Open adaptable Battery Management System software architecture

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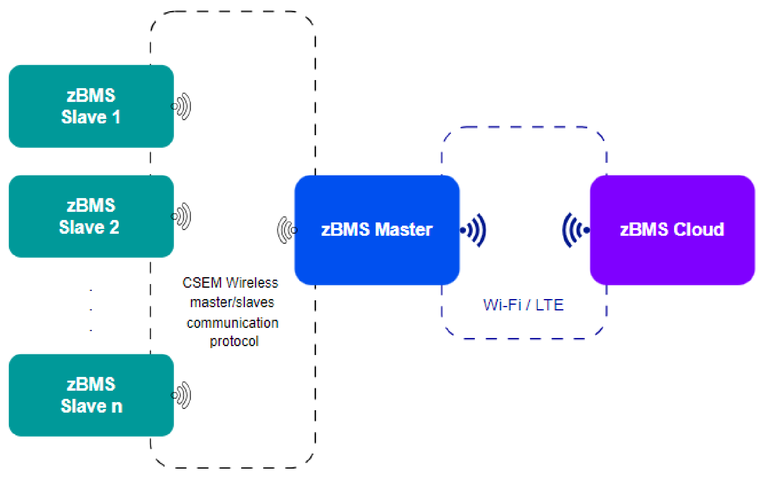
Abstract: *The vision of BATTERY2LIFE is to facilitate the smooth transition of batteries to second-life applications, fostering innovation within the European Battery Industry. The initiative aims to provide essential tools for implementing open, adaptable, and cloud-connected Battery Management Systems (BMS), along with improved system designs. As part of this endeavor, CSEM and EPFL have jointly developed the software architecture for this BMS.*

Global architecture

The Battery2Life zBMS aims to have the most **detailed** current and historical **vison of the state of any kind of battery pack** independent from its configuration and chemistry.

The data collected and stored from the battery pack allows **to create an Equivalent Circuit Model** that evolves during time. From this, accurate state estimation algorithms can be developed such as State of Charge (SoC), State of Health (SoH), State of Power (SoP), State of Safety (SoS) and State of Temperature (SoT). Furthermore, this data and models allows **to build** the **battery passport**.



zBMS Hardware communication architecture

The Battery2Life zBMS is divided in **3 different types of hardware devices: slaves, master and cloud server**.

Software components for the different devices are **modular** , easily **interchangeable**, **structurally open-source** and **open-platform** whilst still enabling **IP protection**. This is achieved via Firmware over the Air Updates from the cloud.

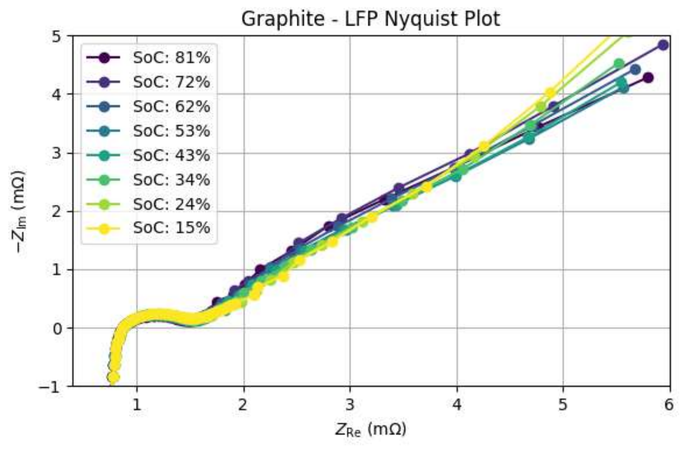
zBMS Slave

The Battery Management System Slave is the device that is in contact with the battery cells and there is one per module.

It is responsible for the **acquisition of measurements from the battery modules** including **cell voltages, internal cell temperature** and full-spectrum **Electrochemical Impedance Spectroscopy** (EIS). It also balances the cells in the module.

EIS sends AC current to the cells and the voltage frequency response is acquired by the zBMS slave. The frequency response depends on the cell SoC, temperature and ageing.

EIS also allows to estimate the cell core temperature since there is a correlation between the cell temperature and one specific frequency response.



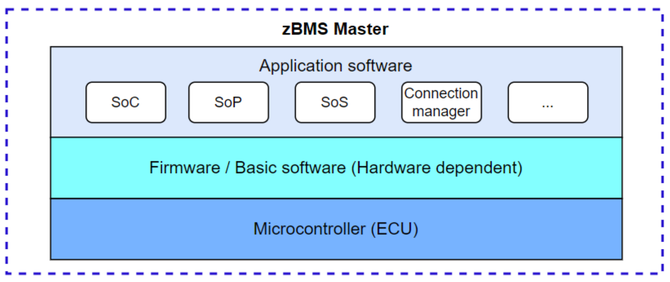
EIS Nyquist plot at different SOCs for a Graphite-LFP battery cell

zBMS Master

The Battery Management System Master has the following application functions or components:

- **Collects information** from the BMS slaves and commands its cells balancing.
- Calculates and communicates the **State of Power** (SoP), **State of Charge** (SoC) of the battery pack and of each cell.
- Manages the connection and disconnection of the battery pack to the DC network to supply power.
- Manages the global battery pack safety (**State of Safety** or SoS) and actuates the contactors in case of a risky event (SIL).

The **application software components are hardware independent**, and they are **modular and interchangeable** thanks to a specific bus architecture.

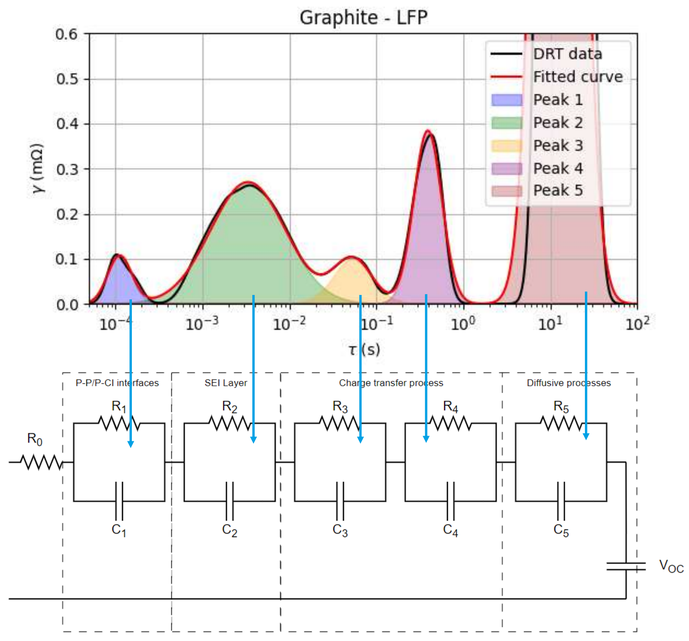


Firmware or Basic software such as Real Time Operating System, Hardware Abstraction layers, communication layers etc. shall be adapted in function of the hardware choice.

zBMS Cloud

The Battery Management System Cloud consists of the following processes:

- **Real-time** and **EIS data processing**
- **Equivalent Circuit Model** construction of the battery pack and of each individual cell.
- **State of Health** (SoH) tracking of the battery pack and of each individual cell.
- **Battery passport** management
- **Firmware-Over-The-Air updates** to deploy new algorithms and enhanced safety features at any time on the zBMS Master.



Equivalent Circuit Model based on DRT (EIS) data analysis

Validation

The **software and hardware** described in the abovementioned architecture **have already been developed and validated in an NMC battery pack** using an electric vehicle as the load. Furthermore, static testing with an inverter has been performed to simulate a second-life application.

The next validation steps will involve validating the architecture with different battery chemistries and hardware to prove its modularity and interchangeability. In 2025, this will be tested with **BATTERY2LIFE** SunLight LFP batteries and new hardware.

The ultimate validation goal is to demonstrate that this open and adaptable BMS architecture helps extend the life cycle of a battery by tracing accurately its degradation evolution and managing it accordingly (e.g., balancing, SoP limitation, SoS, etc.).

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