BMS Alliance Webinar #4 — hosted by NEXTBMS
Online webinar — with NEMO, ENERGETIC, BATMAX & NEXTBMS

EIS-Based Battery State Estimators in Embedded BMS

Martin Perez Chuecos — CSEM (NEMO project)

Co-funded by the European Union

Swiss participant Centre Suisse d'Electronique et de Microtechnique SA - Recherche et Developpement (CSEM) has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).

CONSORTIUM

Meet The Partners

NEMO Consortium is led by VUB and brings together highly experienced and specialized institutions, organizations and companies that conduct cutting-edge research.

VUB

IFAT

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ICONS

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TAAG

TCAG

CSEM

EIS-Based Battery State Estimators in Embedded BMS

From EIS data

State of Temperature
Cell internal core temperature based on EIS phase

State of Charge
Accurate cell level State of Charge using its EIS based ECM in an EKF

State of Health
Cell level Impedance evolution during its lifecycle based on its EIS ECM evolution

State of Power
Cell level power limitation based on its EIS ECM evolution

CSEM Cell Management System to obtain EIS data at cell level

NEMO

NEMO zBMS and zBMS+

Same module, 2 different electronics

Module: Cathode NMC, 12s1p, 72Ah cells

zBMS

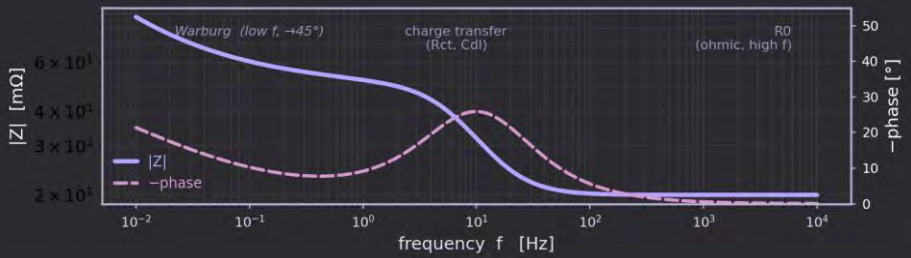
- Cell level EIS by Infineon
- Passive balancing
- Wired communication between cells and master BMS

zBMS +

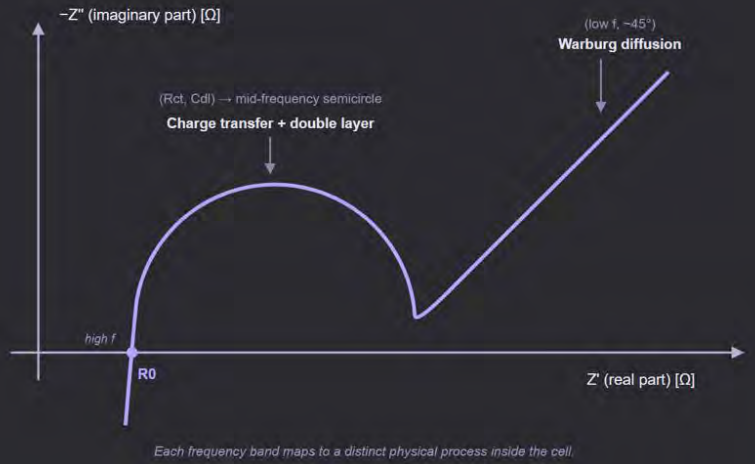
- Cell level EIS by CSEM
- Active balancing SoC/SoH based
- Wireless communication between cells and master BMS
- SoT capabilities

NEMO System architecture

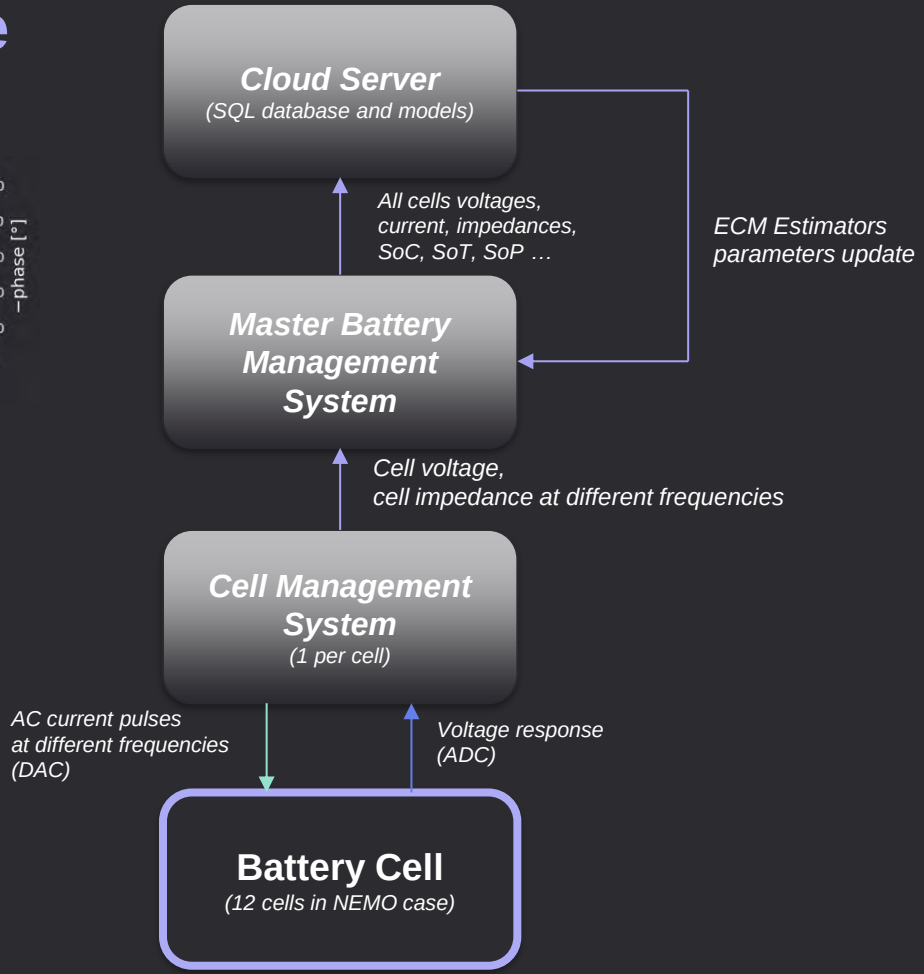
EIS Bode plot



EIS Nyquist plot

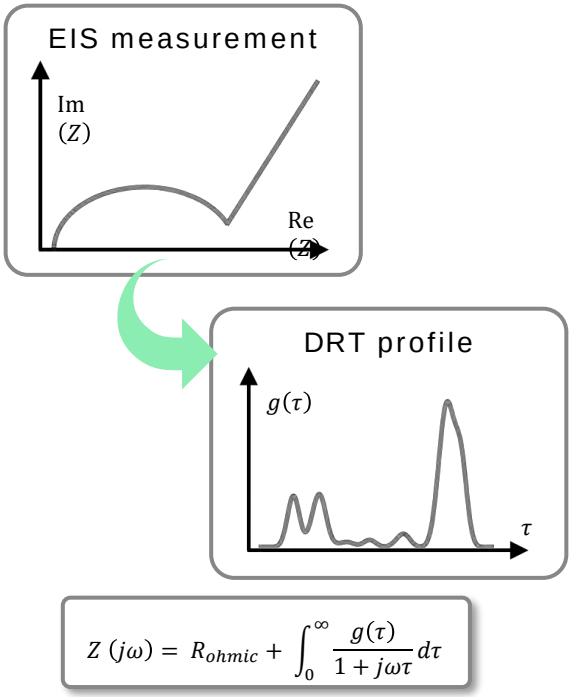


Each frequency band maps to a distinct physical process inside the cell.

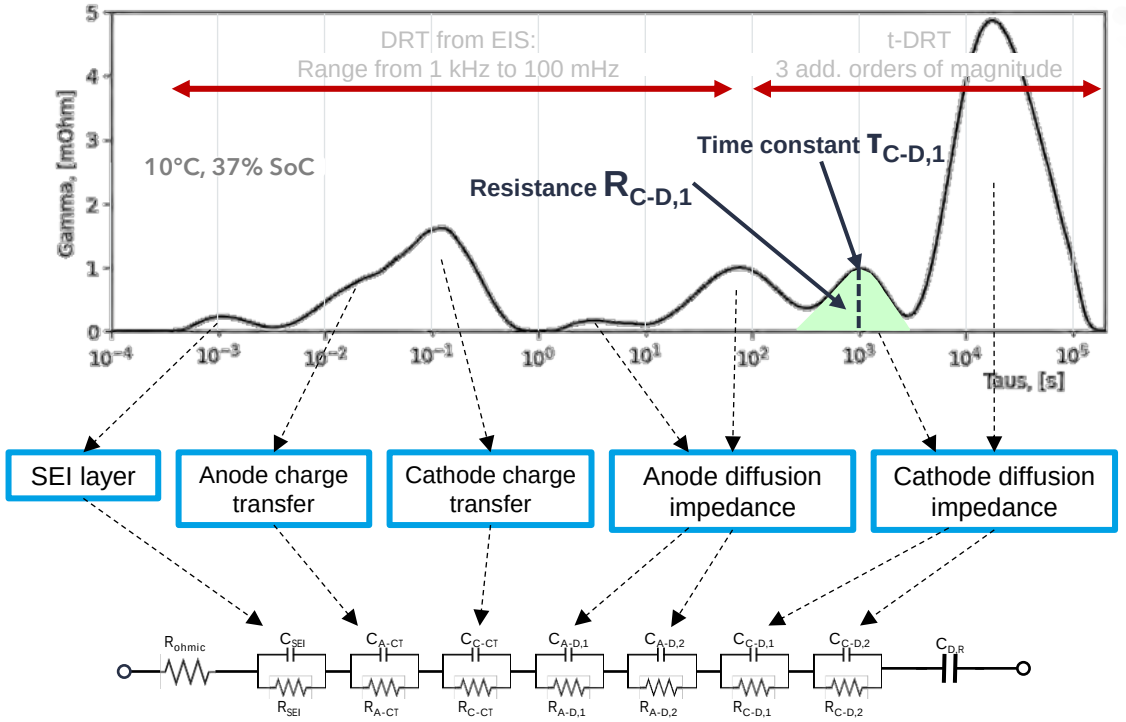


CSEM SOLUTION – DRT-BASED EIS SIGNAL INTERPRETATION

Distribution of Relaxation Time (DRT) approach



BESTIMATOR™



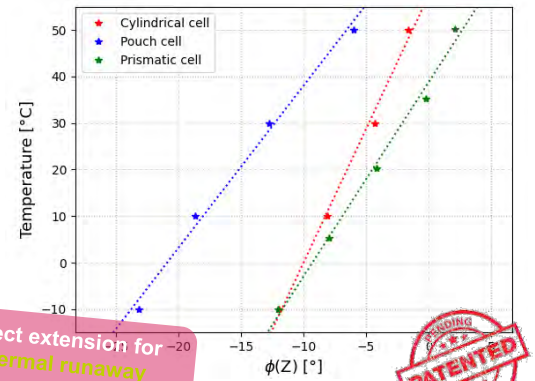
P. Iurilli, et al, "EIS2MOD: A DRT-Based Modeling Framework for Li-Ion Cells", doi: 10.1109/TIA.2021.3134946.

csem

IMPROVEMENTS FOR BATTERY STATE ESTIMATION

SoT

cell core temperature estimation → for all cells in a module/pack



direct extension for thermal runaway prediction

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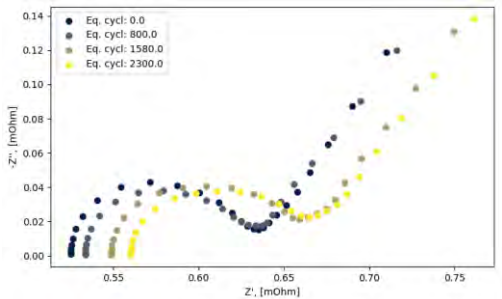
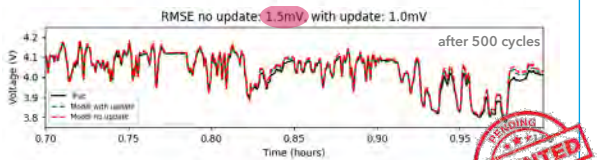
Validation	surface	SoT estimate
RMSE	3.0° C	0.8° C
Max. error	12.2° C	2.2° C

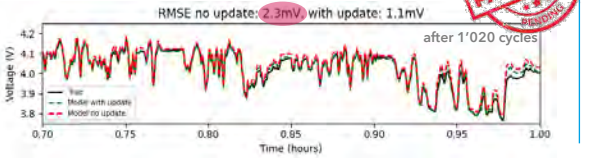
S. Bhoir, et al, "Li-ion cells int. temperature estimation using medium-frequency measurements of impedance argument", doi: 10.1016/j.est.2024.112754.

SoC/SoP

Continuous identification of RC model parameters → measured







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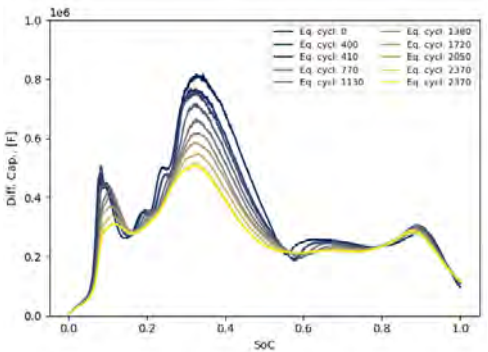
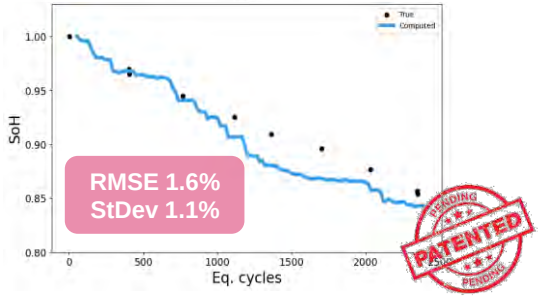
SoH

Measurement of the evolution of the differential capacitance





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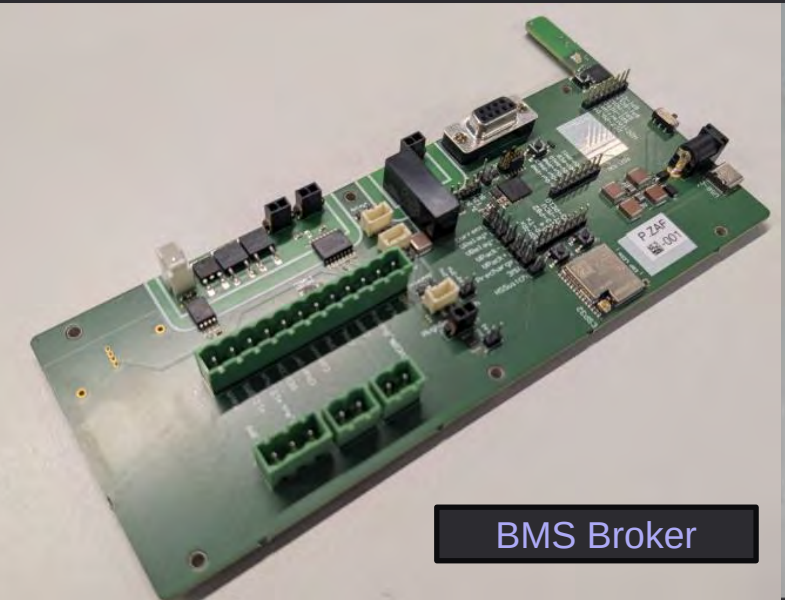
zBMS+ Components

- Switching board allows to bypass any cell during charge or discharge allowing **active balancing**. The bypass done for balancing is SoC and SoH based.
- BMS Broker collects all the information from the CMSs wirelessly and transmits the information to the Cloud Server



zBMS+ assembly and cycling

- EIS lab reference measurement installed in parallel of the module to double check the EIS data accuracy.
- EIS acquisition performed at different SoCs and at frequencies from 0.1 Hz to 2000 Hz.
- Module cycling since April 2026 with some lab reliability issues. Continuous cycling since the 12th of June.

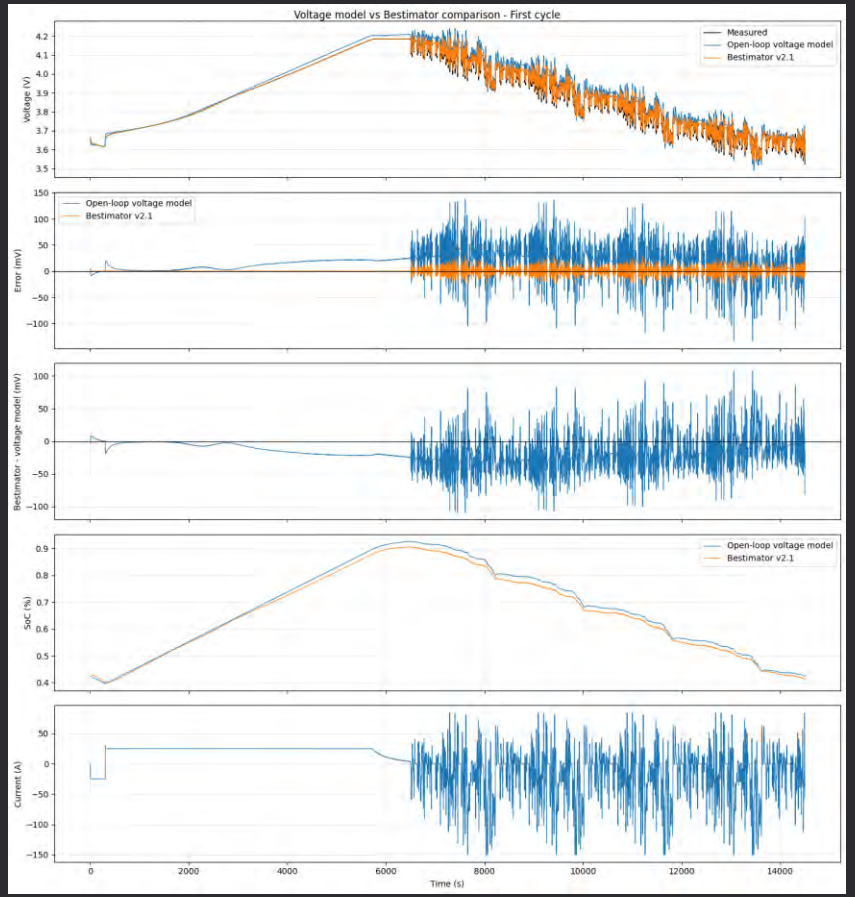
zBMS server data collection and real time monitoring

NEMO zBMS

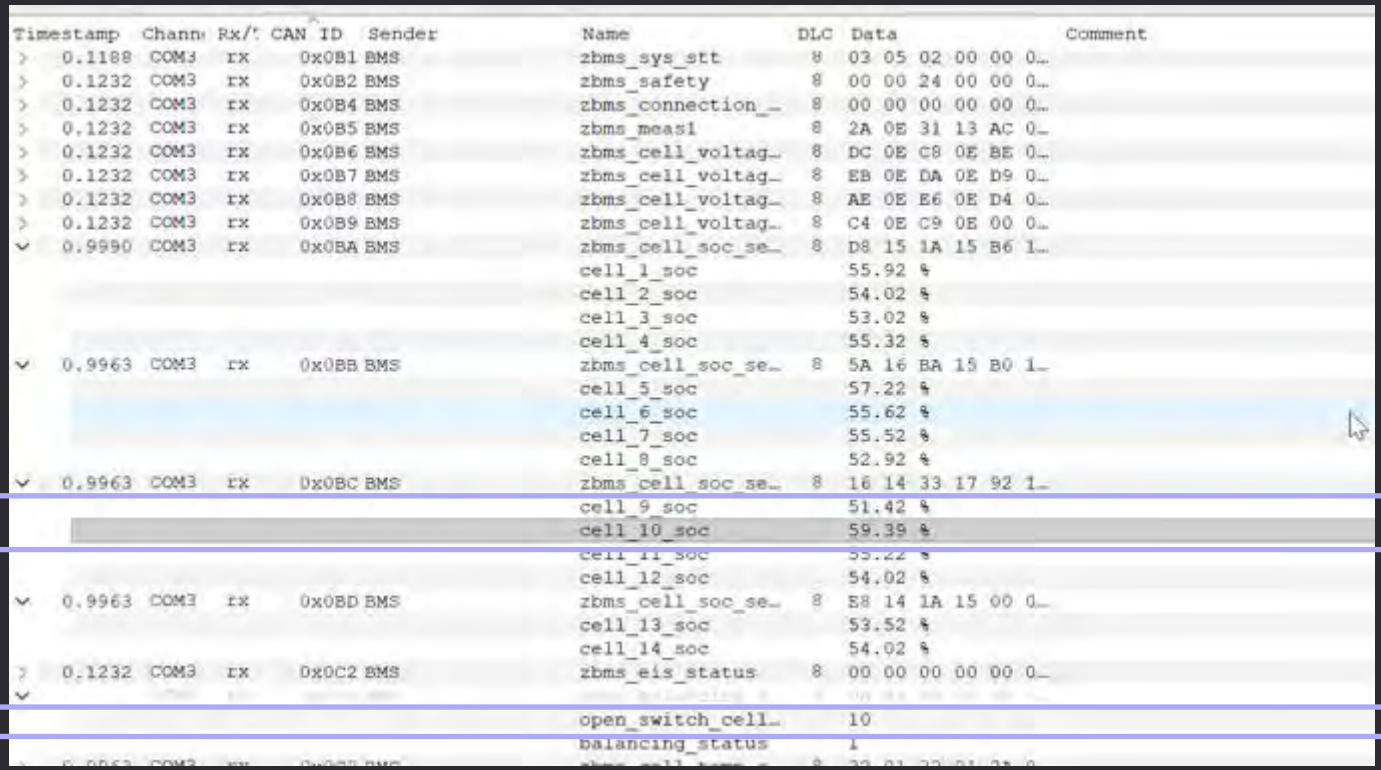
NEMO zBMS+

SoC Battery state-estimation algorithms (CSEM / TUG & VUB)

- SoC algorithm using an EIS ECM based Kalmal Filter
- Based on high accuracy lab data NEMO Bestimator SoC can closely track the SoC ground truth given by the Coulomb Counter.
- In embedded condition, when the Coulomb Counter will drift due to current bias, NEMO Bestimator SoC will remain accurate since it relies on voltage (not just current) to track the SoC.



zBMS+ SoC based active balancing algorithm (CSEM)



Timestamp	Chann	Rx/T	CAN ID	Sender	Name	DLC	Data	Comment
0.1188	COM3	rx	0x0B1	BMS	zbms_sys_stt	8	03 05 02 00 00 0…	
0.1232	COM3	rx	0x0B2	BMS	zbms_safety	8	00 00 24 00 00 0…	
0.1232	COM3	rx	0x0B4	BMS	zbms_connection_…	8	00 00 00 00 00 0…	
0.1232	COM3	rx	0x0B5	BMS	zbms_meas1	8	2A 0E 31 13 AC 0…	
0.1232	COM3	rx	0x0B6	BMS	zbms_cell_voltag…	8	DC 0E C8 0E BE 0…	
0.1232	COM3	rx	0x0B7	BMS	zbms_cell_voltag…	8	EB 0E DA 0E D9 0…	
0.1232	COM3	rx	0x0B8	BMS	zbms_cell_voltag…	8	AE 0E E6 0E D4 0…	
0.1232	COM3	rx	0x0B9	BMS	zbms_cell_voltag…	8	C4 0E C9 0E 00 0…	
0.9990	COM3	rx	0x0BA	BMS	zbms_cell_soc_se…	8	D8 15 1A 15 B6 1…	
					cell_1_soc		55.92 %	
					cell_2_soc		54.02 %	
					cell_3_soc		53.02 %	
					cell_4_soc		55.32 %	
0.9963	COM3	rx	0x0BB	BMS	zbms_cell_soc_se…	8	5A 16 BA 15 B0 1…	
					cell_5_soc		57.22 %	
					cell_6_soc		55.62 %	
					cell_7_soc		55.52 %	
					cell_8_soc		52.92 %	
0.9963	COM3	rx	0x0BC	BMS	zbms_cell_soc_se…	8	16 14 33 17 92 1…	
					cell_9_soc		51.42 %	
					cell_10_soc		59.39 %	
					cell_11_soc		55.22 %	
					cell_12_soc		54.02 %	
0.9963	COM3	rx	0x0BD	BMS	zbms_cell_soc_se…	8	E8 14 1A 15 00 0…	
					cell_13_soc		53.52 %	
					cell_14_soc		54.02 %	
0.1232	COM3	rx	0x0C2	BMS	zbms_eis_status	8	00 00 00 00 00 0…	
					open_switch_cell…		10	
					balancing_status		1	

SoT Battery state-estimation algorithms (CSEM / TUG & VUB)

ZBM+ embedded SoT improved precision

NTC Temperature surface sensors (reference)

SoT Cell Core temperature

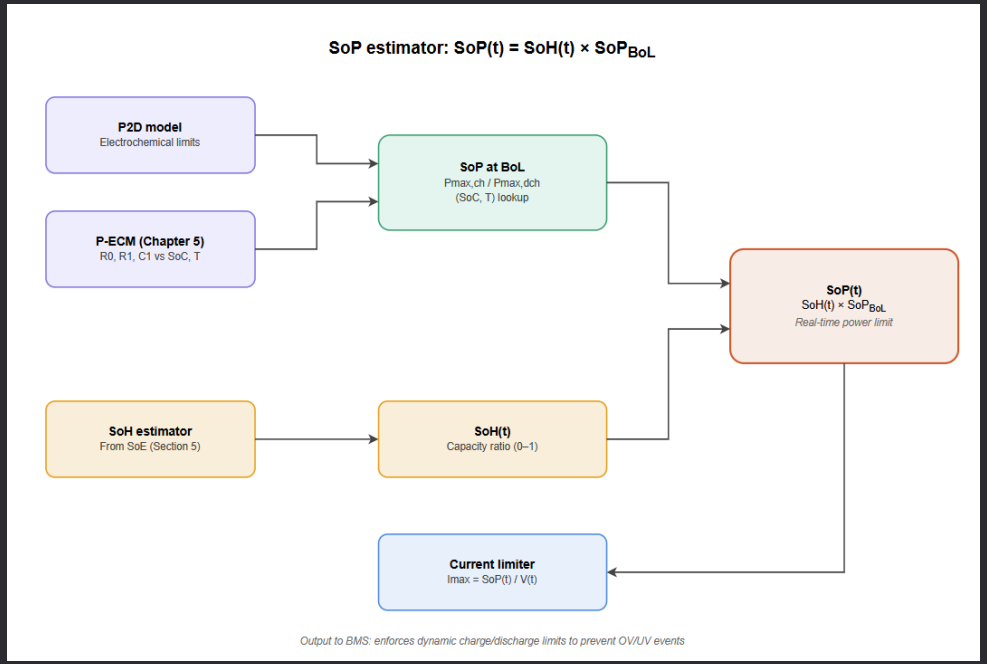
SoT Cell Core temperature filtered with a 10 points moving average

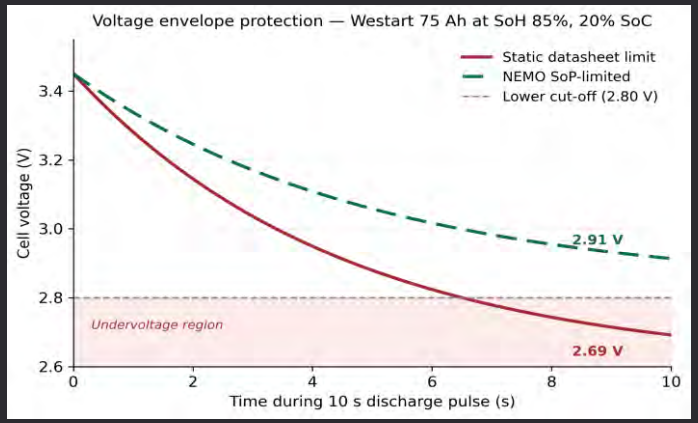
OLD SoT Parameters

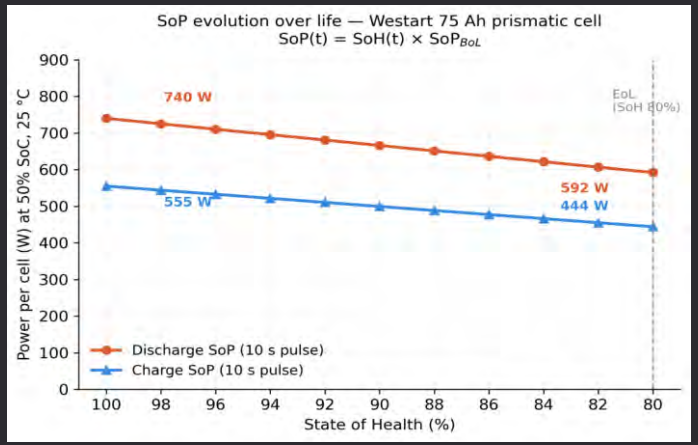
NEW SoT Parameters
(lower noise and higher precision)

SoH and SoP state-estimation algorithm (CSEM)

State of Power adaptation based on State of Heath of the cell (SOHR / DCIR) to make sure that cells avoid over-voltage and under-voltages during its lifecycle.







** Results based on simulation since the module is still under cycling at high SoH

NEMO zBMS/zBMS+ concept trade-offs

- Cost competitiveness of Cell Management System, one MCU per cell that makes the technology expensive against the State of the Art.
- Low-frequency points are slow to acquire
- Needs good Signal Noise Reduction and ADC resolution
- zBMS+ Switching board for active balancing shall be developed with the specific geometry of each module that makes the cost of module higher.
- Wireless communication in zBMS+ from CMSs transmits new voltages every 200ms, that might be insufficient for safety critical applications.
- Spectrum drifts with temperature and SoC
- Server costs of hosting in a database the whole lifecycle of each individual cell of a battery pack. Server/Master BMS computing power and data upload costs shall be considered too.

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