Mondragon Unibertsitatea
Faculty of Engineering

Mondragon University Electrical Energy Research line – Energy Storage

Outline

Mondragon Unibertsitatea
Faculty of Engineering

1

Introduction

Electrical energy research line

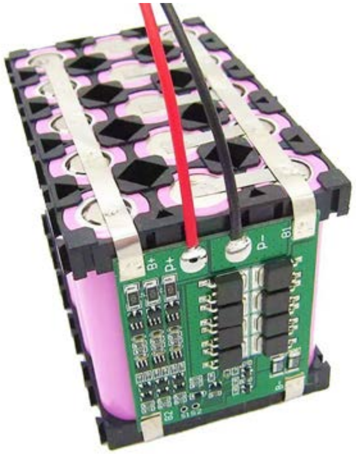
Mondragon Unibertsitatea
Faculty of Engineering

30 researchers, 20 doctors and 12 PhD students in these fields

Electric machines

Power electronics

Energy storage systems



Energy Storage team

Mondragon Unibertsitatea
Faculty of Engineering

Staff

- 10 researchers
- 5 PhD
- 4 Master projects

Location

- Hernani
- Arrasate

Research areas

Cell level:

Test and characterization different technologies (Lithium, Ultracaps, post-lithium…)
Thermal and electrical behaviour models
Electrochemical models

Module and full pack level:

Thermal and electrical behaviour models
Auxiliary electronics: cell equalization techniques, BMS, electrical safety
Estimation algorithm: SOC, SOH, SOF

Integration:

Power electronics for energy storage systems
Energy management techniques

Applications:

Portables
Stationary for grid or off-grid
Electromobility

Facilities

Arrasate

Cell testing and characterization laboratory

Cell and chamber cyclers with temperature control

Microgrid laboratory

Energy management in AC, DC or AC-DC microgrid

Medium Voltage Laboratory

MV network connection for testing of stationary storage systems with high power and energy capacity

Electromobility Laboratory

Infrastructure for working with electric vehicles including a power bench for static testing

Low, medium and high power power train test benches (elevators, electric vehicle and railway)

Hernani

Energy Laboratory

Cell, module and chamber cyclers with temperature control

Low power energy storage applications

Smart building Laboratory

Shared with Ikerlan for stationary storage system and energy management.

Partners

ikerlan

Topics: Energy storage technologies and energy management

5+5 researches work together in Hernani

We share equipment and infrastructure

CIC energiGUNE energy cooperative research centre

Topics: electrochemical behavior and characterization of cells

We have access to the CIC's equipment

Universidad Zaragoza

Topics: high efficiency converters for energy storage systems and energy management

Basic research collaboration based on PhDs and researchers work together

Background

- 10 years working in the field of energy storage systems.
- First PhD works within the research line:
  - *Integration of distributed generation using energy storage systems,* ***Dr. Ander Goikoetxea Arana, 15/02/2011***
  - *Development and implementation of SOC and SOH estimators for lithium based energy storage systems,* ***Dr. Mikel Oyarbide Urquizu, 26/03/2013***
  - *Electro-thermal optimization of an energy storage system based on lithium ion batteries,* ***Dr. Unai Iraola Iriondo, 01/07/2014***
  - *Energy efficiency improvement of li-ion battery packs via balancing techniques,* ***Dr. Iosu Aizpuru Larrañaga, 01/07/2015***

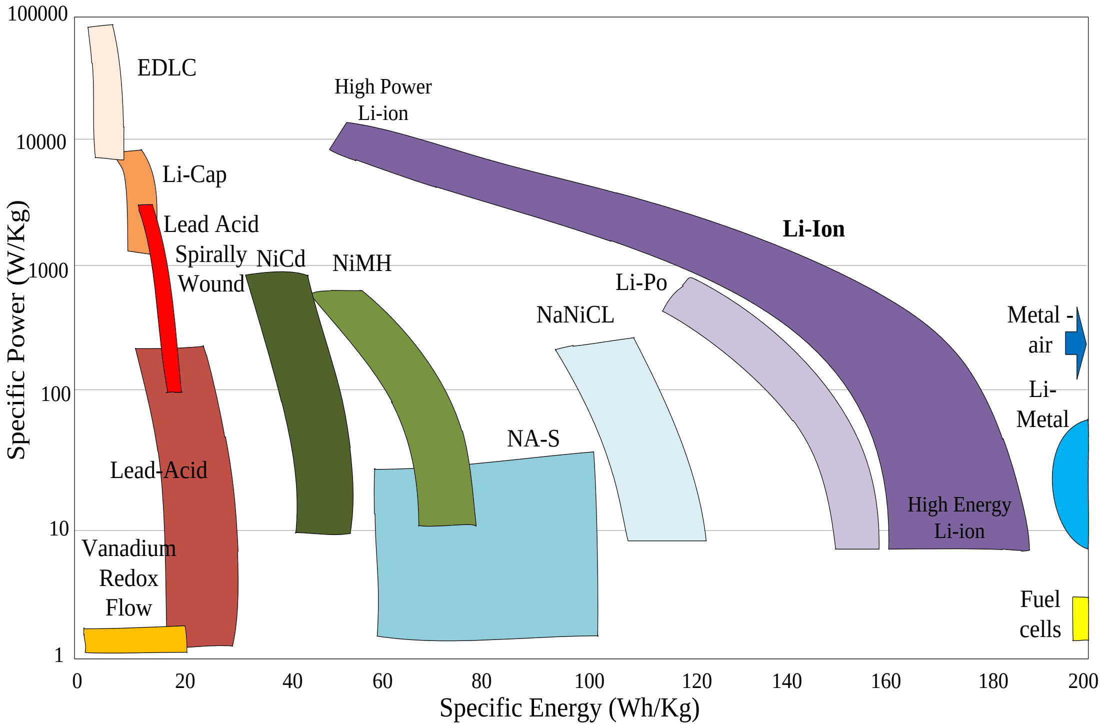
Framework

- Battery based energy storage systems are a promising technology for many applications.

Framework

Mondragon Unibertsitatea
Faculty of Engineering

- Battery based energy storage systems are a promising technology for many applications.



Wide range of applications

Lithium ion technology covers many of them

There is no technology covering the whole range of applications

Framework

- Degradation is one of the most important drawbacks for many of these applications.
  - Calendar life
    - Temperature
    - State of charge (SOC)
  - Cycle life
    - Temperature
    - Depth of discharge (DOD)
    - Current rate
    - Overdischarge and overcharge

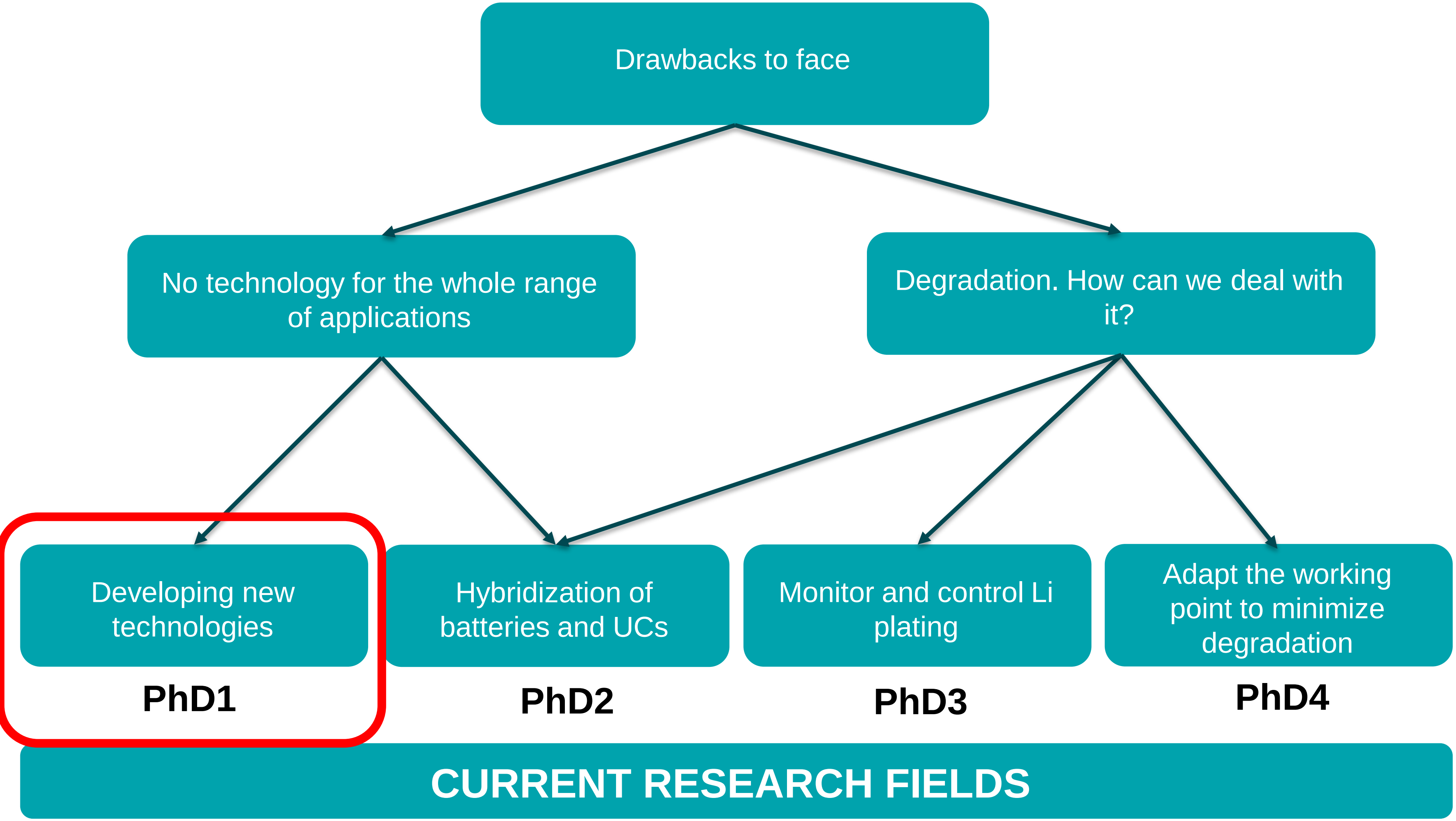
Lithium plating

- Low temperatures
- High SOCs
- With high C rates

SEI growth

- Type of graphyte
- Electrolyte composition
- Electrochemical conditions
- High temperatures

Framework


Drawbacks to face
No technology for the whole range of applications
Degradation. How can we deal with it?
Developing new technologies
Hybridization of batteries and UCs
Monitor and control Li plating
Adapt the working point to minimize degradation
PhD1
PhD2
PhD3
PhD4
CURRENT RESEARCH FIELDS

2

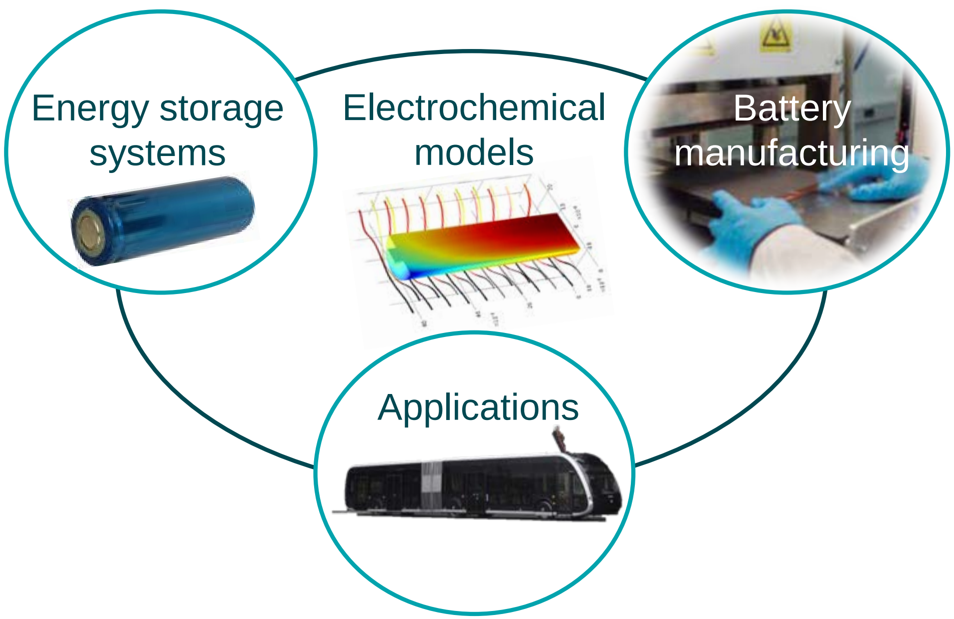
Current research lines based on 4 PhD works

PhD1 – Developing new technologies

Mondragon Unibertsitatea
Faculty of Engineering

- PhD in collaboration with CIC Energigune.
- *Optimization of the fabrication process of pouch cells for industrial applications through advanced electrochemical models,* ***Laura Oca. (Last year)***

Challenges



Huge amount of samples/trials until reaching a good aproximation

Difficult to know if the proposed solution is the best one or only better tan the previous one

Methodology to optimize the manufacturing process is proposed.

PhD1 – Developing new technologies

Mondragon Unibertsitatea
Faculty of Engineering

State of the art

- ISEA (Ecker2015 and Schmalstieg2017): complete parameterizations
- CEA (Dufour2016 and Falconi2018): partial parameterizations

* Validated only against galvanostatic discharges

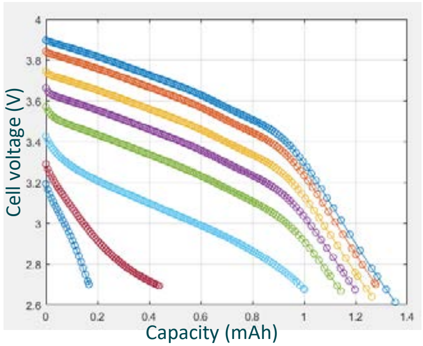
Our proposal:
Build a new physico-chemical parameter obtention methodology

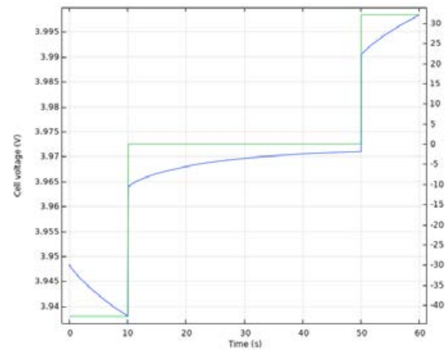
Validate the obtained results with experimental test on:

- Model response evaluation (Galvanostatic cycles, pulses and EIS)
- Internal variable validation

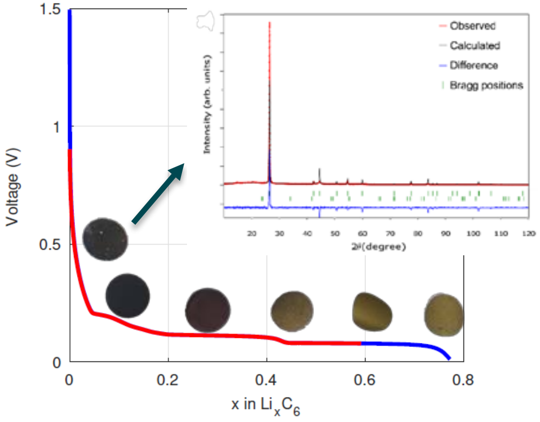
Our work (1.25 Ah commercial cell)

Model response evaluation





Internal variable validation (ongoing)



Graphite electrode solid lithium content:

- Color change
- XRD refinement

PhD1 – Developing new technologies

Mondragon Unibertsitatea
Faculty of Engineering

State of the art

- Usually experimental optimizations are used
- Simulated-supported optimizations try to reduce errors against galvanostatic discharges (changing parameters without a extended justification)

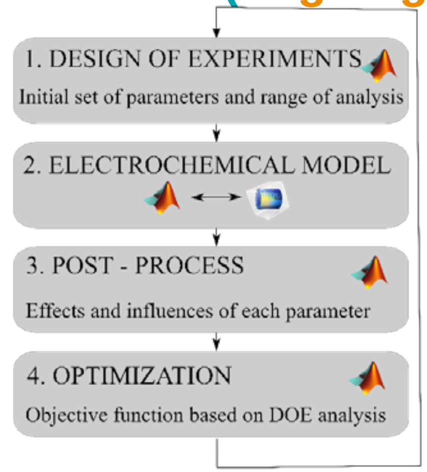
* One work use DOE for evaluating the effects and interactions (no own parameters)

Our proposal:
Build a new methodology for battery optimization focusing in the calendering process optimization (for positive electrode)

Validate the obtained results with experimental test on:

- Galvanostatic process, EIS
- In-range optimized prototyped cells

Our work (ongoing with prototyped cells)



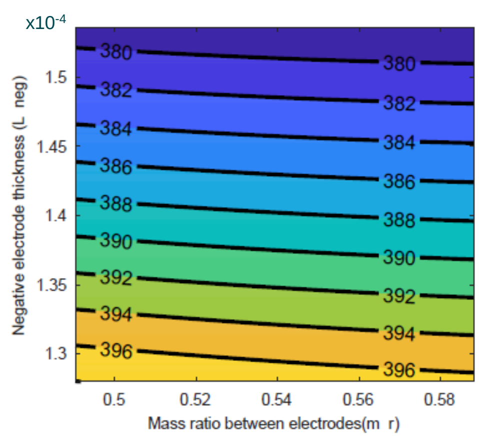
DOYLE CELL case study:

- Studied parameters: 7

- Evaluated responses: Energy and power density
- Initial values:
  Em = 32 (Wh kg^{-1})
  Pm = 396 (W kg^{-1})
- Optimized values:
  Em = 31 (Wh kg^{-1})
  Pm = 408 (W kg^{-1})

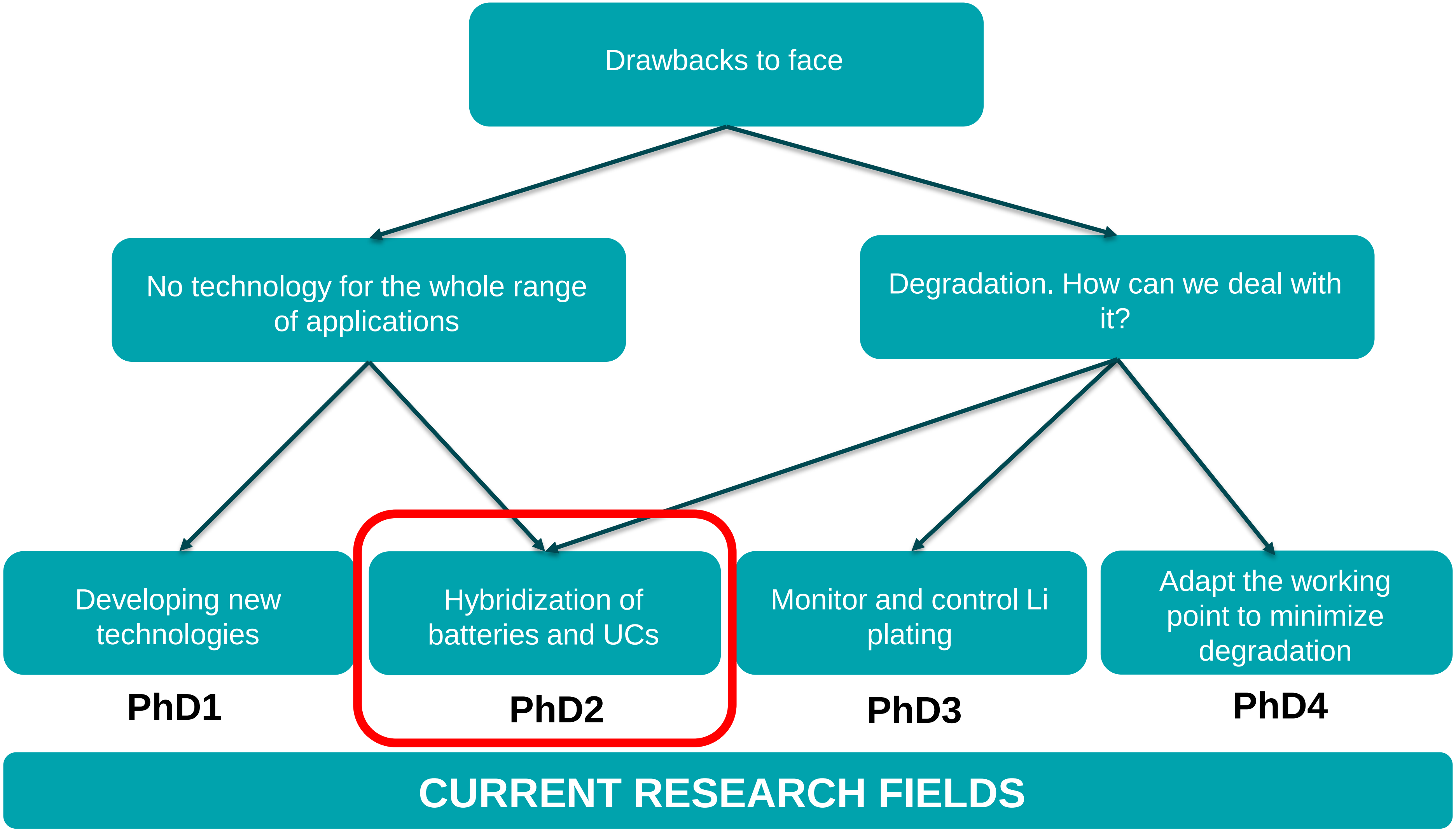
Compromise between Em and Pm!

Interaction effects for power density (W kg^{-1})



The impact of the negative electrode thickness is bigger than the mass ratio between electrodes for the power density response (in the analysed range)

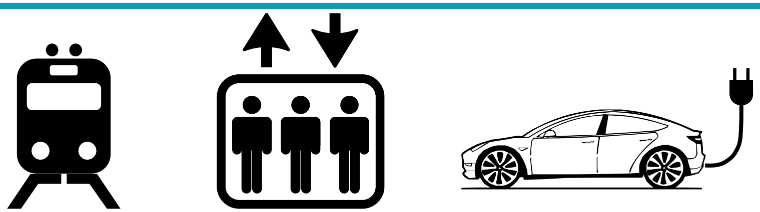
Framework

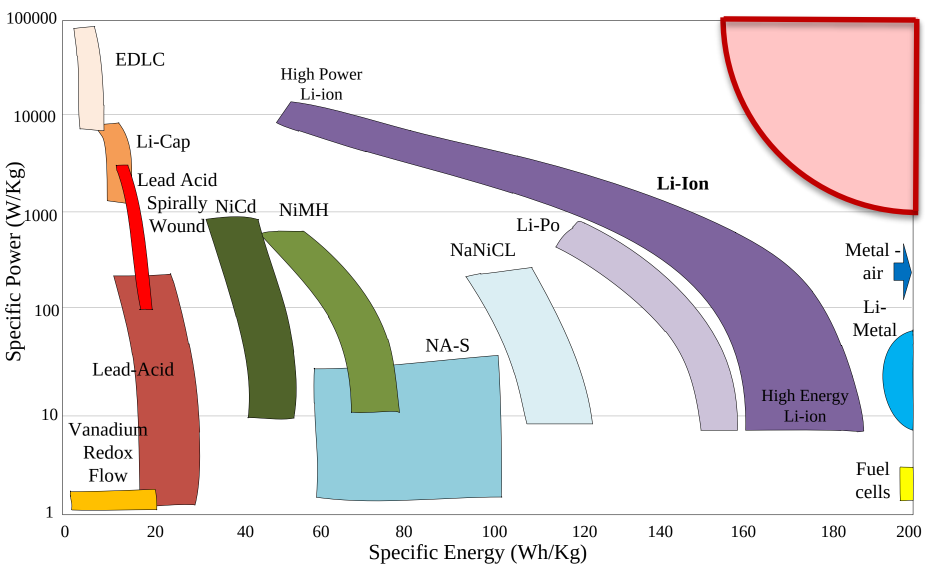

Drawbacks to face
No technology for the whole range of applications
Degradation. How can we deal with it?
Developing new technologies
Hybridization of batteries and UCs
Monitor and control Li plating
Adapt the working point to minimize degradation
PhD1
PhD2
PhD3
PhD4
CURRENT RESEARCH FIELDS

PhD2 – Hybridization of batteries and UCs

- PhD in collaboration with CIC Energigune.
- *Hybrid Energy Storage Systems via Power Electronic Converters,* ***Erik Garayalde. (PhD defense next February)***

Traction applications





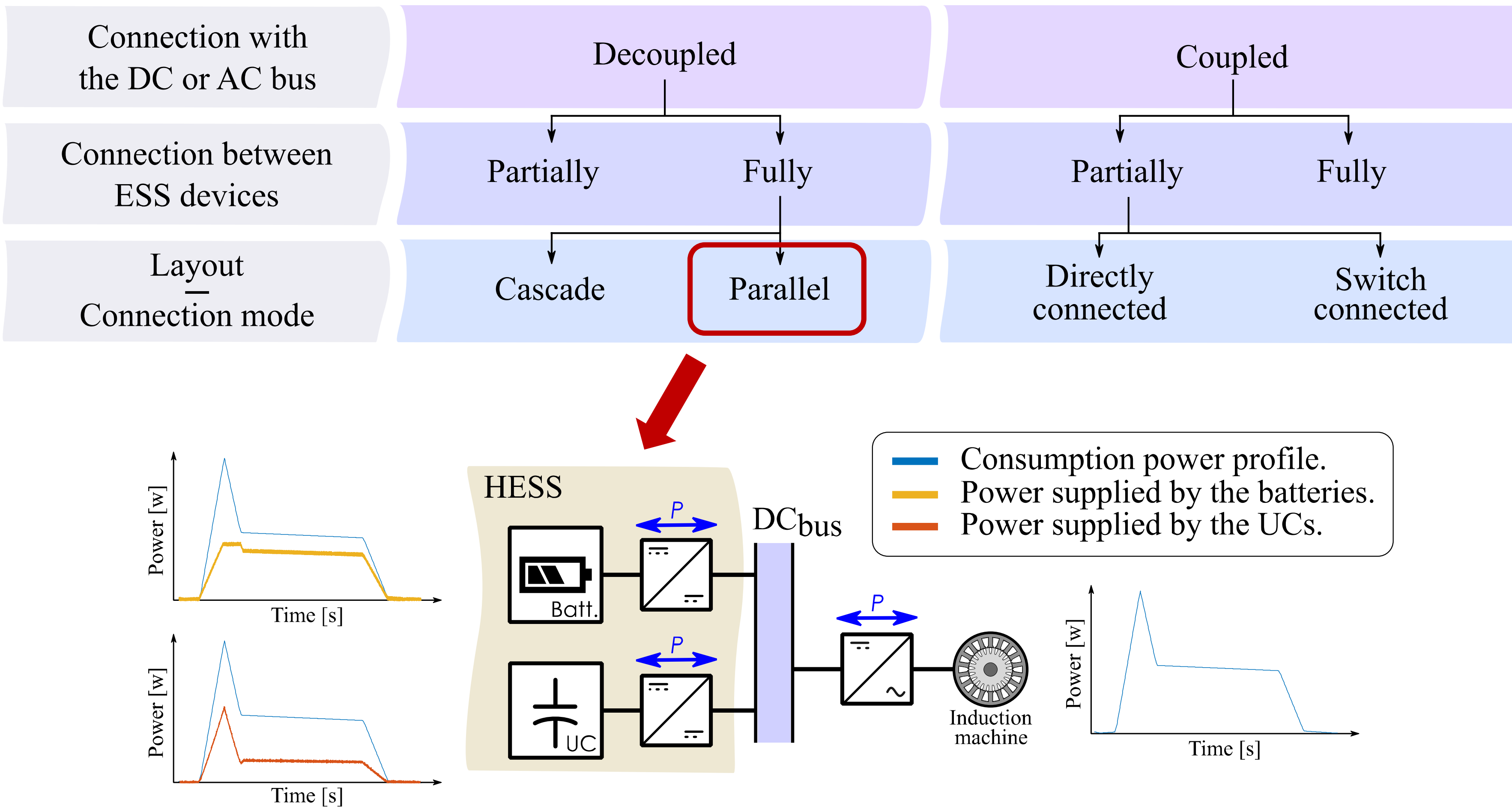
Average consumption
+
Power transients

Energy Storage Power and Energy Ratio improvement

Energy Storage Hybridization

PhD2 – Hybridization of batteries and UCs

Multiple HESS topologies



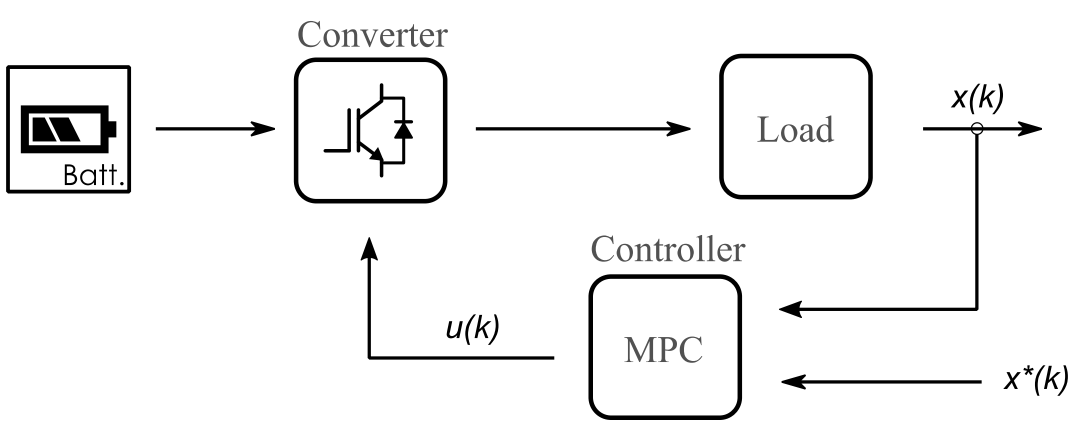
PhD2 – Hybridization of batteries and UCs

Modern Control Techniques

PI control

→ Improve the dynamic response of Classical PI controllers →

Model Predictive Control



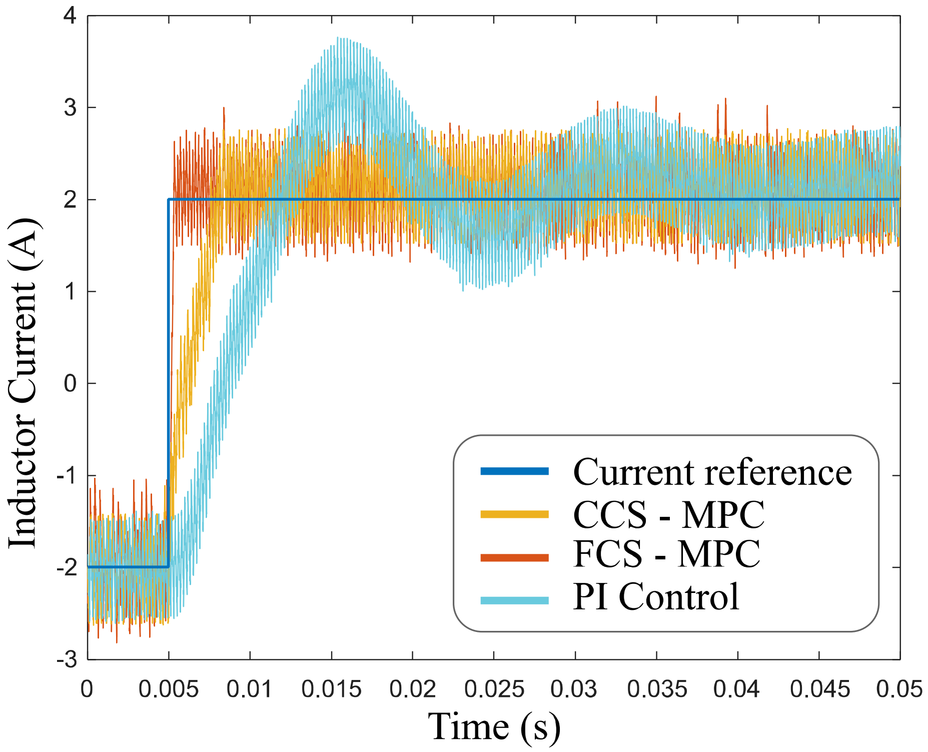
- Faster dynamic response
- Multivariable control
- Simplify tuning process
- Anti-windup is not necessary

MPC algorithm making use of **Converter and Battery models.**

PhD2 – Hybridization of batteries and UCs

Mondragon Unibertsitatea
Faculty of Engineering

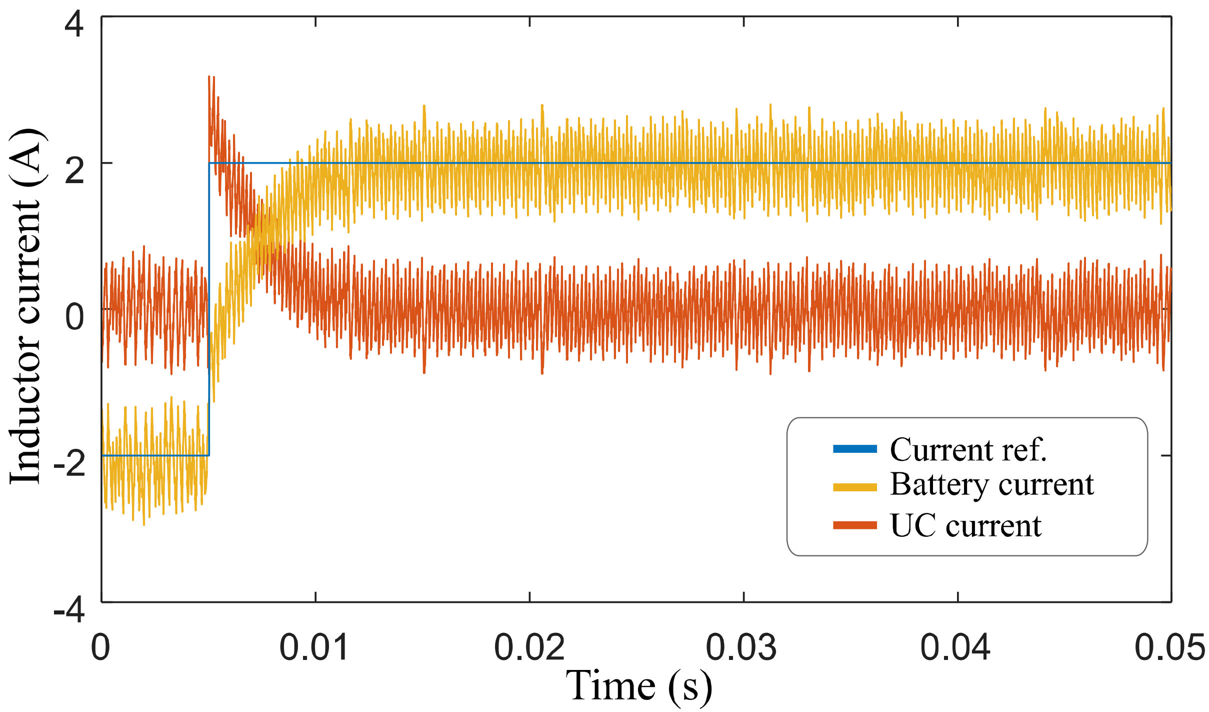
Experimental comparison of PI and MPC



- Inductor Current Control using MPC:
  - Faster dynamic response
  - Less oscillations
  - Less overshot

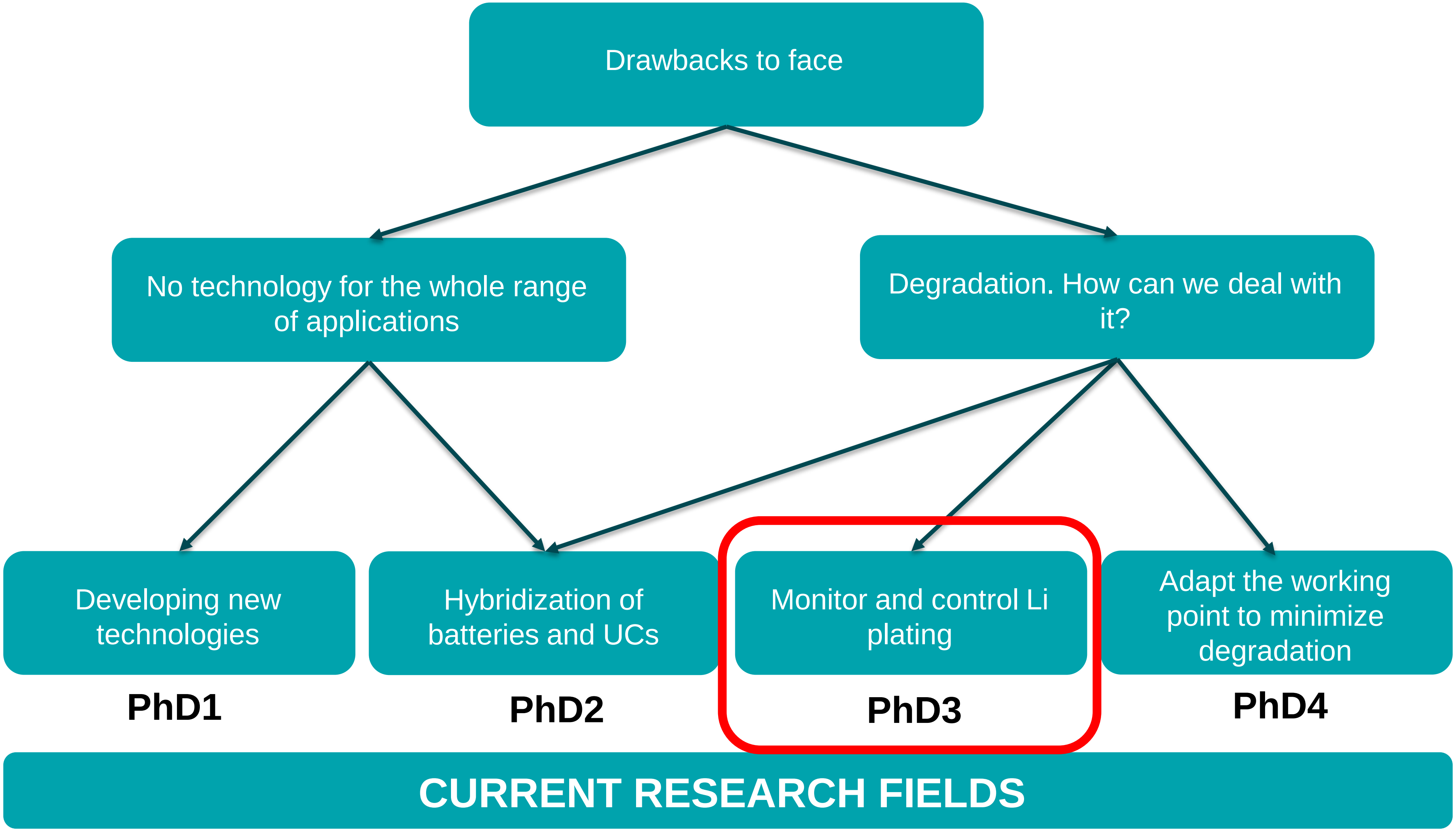
PhD2 – Hybridization of batteries and UCs

HESS Experimental Performance



- The battery supplies the load in steady state.
- The UC provides all the required current during transients.
  - This will reduce the battery stress.
  - Small energy amount from UCs. (Small UC bank)

Framework



Drawbacks to face
No technology for the whole range of applications
Degradation. How can we deal with it?
Developing new technologies
Hybridization of batteries and UCs
Monitor and control Li plating
Adapt the working point to minimize degradation
PhD1
PhD2
PhD3
PhD4
CURRENT RESEARCH FIELDS

Problem description

Lithium plating is one of the most critical aging mechanism in li-ion batteries and it is directly linked to fast charging scenarios.

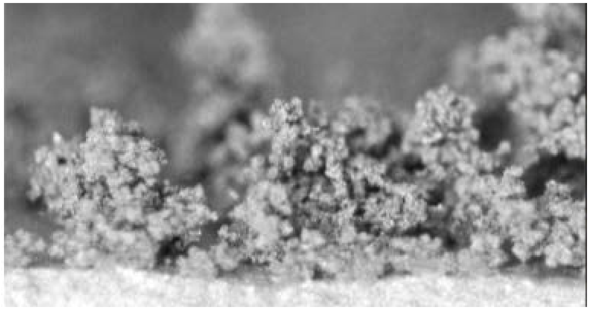
High polarization due to high C-rate

↓

Li plating at high SOC values (specially at low temperatures)

↓

- Loss of capacity
- Safety issue



Wood KN, Kazyak E, Chadwick AF, Chen KH, Zhang JG, Thornton K, et al. Dendrites and pits: Untangling the complex behavior of lithium metal anodes through operando video microscopy. ACS Cent Sci 2016. https://doi.org/10.1021/acscentsci.6b00260

Problem description

NOWADAYS

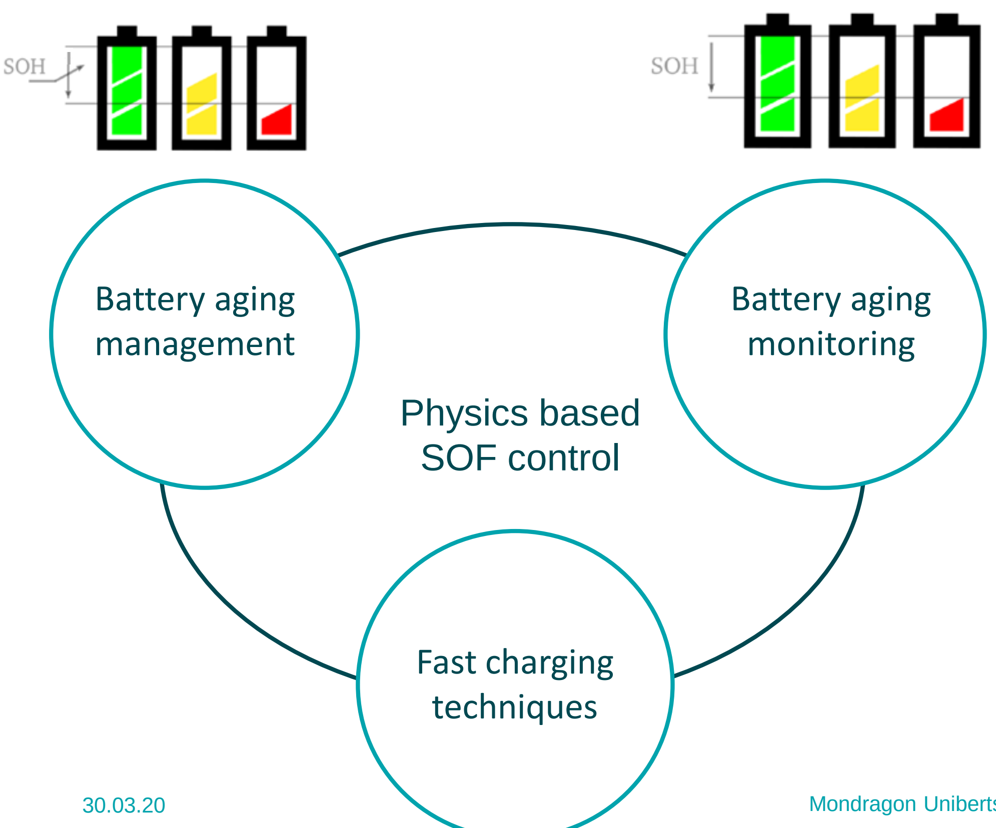
- Fast charging protocols are based on empirical testing to define their strategies.
- In general, aging (SEI growth, lithium plating, etc.) tracking is done:
  - **Offline**
  - Based on **empirical data**.
- Identifying the current state of batteries is:
  - Test based
  - No information about the aging mechanisms happening inside the cells is obtained in "real time".

PhD3 – Monitor and control Li plating

Mondragon Unibertsitatea
Faculty of Engineering

- PhD in collaboration with CIC Energigune.
- *Electrochemical Model-Based Advanced Battery Control Systems,* ***Eduardo Miguel. (Finished)***

Challenges



Aging tracking is done offline and with huge amount of empirical tests.

No information about aging mechanisms in the BMS, dangerous for fast charging for example

To run an electrochemical ROM in the BMS and control de aging of batteries

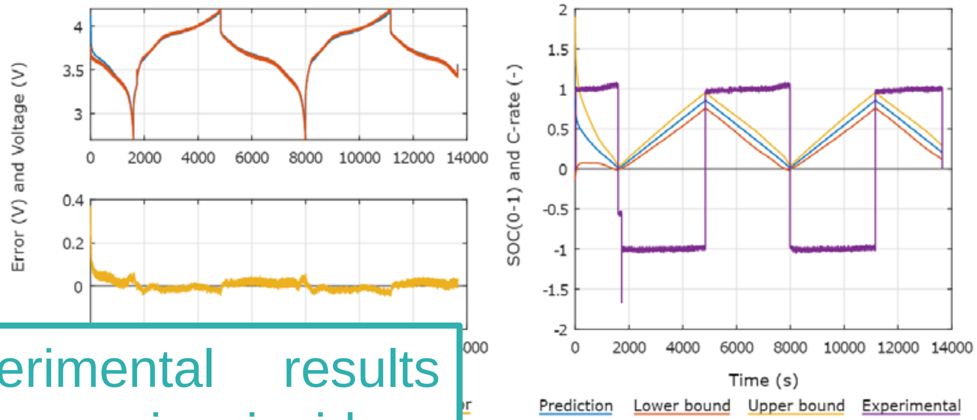
PhD3 – Monitor and control Li plating

State of the art

- Wide amount of theoretical work
- Few research of ROM models

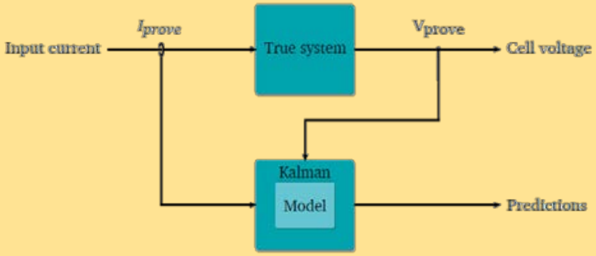
- Parameters identification is a crucial and complex step
- Few experimental validation

Our results

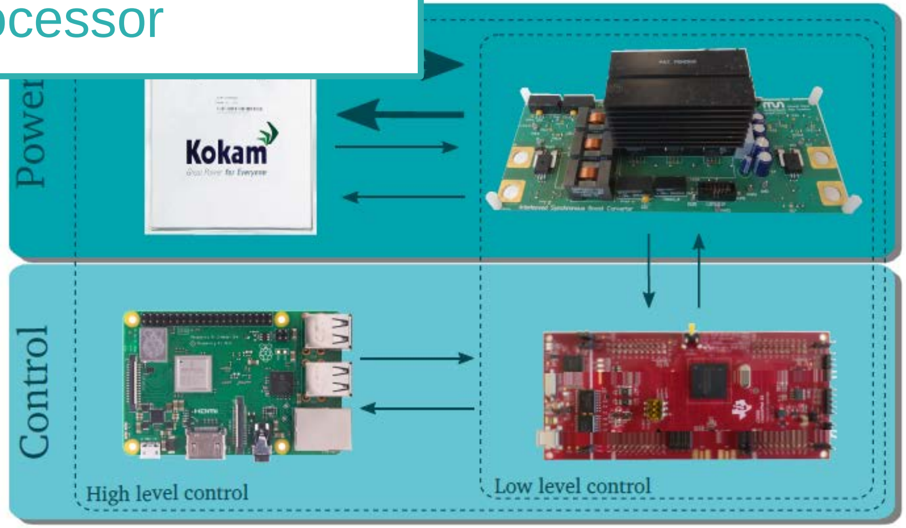


Accurate experimental results with the system running inside a low cost microprocessor

Our proposal:
Newly developed augmented model working in combination with a sigma-point kalman filter

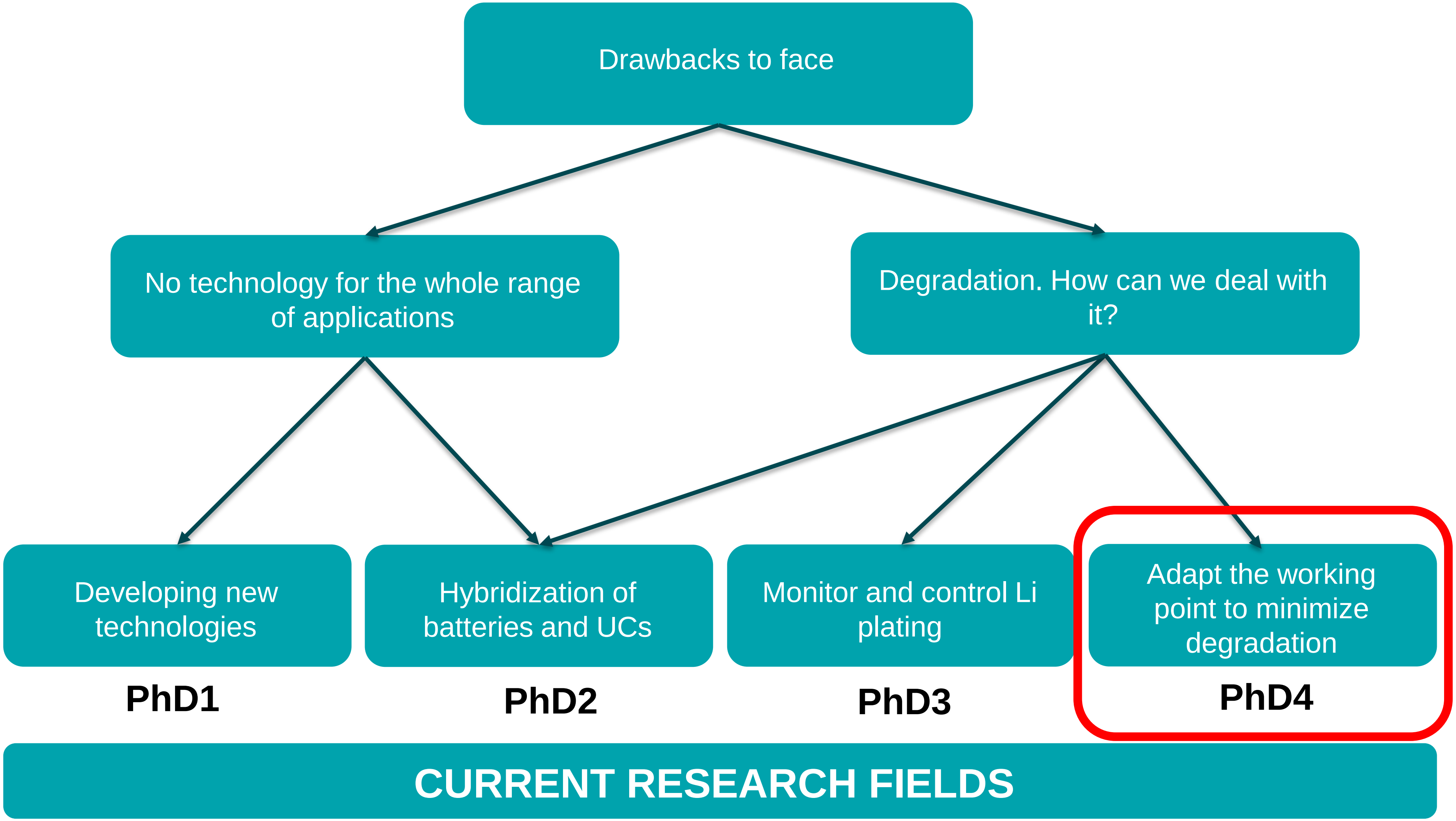


Accurate prediction of internal variables



Framework

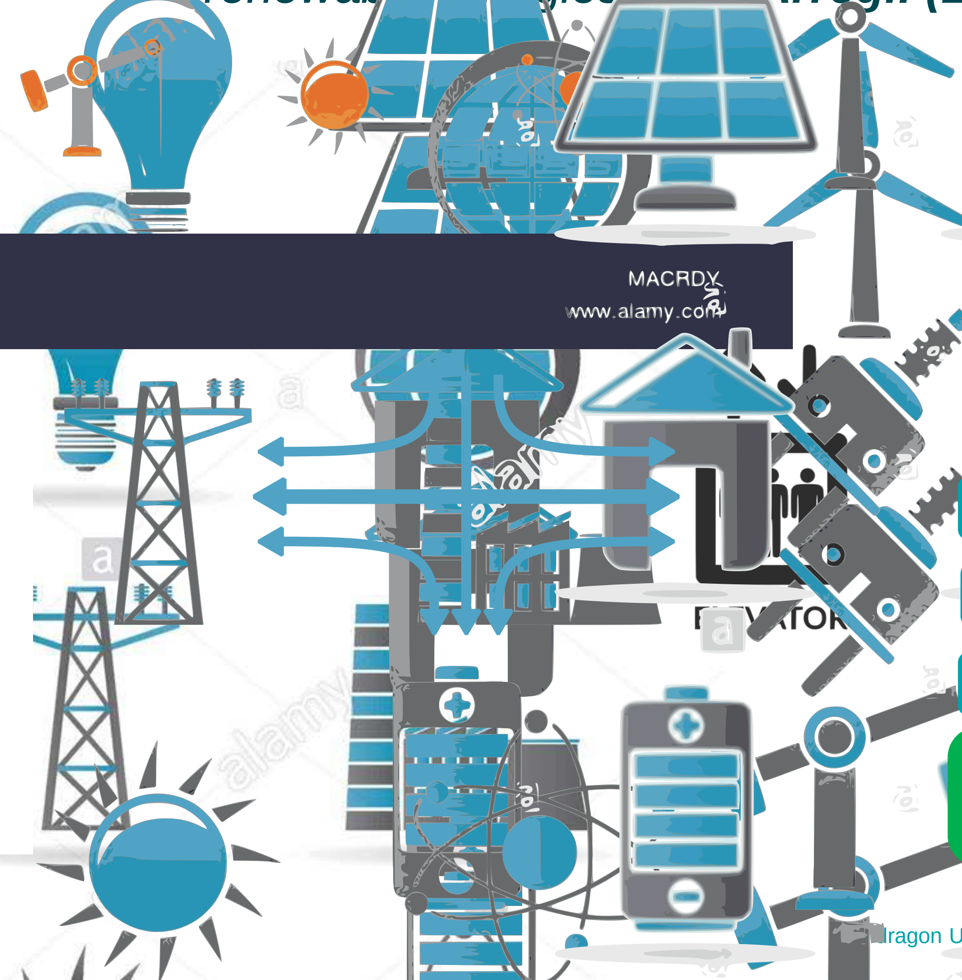
Mondragon Unibertsitatea
Faculty of Engineering



PhD4 – Adapt the working point to minimize degradation

Mondragon Unibertsitatea
Faculty of Engineering

- PhD in collaboration with Orona and Ikerlan.
- *Energy management in elevators with battery based storage systems and renewable energies.* ***Oier Arregi. (1st year, PhD proposal)***



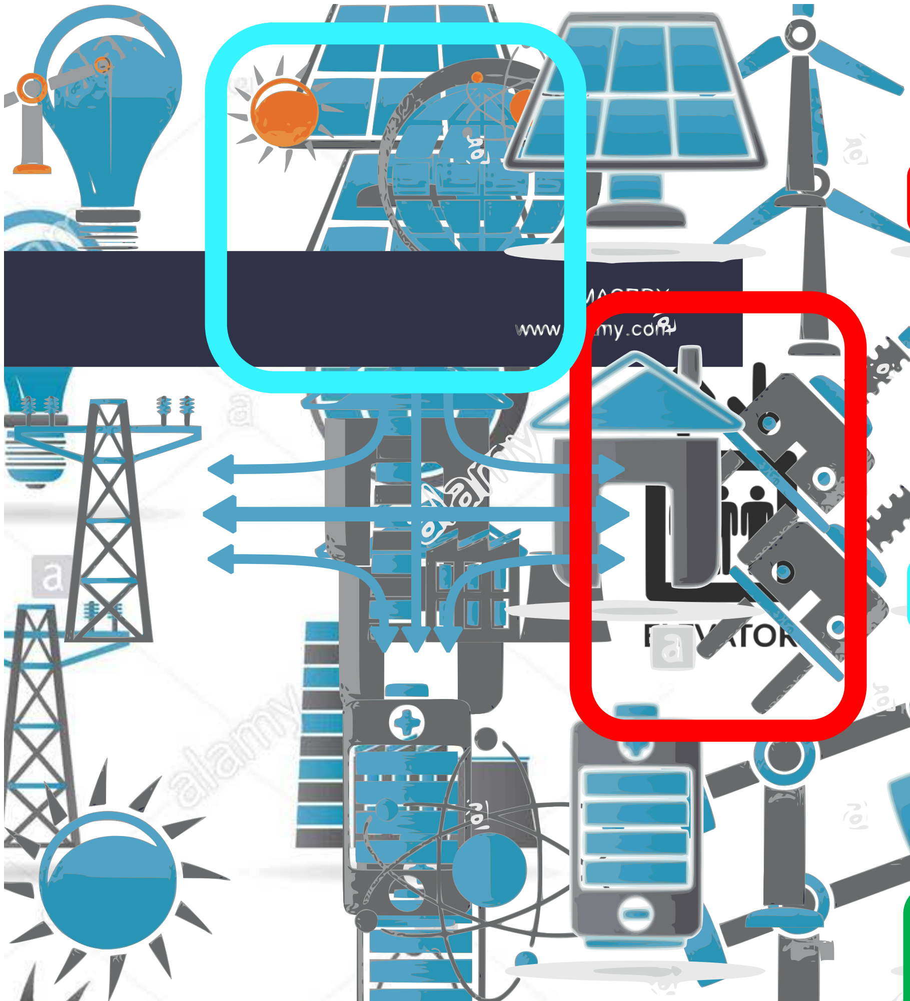
GENERAL OBJECTIVE

Develop new energy management strategies for elevators with energy storage systems and renewable energies.

Different objective variables to be optimized by the energy management strategies:

- MINIMUM CONSUMPTION FROM THE GRID
- MAXIMUM PV GENERATION
- BEST END USER SERVICE
- ENLARGE THE LIFESPAN OF THE BATTERY LOWERING THE AVERAGE SOC

PhD4 – Adapt the working point to minimize degradation



WHICH ARE THE CHALLENGES WE ARE FACING IN THIS PROJECT?

STOCHASTIC CONSUMPTION PROFILE

- Season of the year
- The types of the families living in a certain building.
- Culture

STOCHASTIC PV GENERATION PROFILE

MACHINE LEARNING TECHNIQUES WILL BE APPLIED TO PREDICT THESE BEHAVIOURS

3

Summary and conclusions

Summary and conclusions

Mondragon Unibertsitatea
Faculty of Engineering

- Nowadays we are trying to give a solution to 2 main issues:
  - No technology to cover all the range of applications requiring energy storage systems.
  - Degradation of the available technologies.
- We are looking for collaborative research with other universities, research centers and companies.
- Our future lines are:
  - Electrochemical modeling BMS solution
  - Develop simulation tools to help into the prototyping of new battery technologies
  - MPC control for BMS applications
  - Machine learning techniques for energy management systems

4

Next steps

Next steps

- We want to continue working in **four** main topics:
  1. **Development of new technologies:** Simulation tools to help into the prototyping process of new cell technologies.
  2. **BMS hardware and algorithms:** Development of advanced BMS systems from the hardware and software point of view (including SOF estimators)
  3. **Energy storage systems related power hardware:** Design, implementation and control of the hardware associated to battery modules/packs (fast charging, partial power, control of battery modules for minimization od the degradation processes)
  4. **Energy management in systems with renewables and battery technologies:** Use of machine learning for the optimization of the system from the energy point of view.

Mondragon Unibertsitatea
Faculty of Engineering

Eskerrik asko
Muchas gracias
Thank you

José Mª Canales
jmcanales@mondragon.edu
Loramendi, 4;20500 Arrasate-Mondragón (Spain)
Tel: (34) 670 61 11 34 / Ext: 5206
(34) 943 79 47 00 (switchboard)