačiū!