Lithium-ion batteries: characterization, modeling and simulation
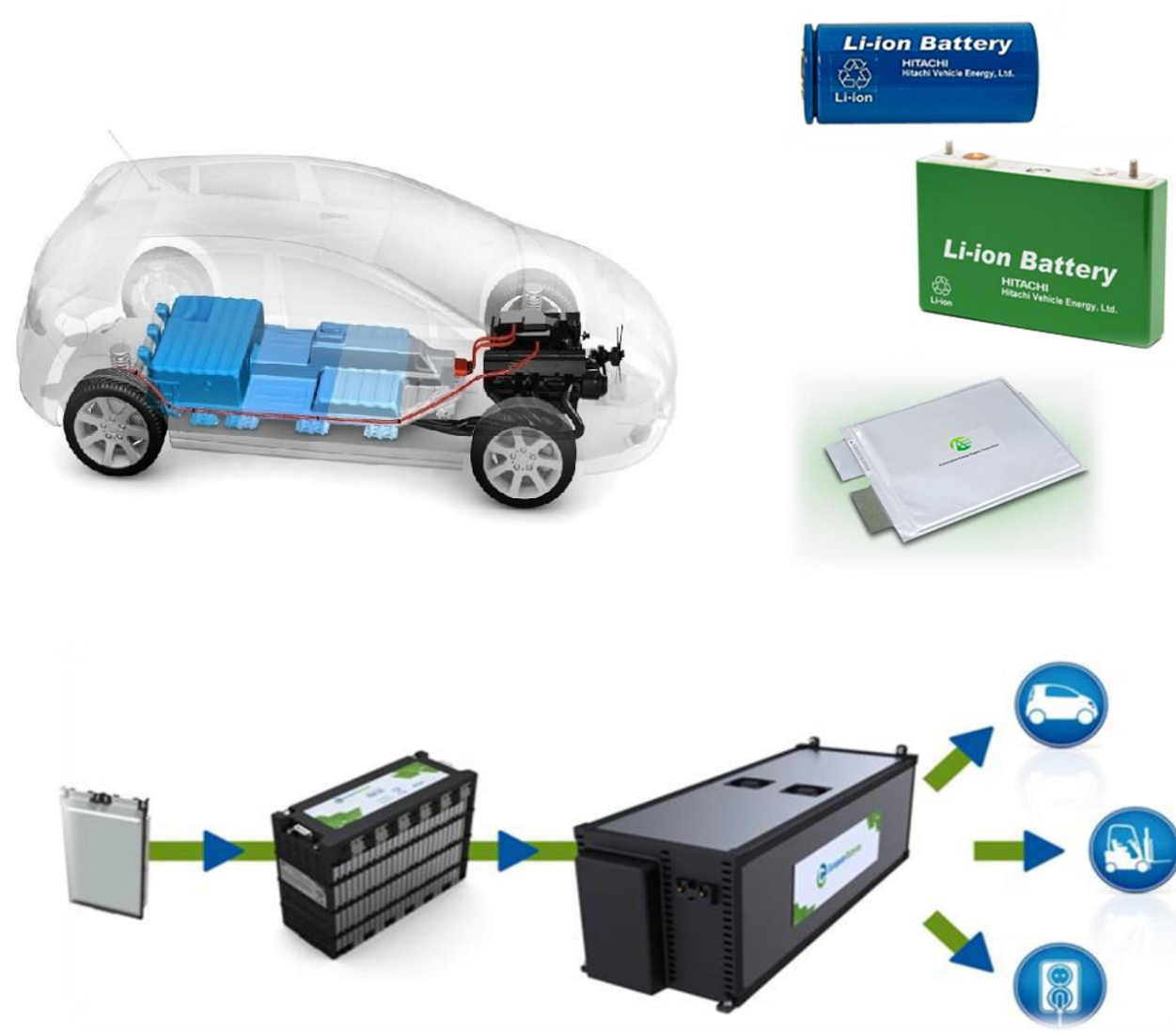
Politecnico di Torino

Department of Mechanical and Aerospace Engineering (DIMEAS)
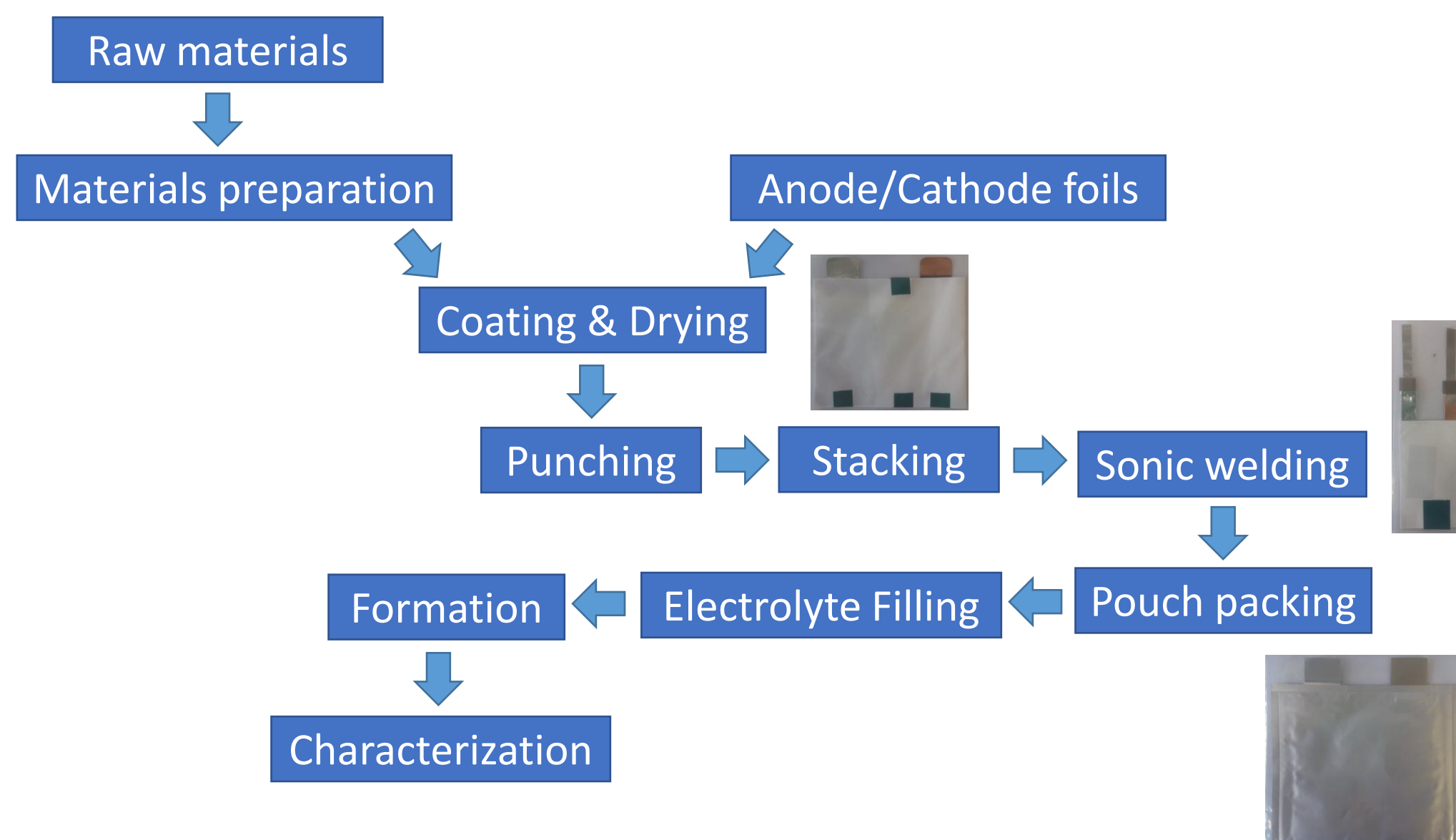
ScuDo – XXXII cycle

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The first Electric Vehicle (EV) was invented in 1834 but, because of the development of Internal Combustion Engine Vehicles (ICEVs), EVs vanished from the scene. Nowadays, due to the environmental issue, the interest on EVs and on Hybrid Electric Vehicles (HEVs) is growing again thanks to their lower pollutant emissions. The main difference between an ICEV and an EV or HEV is the presence of the battery pack used to power the vehicle. It is a system of cells connected in series and in parallel. Among the technologies established on the market, the major focus is on Li-ion cells because of their better performance in terms of energy and power density. Batteries are the main limitation in electric vehicles spread due to their limited capacity, lifetime, cost and safety. To guarantee the best working conditions, voltage, current and temperature of the single cells are handled by an electronic unit called Battery Management System (BMS). Moreover it estimates the State Of Charge (SOC) of the cells. The activity of this year first of all has been devoted to an inner inspection of cells composition. Then a study of the literature on the main battery models has been conducted and an own model has been built. An algorithm to estimate the state of charge has been implemented. Finally an analysis of the thermo-mechanical behavior has been carried out.
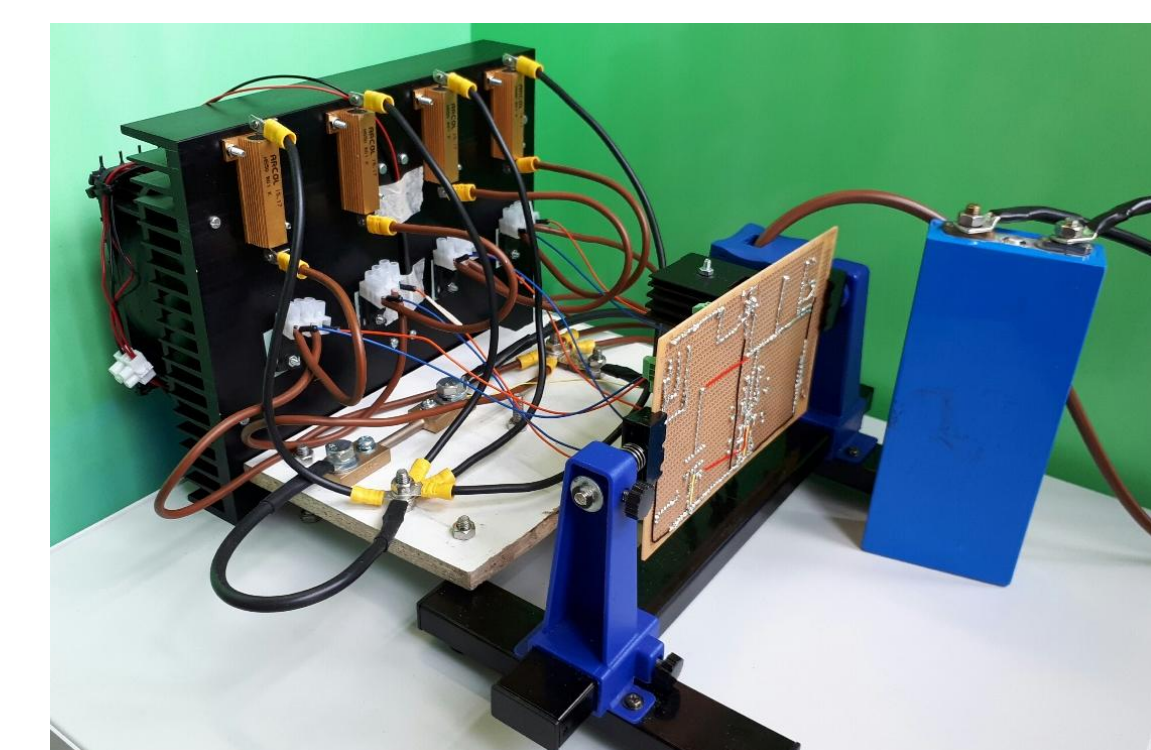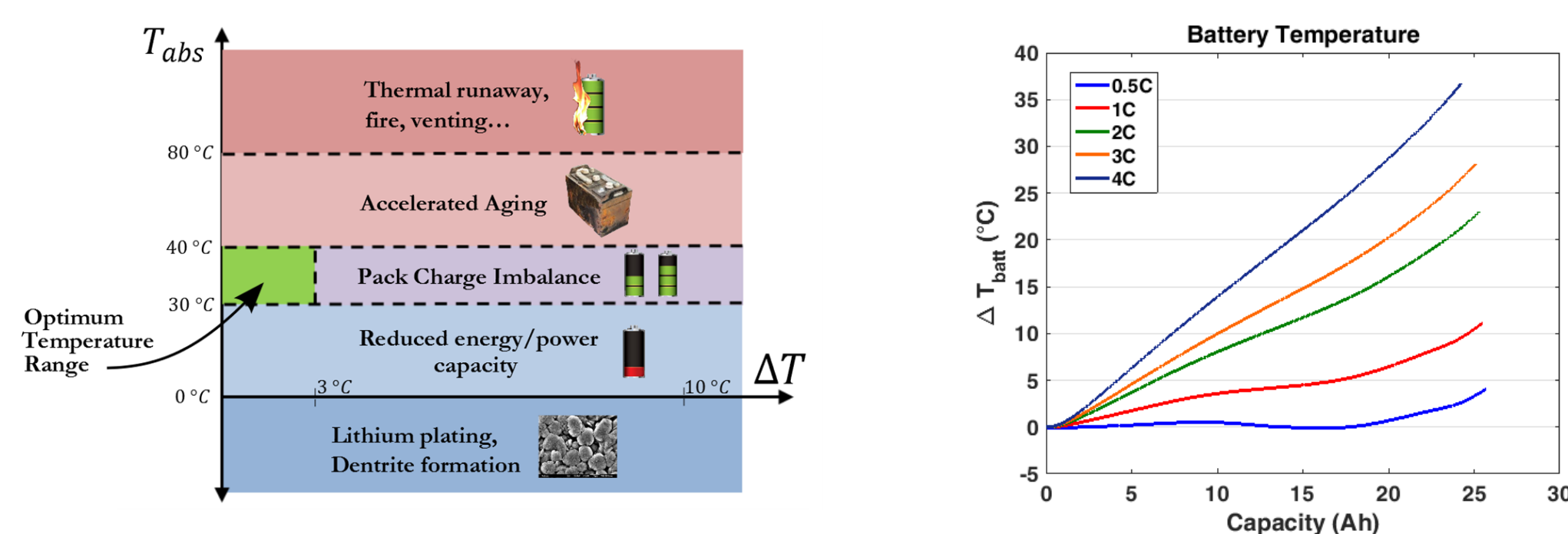
Manufacturing process

Lithium-ion batteries are part of our daily life and we continuously use them.
The need to properly understand what is inside a cell and how it behaves has been the driving force for investigating the cell manufacturing process in first person.

Raw materials → Materials preparation → Coating & Drying → Punching → Stacking → Sonic welding → Pouch packing → Electrolyte Filling → Formation → Characterization

Anode/Cathode foils → Coating & Drying

Thermo-mechanical behavior

When exercising charging/discharging cycles, the cell tends to change its volume, because of the electrons moving through the separator from one electrode to the other; it is also subjected to vibrations due to the working conditions.
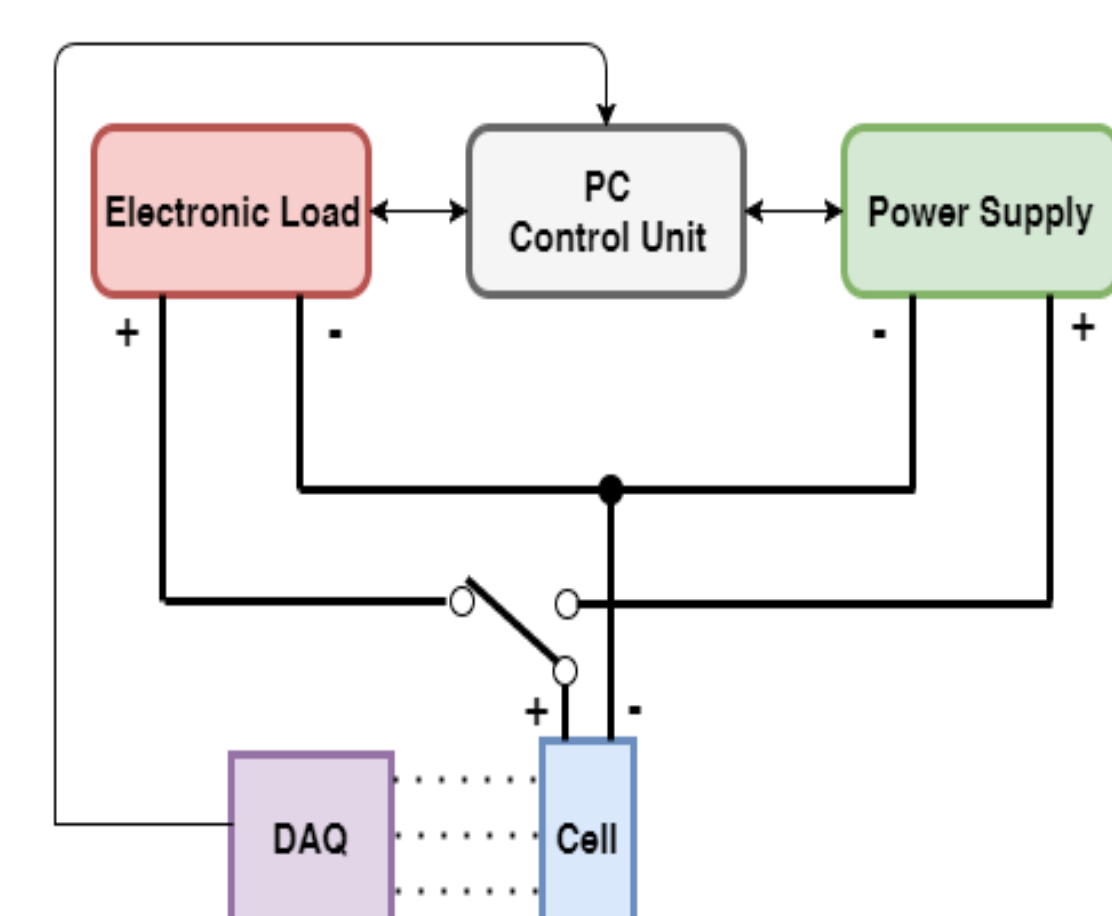Furthermore the cell shows a non-uniform temperature increase due to the current flowing and it expresses its best performance in the range $30 - 40$ °C.

Battery testing

To study the cell behavior in conditions like to the real ones, it is necessary to be able to discharge it at similar current rates.
This is the reason why a prototype for the discharging was built. It allows to discharge a cell with a continuous current up to 120 A thanks to a properly designed cooling system. With a dedicated software written in MATLAB, it is possible to obtain complex predefined current load profiles for cell testing.
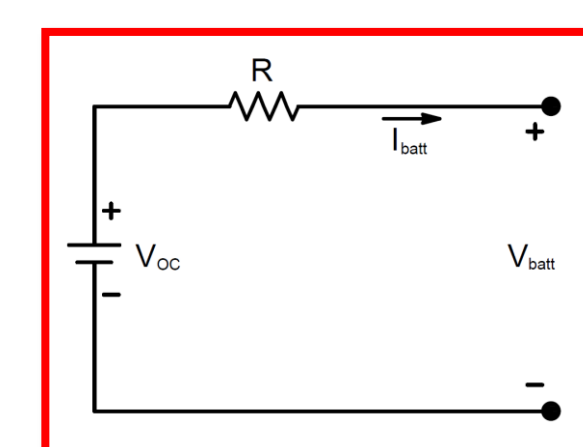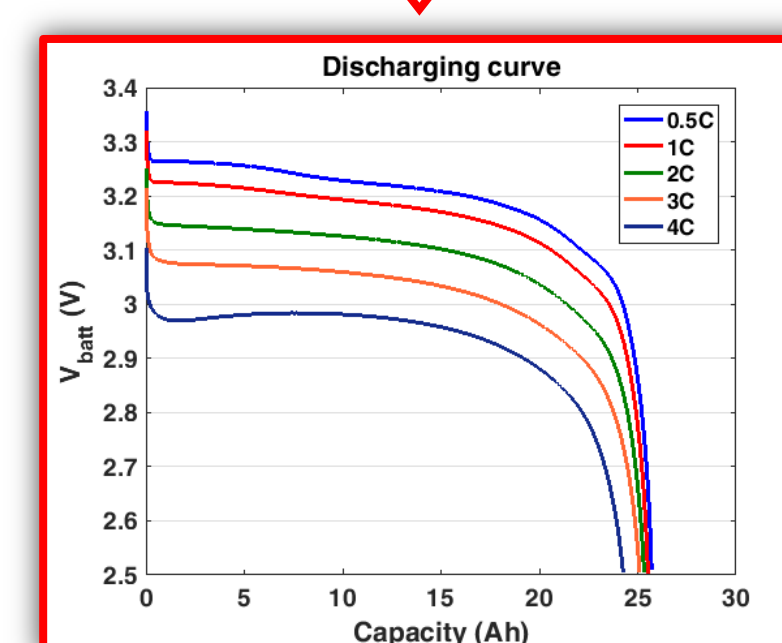
Experimental setup

The test bench built can be used to perform cyclic charging/discharging tests.
It is made up by a control unit and two main devices that are the programmable electronic load for the discharging stage and the programmable power supply for the charging stage.

Battery modeling

The battery terminal voltage can be modelled according to a Rint model. In particular for the Open Circuit Voltage (V_{OC}) a five parameters Combined model was selected.
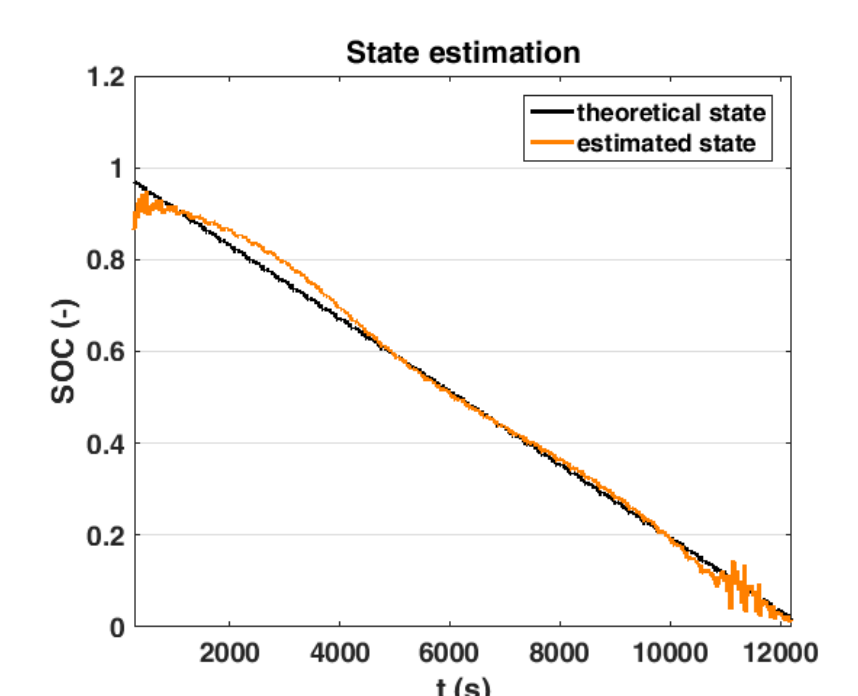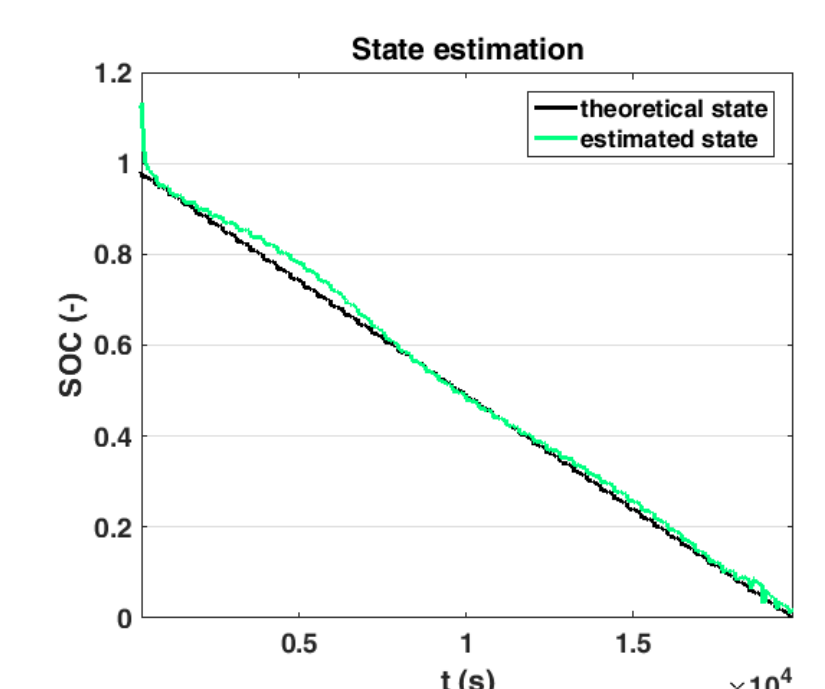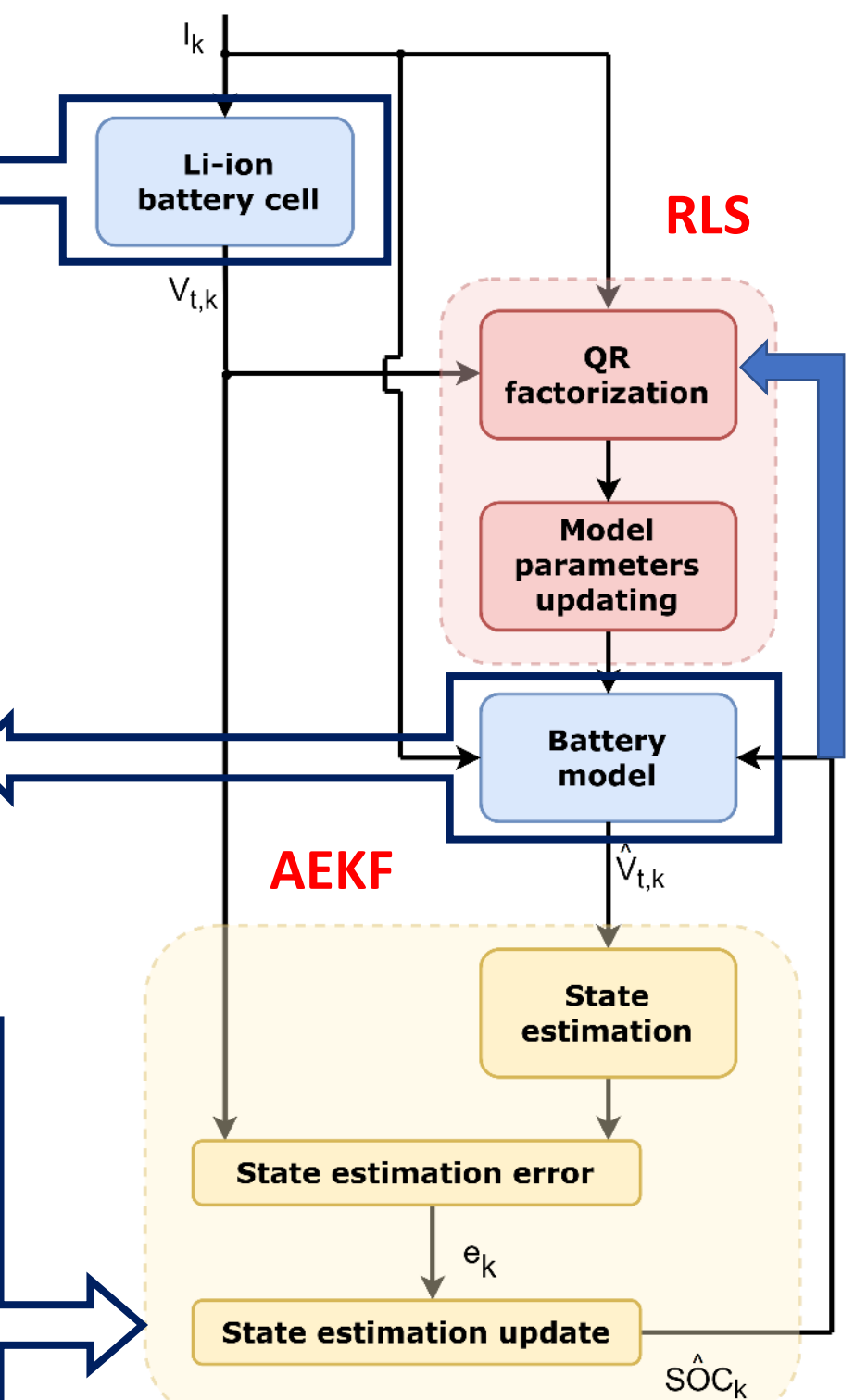
$$SOC(t) = SOC(0) - \frac{1}{Q} * \int_0^t i(t)dt$$

$$V_{BATT} = K_0 - \frac{K1}{z} - K_2 * z + K_3 * \ln z + K_4 * \ln(1-z) - R_0 * I$$

State of charge estimation

According to the physics to be described, a RLS-AEKF algorithm was implemented. It is based on the idea that the SOC is not a measurable quantity so it needs to be estimated. In particular the measurable voltage can be exploited as a reference to update the estimated SOC.

Results & Future work

The estimated SOC can properly fit the theoretical one so the algorithm results are satisfactory.
The study of the thermo-mechanical behavior of a cell has allowed to identify a field in which it's possible to exploit the mechanical background so further research will focus on these aspects and on their influence on the overall battery performance. In particular the effects of the working conditions on the aging effect will be taken into account in order to find the ones that allow to stress less the cell and so to preserve the lifetime and to work in safety.

Conference Papers

- F. Mocera, E. Vergori, Study and identification of the thermo-electric behavior of lithium-ion batteries for electric vehicles, AIAS 2017, Pisa
- E. Vergori, F. Mocera, A. Somà, Battery modeling and simulation using a programmable testing equipment, CEEC 2017, Colchester

Courses

Hard Skills:
- The measurement of electrical impedance (2 CFU)
- Techniques of robust control (6 CFU)
- Structural Health Monitoring using Machine Learning (4 CFU)
- Progettazione e simulazione eterogenea con tecniche di «System Engineering» (4 CFU)

Soft skills:
- Writing Scientific Papers in English (3 CFU)