EMR'25, Lille (France)

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Canada Research Chair
in Efficient Electric Vehicles with Hybridized Energy Storage Systems
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« EMR-based Control of an Innovative off-road EV »

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1 Context

2 Modeling and control the EV system in EMR

3 Results and discussion

4 Conclusion and perspective

« Context »

Battery Electric Vehicles (BEVs)

The goal of **minimizing the environmental impact** of personal transportation for a sustainable transportation future.

Renewable energy

Zero CO_2

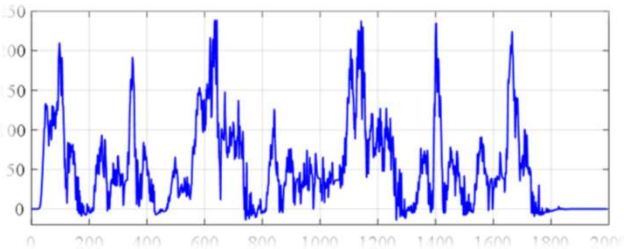
Pros

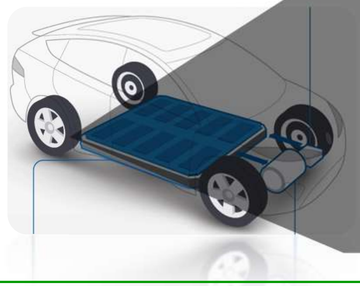
- Short driving range per charge
- Limited top speed
- Battery lifetime

Cons

- Zero emissions of carbon dioxide
- Oil independence
- High efficiency
- Reduced maintenance costs

Battery-only issue





Frequent charging/discharging

⇩

Aging rate increase

⇩

Short cycle life

Bat/SC hybrid energy storage system

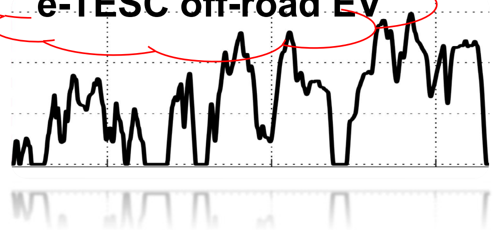
High energy density (Bat.) → Long driving range

AND

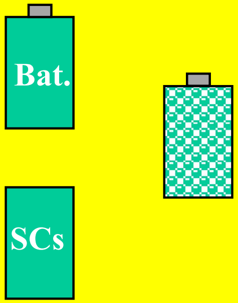
High power density (SCs) → Peak power during transient driving

Research GAP

e-TESC off-road EV



Hybrid energy storage system (HESS)



SCs reduces the high peak battery current

Extend the Bat. lifetime

Battery voltage drop reduction

Research GAP

Objectives and means of the study

- **Objectives:** Analyze the **impacts** of the **battery/SC HESS** on the **battery voltage** for **off-road applications**

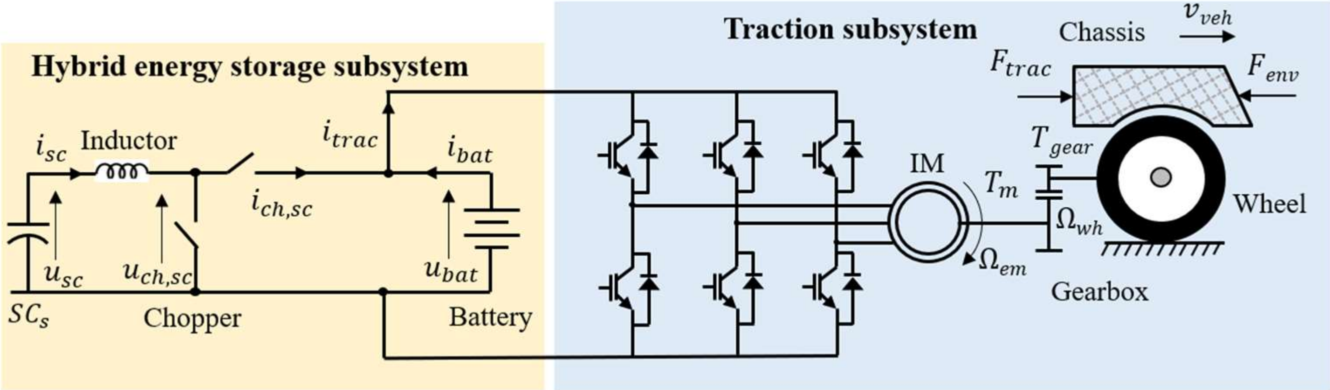
- **Tools:**
  - ✓EMR for modeling and control
  - ✓MATLAB/Simulink™

- **Steps:**
  - ✓Modeling and control using EMR
  - ✓Implement different scenarios (cut-off frequency and the SCs size)
  - ✓Evaluate battery voltage drop
  - ✓Evaluate frequent charge/discharge rate

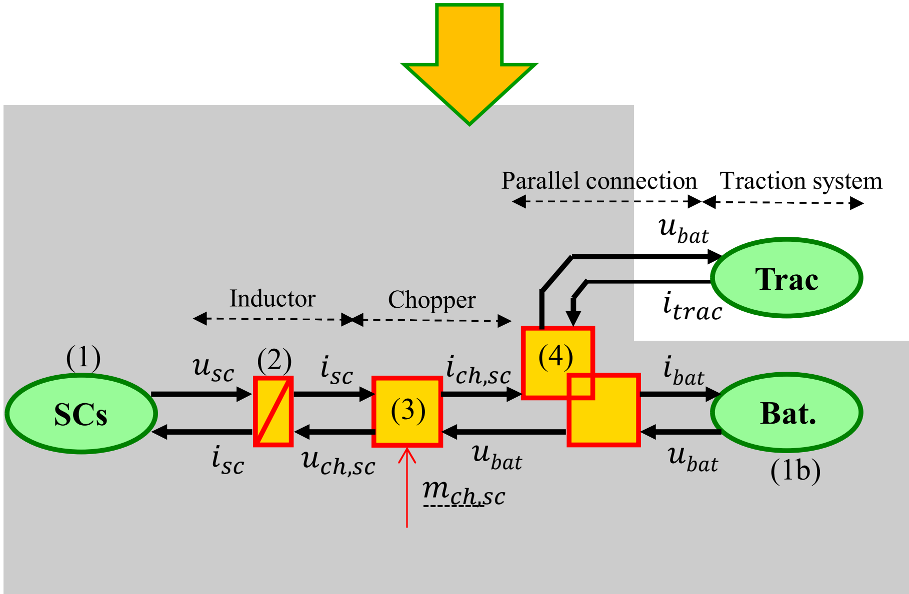
e-TESC 4WD platform

« Modeling and control the EV system in EMR »

Modeling the EV system in EMR



[Nguyen 2022]



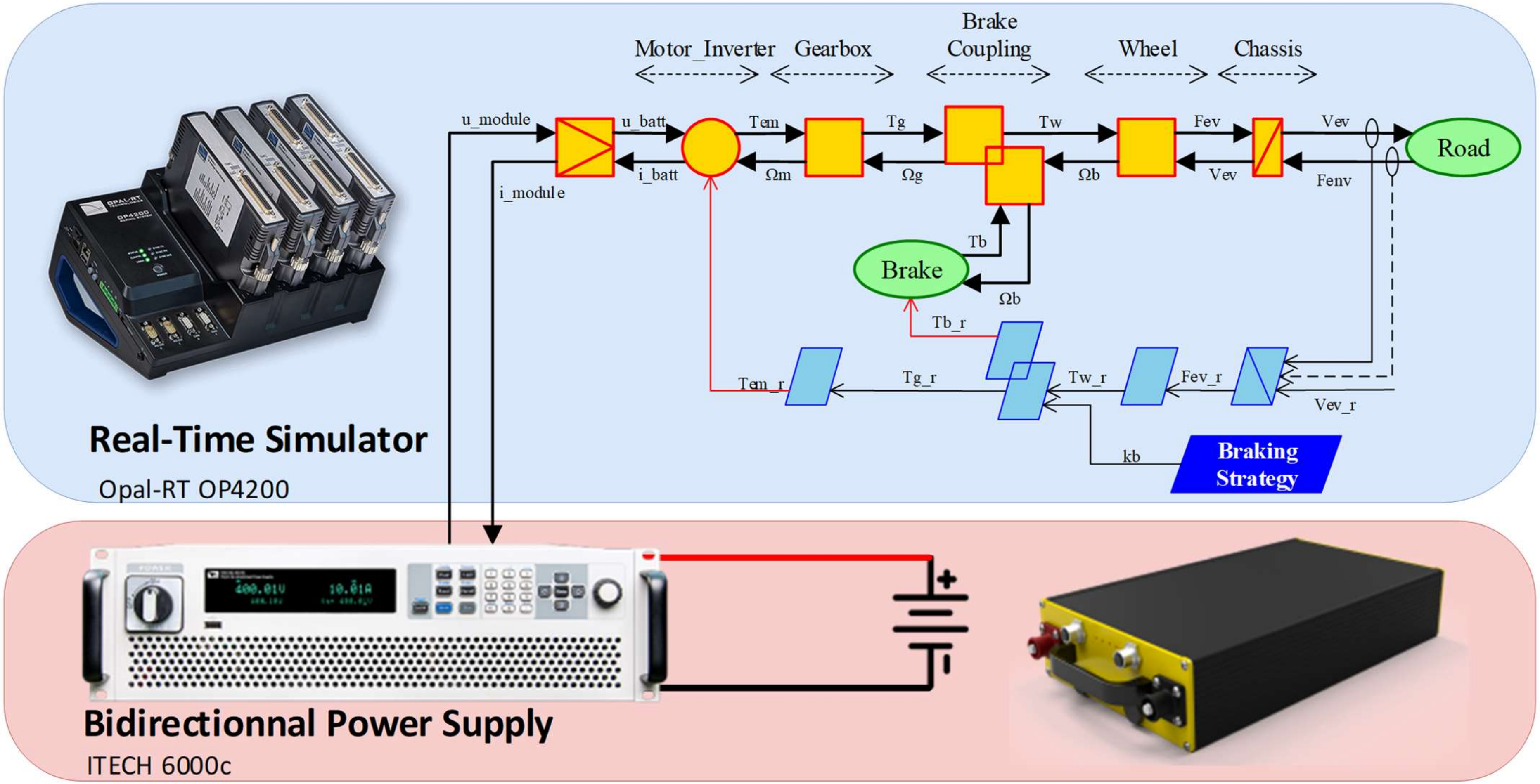
$$u_{SC} = u_{SC_{init}} - \frac{1}{C_{SC}} \int_0^t i_{SC}\, dt \quad (1)$$

$$u_{SC} = L\frac{d}{dt} i_{SC} + r_L i_{SC} + u_{ch,SC} \quad (2)$$

$$\begin{cases} u_{ch,SC} = m_{ch,SC} u_{bat} \\ i_{ch,SC} = m_{ch,SC} \eta_{ch,SC}^{k_{ch,SC}} i_{SC} \end{cases} \quad (3)$$

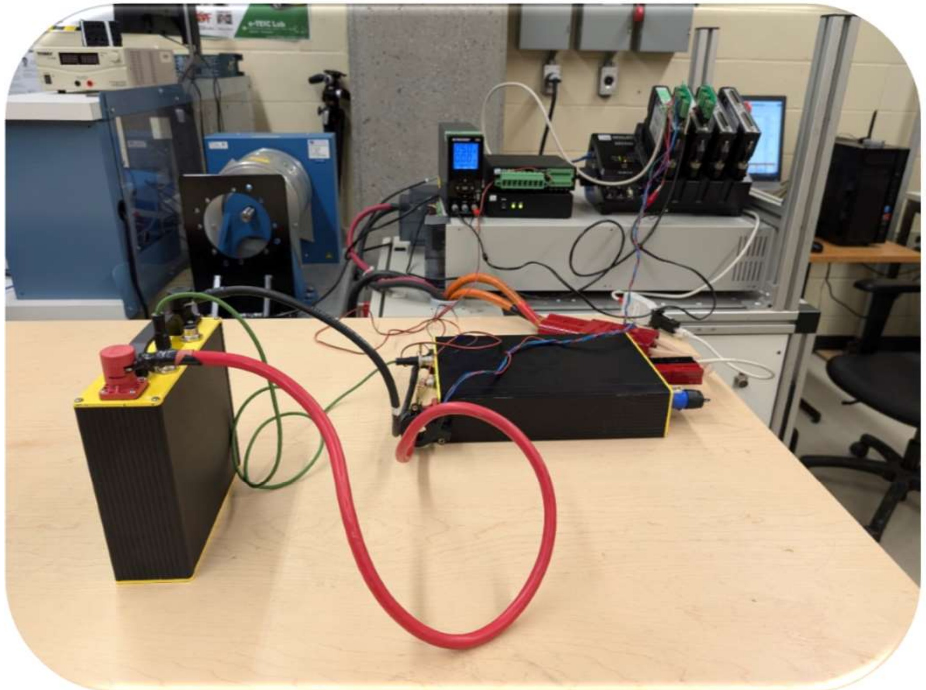
$$\begin{cases} u_{bat}\ common \\ i_{trac} = i_{bat} + i_{ch,SC} \end{cases} \quad (4)$$

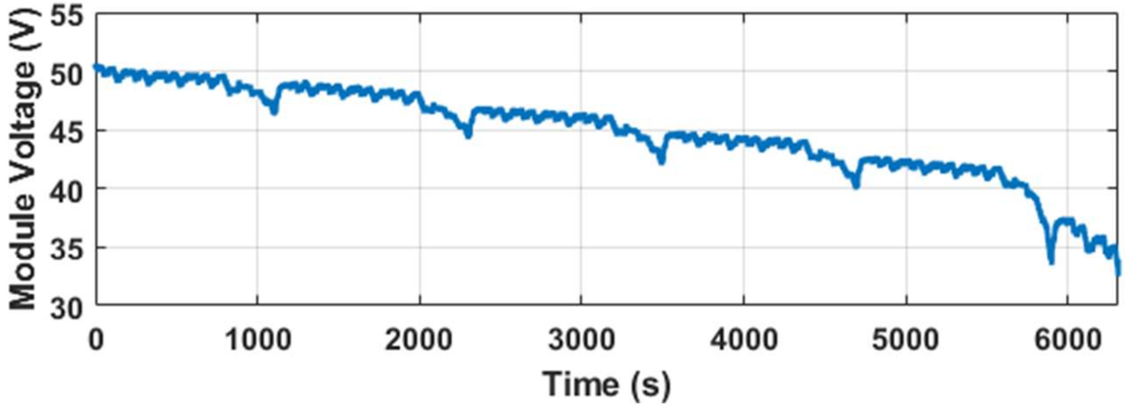
$$u_{batt} = u_{ocv} - i_{batt} R_{int} - \frac{R_1}{R_1 C_1 s + 1} i_{batt} \quad (1b)$$
$$u_{ocv} = f(SoC)$$

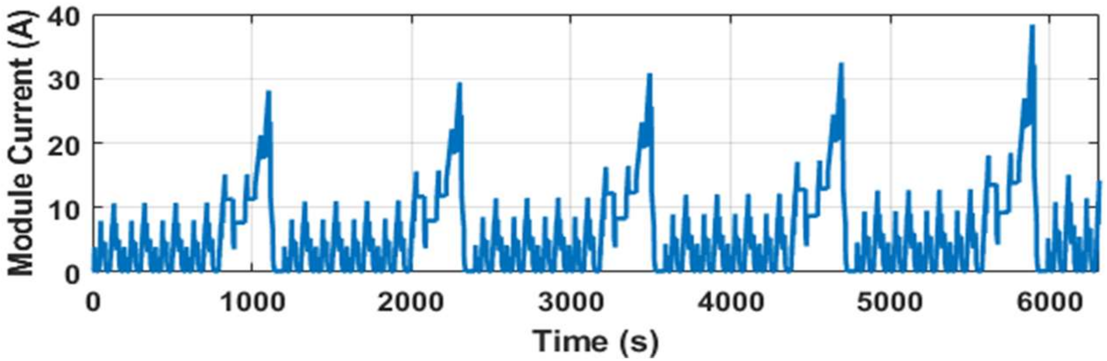


[Messier 2024]

1 Module



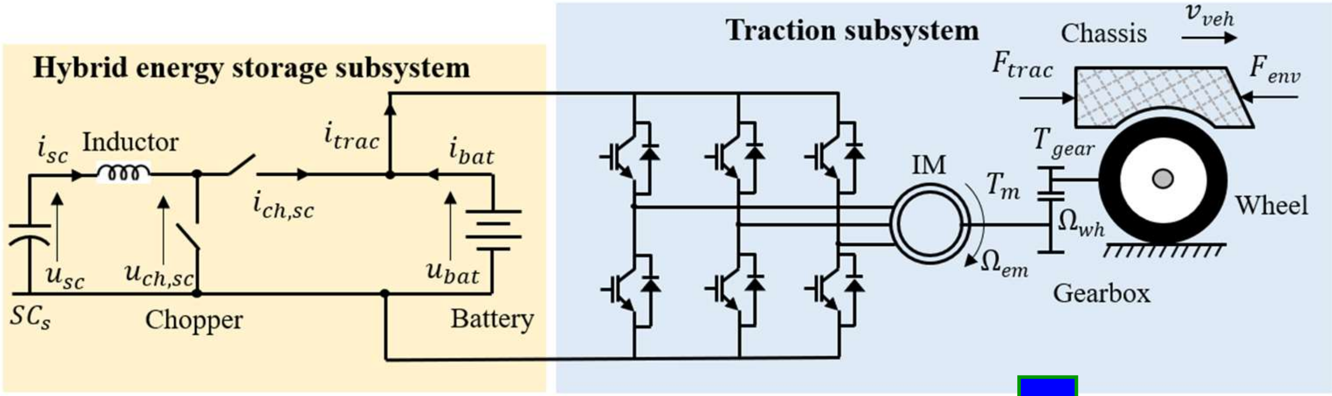

Module Voltage (V)
55
50
45
40
35
30
0
1000
2000
3000
4000
5000
6000
Time (s)

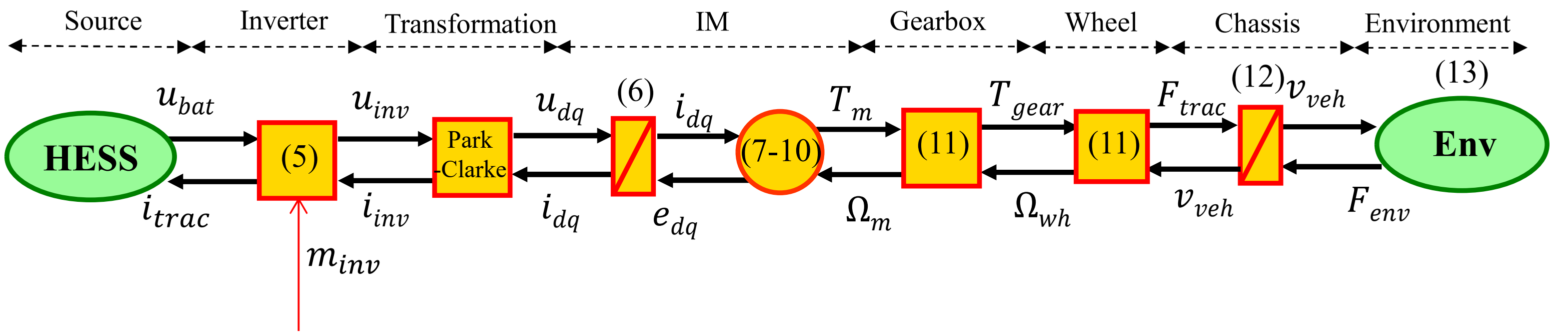

Module Current (A)
40
30
20
10
0
0
1000
2000
3000
4000
5000
6000
Time (s)

[LeBel 2022]

Modeling the EV system in EMR

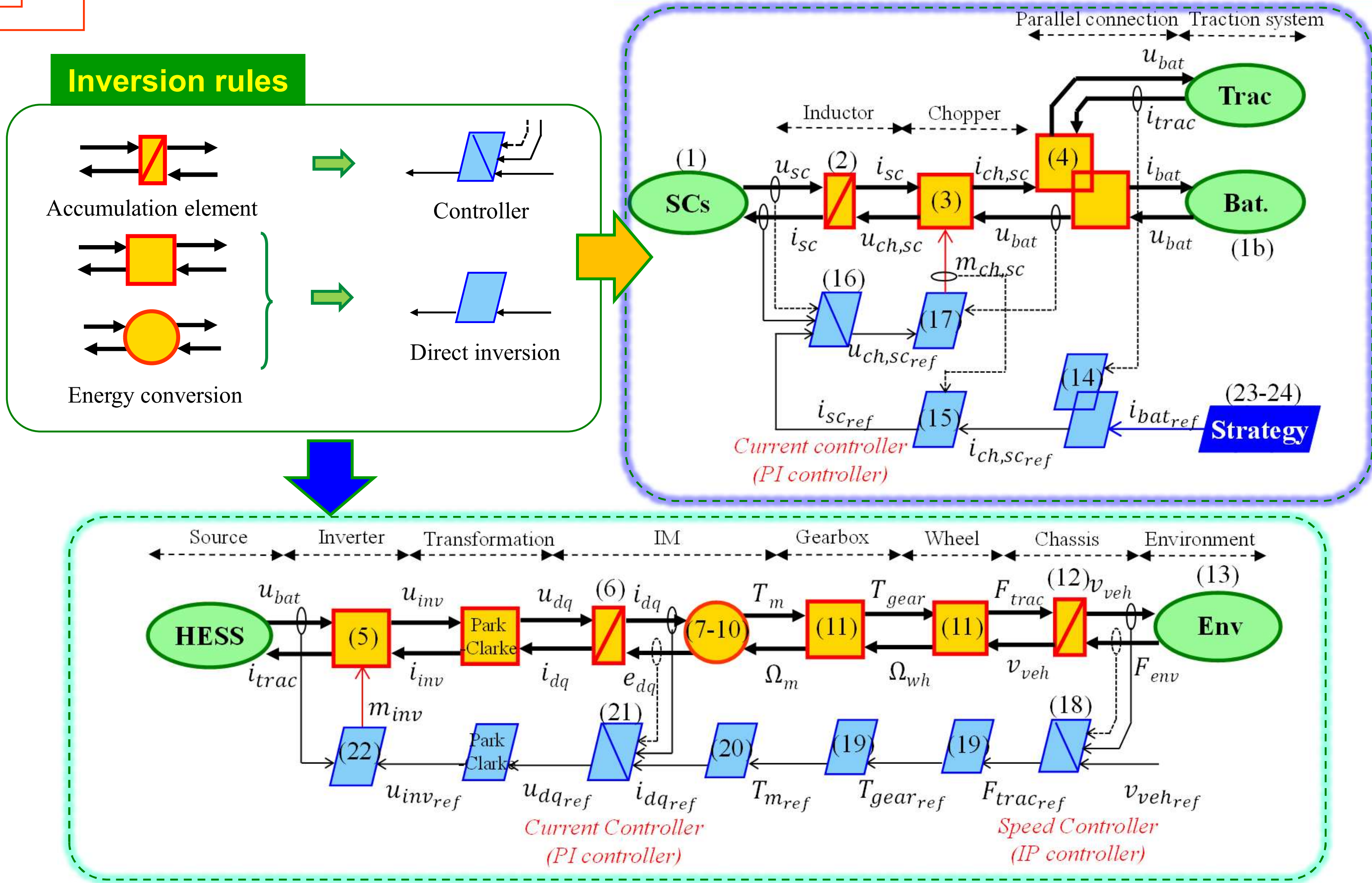
[Nguyen 2022]





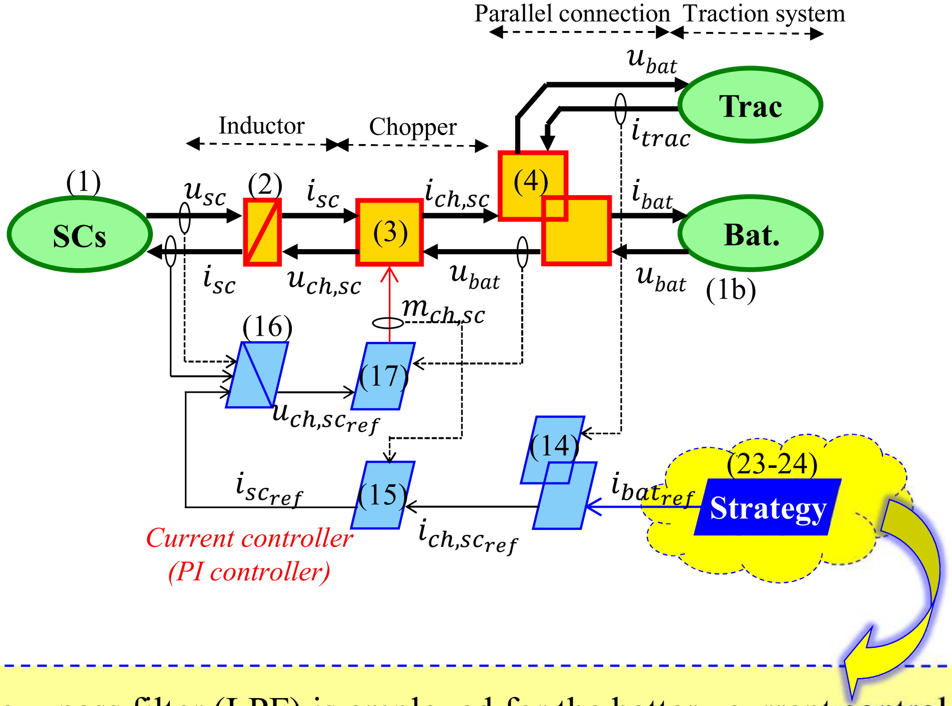
Inversion-based control

[Nguyen 2022]



Modeling the EV system in EMR

[Nguyen 2022]



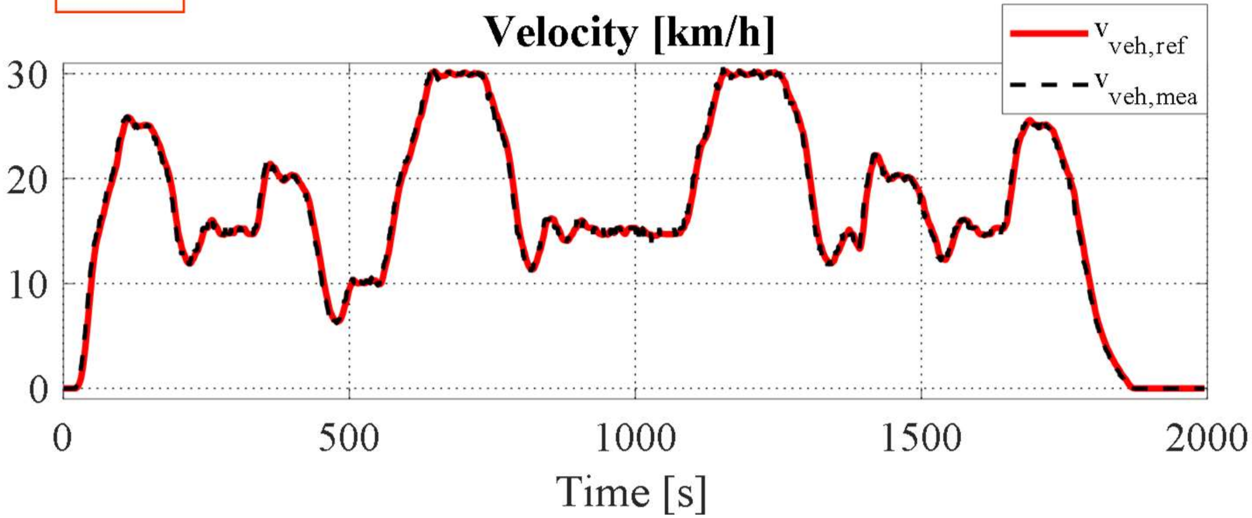
Low-pass filter (LPF) is employed for the battery current control

$$i_{bat_{ref}} = \frac{1}{\tau_{LPF}s+1} i_{trac_{mea}} \qquad (23)$$

τ_{LPF} is the time constant of the LPF and computed by

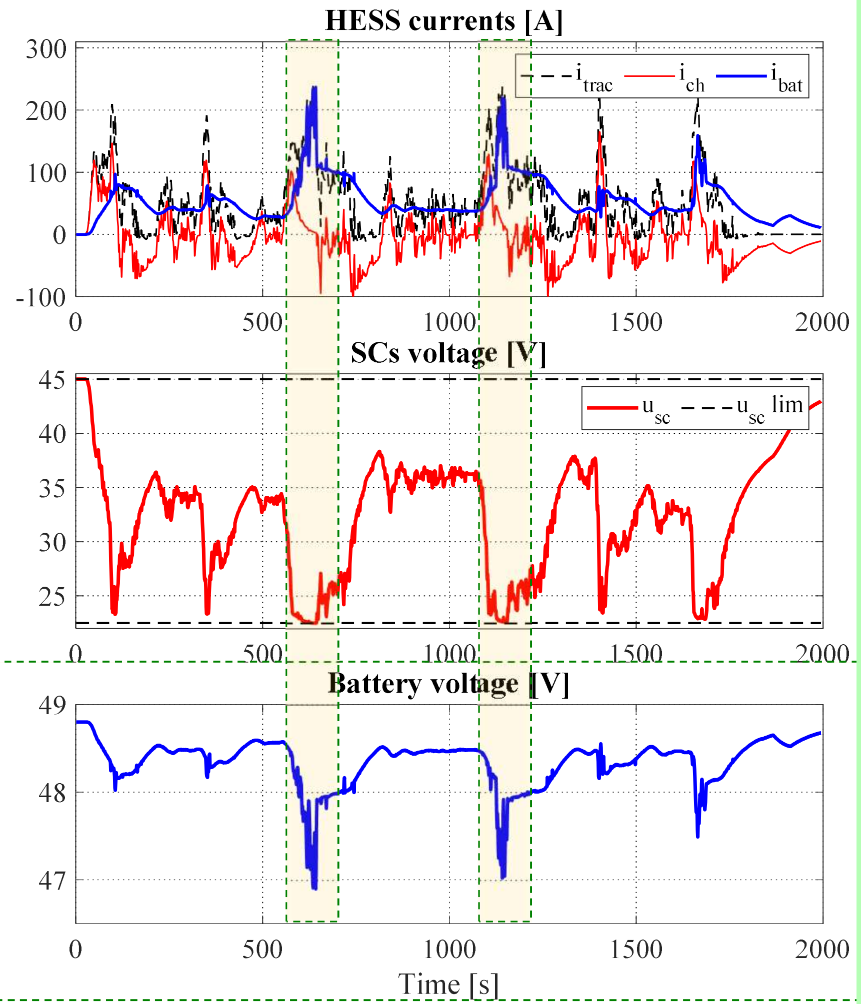
$$\tau_{LPF} = \frac{1}{2\pi f_c} \qquad (24)$$

« Results and discussion »



Battery (Lithium-ion LG Chem ICR2 cell)	
Cell capacitance	2500 mAh
Ns/Np	12/48
Maximum voltage	51 V
SCs (Maxwell BMOD0058 E016B02 modules)	
SCs module capacitance	58 F
SCs module nominal voltage	15 V
Ns/Np	3/3 or 3/6
DC-DC converter efficiency	95%

	Case 1	Case 2	Case 3	Case 4
f_c	20 mHz	20 mHz	40 mHz	40 mHz
SCs Sizing ($n_{se_{SC}}$ x $n_{pa_{SC}}$)	3 x 3	3 x 6	3 x 3	3 x 6



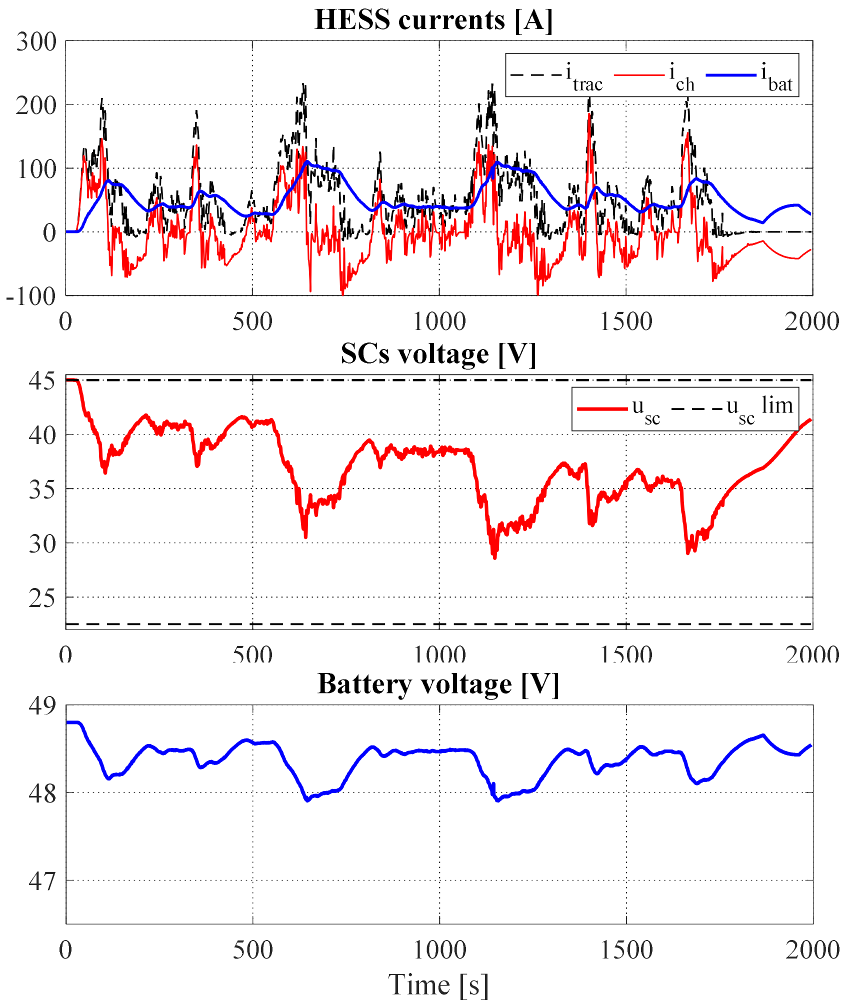
Case 1: f_c=20 mHz, $N_{SC_{ne}}$x$N_{SC_{pa}}$=3x3

$i_{ba\ rms}$ reduced by 12.5% compared to the sole battery source

At 635 s, and 1148 s, the SCs are completely discharged

The battery is used only

The battery current accordingly hits the peak of the traction current leading to corresponding large voltage drops



Case 2: f_c=20 mHz, $N_{SC_{ne}}$x$N_{SC_{pa}}$=3x6

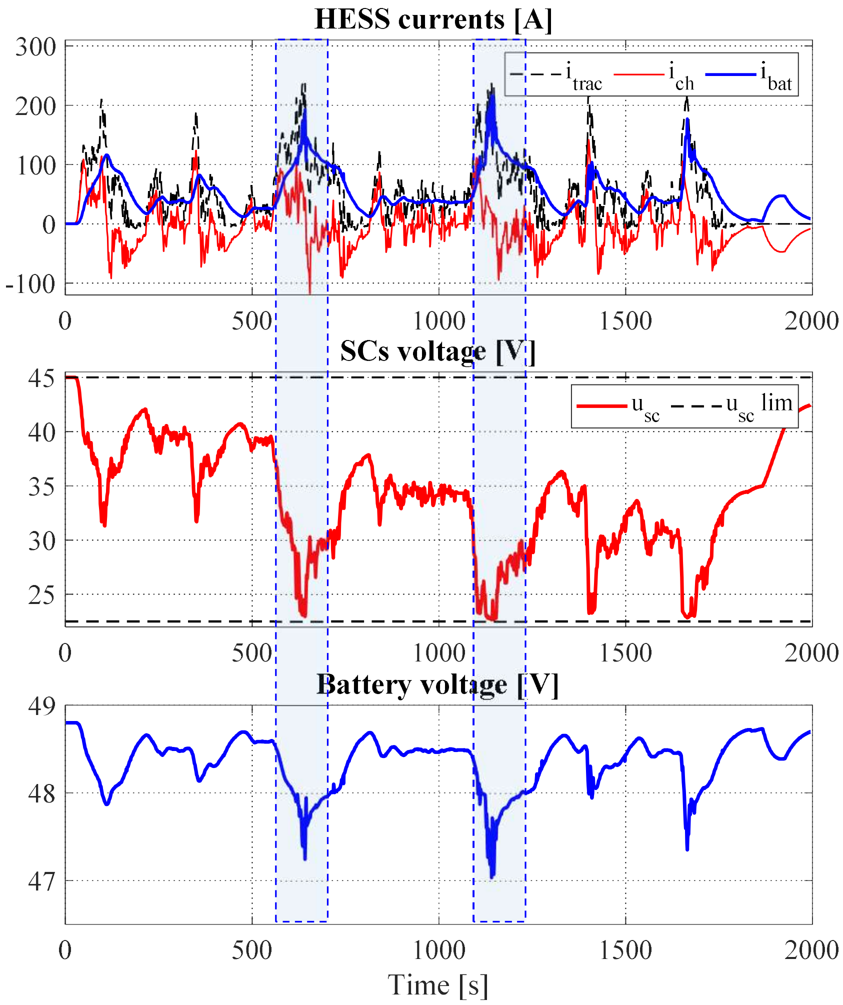
Increasing the number of parallel branches means a greater capacitance

Avoid the SC's potentially full charge or discharge

Peak currents in case 1 are eliminated

$i_{ba\ rms}$ is about 11% lower than case 1

$i_{ba\ max}$ reduced by 53.4%, Δu_{bat} increased by 52.6% compared to case 1



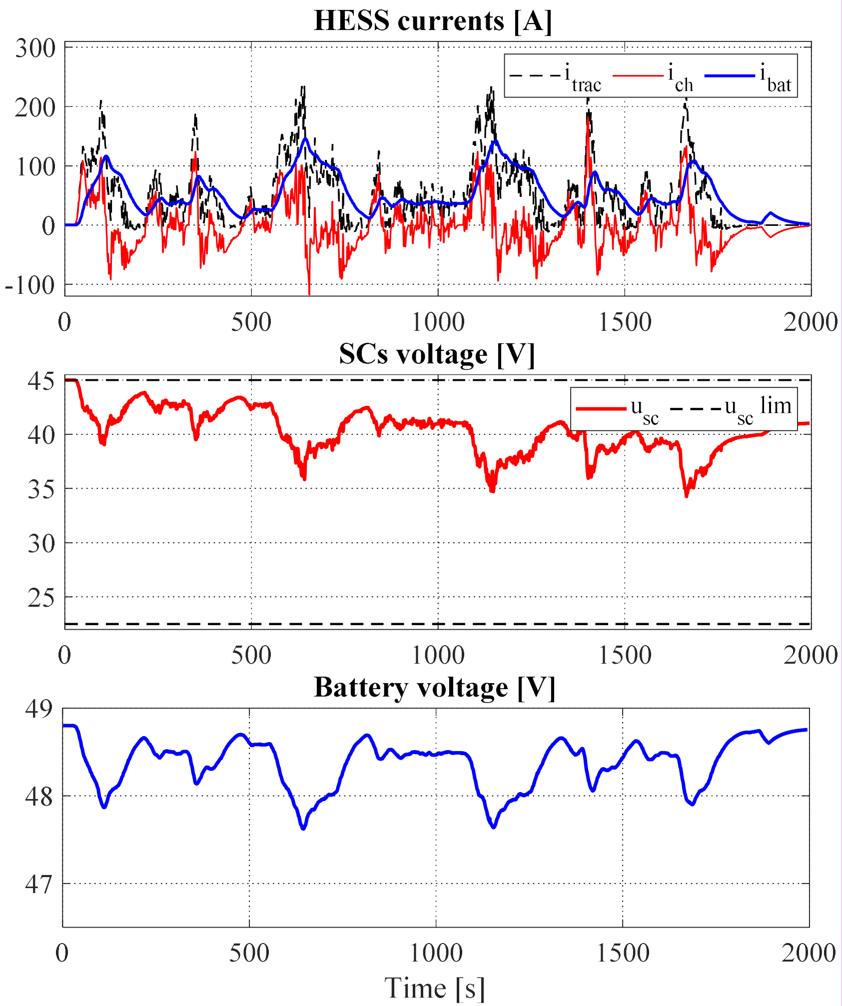
Case 3: f_c=40 mHz, $N_{SC_{ne}}$x$N_{SC_{pa}}$=3x3

$i_{bat_{rms}}$ reduced by 11.6% compared to battery-only storage

Higher cut-off frequency → higher-frequency fluctuations of the output battery current/voltage

Similar to case 1, when the SCs is fully discharged, the power demand will be supplied by the battery only

High battery voltage drops hence can appear



Case 4: f_c=40 mHz, $N_{SC_{ne}}$x$N_{SC_{pa}}$=3x6

Higher charging/discharging capability of the SCs

Remove the peak points in the battery current/voltage

The reduction of the peak point is about 32.8% for the battery current and 33.3% for the battery voltage drop compared to case 3

« Conclusions »

Summary

- **Off-road EV model** equipped with the **semi-active HESS** is developed by using **EMR**.
- Study **different** cases associated changes in the **cut-off frequency** and the **SCs size**.
- The peak current, the **voltage drops**, and current/**voltage** fluctuations of the battery are **evaluated**.
- With the **appropriate SCs** model and **cut-off frequency**, the **HESS** can **effectively** reduce and smooth the battery current/voltage

Future works

- Develop a **real-time algorithm** for optimal **energy management** in the HESS with predefined SCs sizing and considering it in the EMS development.

« Biographies and references »

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- References -

[Nguyen 2022] N. Chi T. P., B.-H. Nguyễn, J. P. F. Trovão and M. C. Ta, "Effect of Battery/Supercapacitor Hybrid Storage System on Battery Voltage in Electric Vehicles," 2022 IEEE Vehicle Power and Propulsion Conference (VPPC), Merced, CA, USA, 2022, pp. 1-6, doi: 10.1109/VPPC55846.2022.10003471.

[Bouscayrol 2023] A. Bouscayrol, B. Lemaire-Semail, "Energetic Macroscopic Representation and Inversion-Based Control ", Encyclopedia of electrical and electronic power engineering, Vol. 3, pp 365-375, Elsevier, DOI : 10.1016/B978-0-12-821204-2.00117-3, ISBN : 978-0-12-823211-8, 2023.

[LeBel 2022] Félix-A. LeBel, Pascal Messier, Ali Sari, João Pedro F. Trovão, "Lithium-ion cell equivalent circuit model identification by galvanostatic intermittent titration technique," Elsevier Journal of Energy Storage, Volume 54, 2022, 105303. doi: 10.1016/j.est.2022.105303.

[Messier 2024] P. Messier, M. Blanchard, F. -A. LeBel and J. P. F. Trovão, "Power-Hardware-In-The-Loop for Electric Vehicle Battery Validation," *2024 IEEE Vehicle Power and Propulsion Conference (VPPC)*, Washington, DC, USA, 2024, pp. 1-6, doi: 10.1109/VPPC63154.2024.10755361.

[Lenoir 2022] T. Lenoir, P. Messier, J. P. F. Trovão and F. -A. Lebel, "Passive Coupling of Batteries and Supercapacitors Based on Module-Scaled Models," *2022 IEEE Vehicle Power and Propulsion Conference (VPPC)*, Merced, CA, USA, 2022, pp. 1-6, doi: 10.1109/VPPC55846.2022.10003348.

Thanks for your attention !