

E-mobility in Canada and Portugal, case of an Innovative off-road EV

Challenges and Opportunities for Next-Generation Electric Vehicle Engineers



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Canada Research Chair

In Efficient Electric Vehicles with a Hybridized
Energy Storage Systems



Université de
Sherbrooke

Université de Sherbrooke, Canada

Cold-Climate EV & Traction Drives & HESS
Control & BMS Aging

INESCC
Institute for Systems Engineering
and Computers at Coimbra

**Coimbra Institute
of Engineering**
Polytechnic University of Coimbra

INESC Coimbra

Polytechnic University of Coimbra, Portugal

Fleet Management & Smart Infrastructure & V2G &
Battery Aging

Presentation Outline & Strategic Roadmap

Navigating Regional Transitions, Cold-Climate Control, and Future Engineering Horizons

1



Part I: Regional E-Mobility Realities (Canada & Portugal)

- Contrast cold-climate vast territory challenges against dense urban smart-grid infrastructure.

2



Part II: Comparative Diagnostic Analysis

- Side-by-side regional matrix:
 - Climate
 - Charging topography
 - Grid synergy
 - BMS priorities

3



Part III: Case Study – The Off-Road e-Commander

- Subzero battery dynamics
 - Electro-thermal self-heating
 - EMR modeling
 - Optimal flux-weakening
 - HESS peak shaving

4



Part IV: Real Opportunities for Future Engineers

- Core technical focus areas:
 - Electro-thermal BMS
 - SiC/GaN power electronics
 - Smart grid integration
 - Global research networks

1

2

3

4





E-Mobility in Canada: Electrifying the World's Second-Largest Country

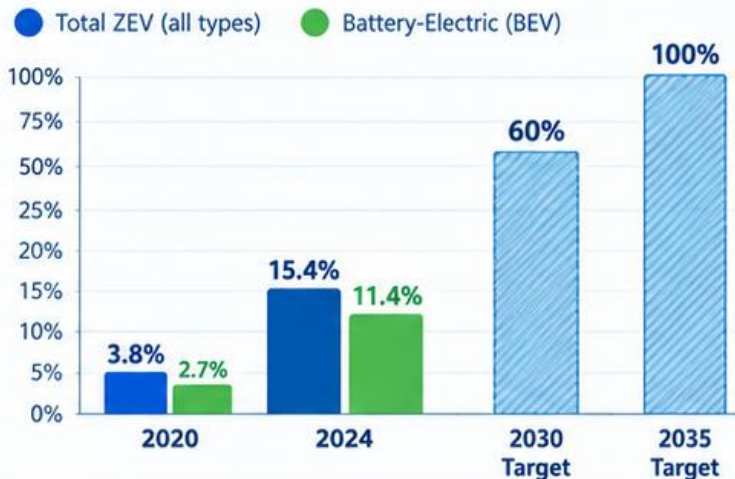
1 Geographic & Climatic Realities



EV driving range loss
-14% to -39%
Due to slowed battery electrochemistry and high cabin heating loads

2 Rapid Adoption & Policy Targets

ZEV Market Share in Canada

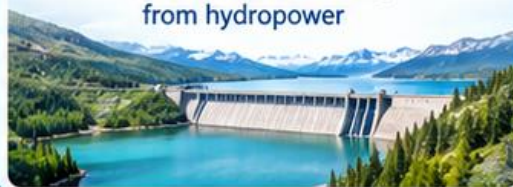


Public chargers
38,364
in 2025
(projected 39,220 by March 2026)

Federal targets
60% ZEV sales by 2030
100% light-duty sales by 2035

3 Clean Energy & Mineral Resources

Clean Grid
~60%
of Canada's electricity from hydropower



Critical Minerals
\$49.4B
in exports (2025)
Across the battery value chain





E-Mobility in Portugal: Rapid Adoption & Energy Management Focus



Market Penetration (ZEVs – BEVs + PHEVs)



~34%
of new vehicle
registrations in 2025



Charging Infrastructure

12,860+
public charging points
(2,600+ fast chargers)



~118
points per 100 km
of road



160
points per 100,000
inhabitants



Charging Activity Surge



6.4+ million
public charging sessions
Jan – Sep 2025

+48%
vs. 2024

Full Vehicle Energy Flow & Regenerative Recovery



Battery Output
100%
(DC)



Electric Drive System Losses
(motor + inverter)
16%



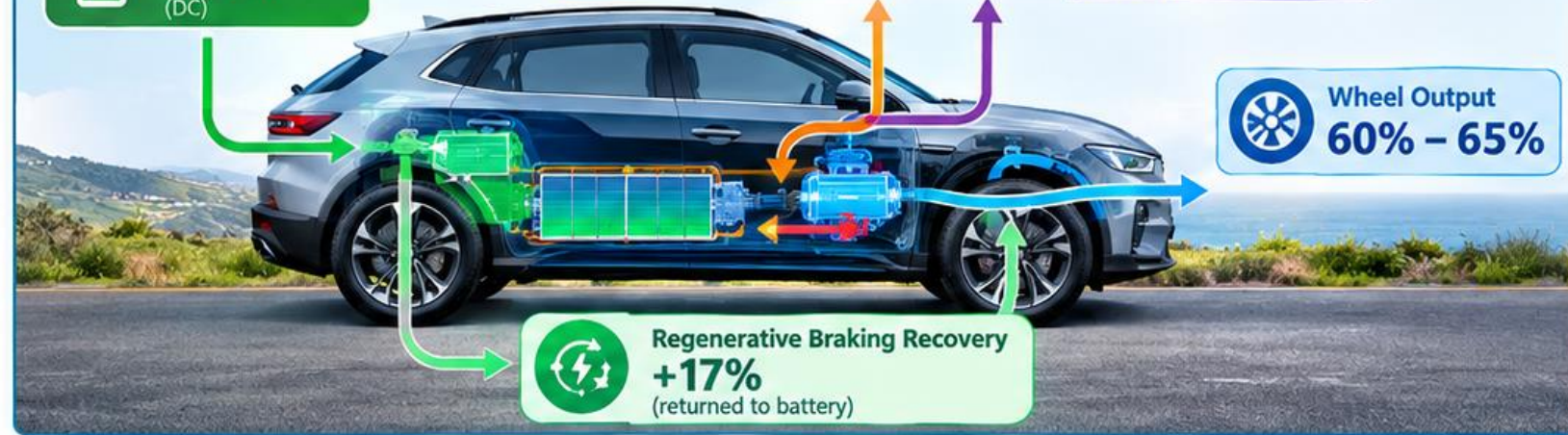
Auxiliary & Climate Loads
(HVAC, electronics, etc.)
2.5%



Wheel Output
60% – 65%



Regenerative Braking Recovery
+17%
(returned to battery)



Energy Management Systems (EMS)



Goal
Maximize driving range per charge



Key Strategies

- Optimize motor/inverter power allocation
- Harvest ~17% of kinetic energy via regenerative braking



Battery Management Systems (BMS)

- Prevent capacity fade
- Manage fast-charging thermal stress
- Handle cycling and aging



Higher Charger Density

Increased Charging Activity

Smarter Energy Management

A More Sustainable Future



Portugal driving
the clean energy transition



Comparative Analysis: Regional Realities & Engineering Opportunities

Two regions. Different climates.
Shared goal: sustainable and
resilient e-mobility.



CANADA



Climate & Battery Aging

Temperature impact on battery performance and lifetime.



SUBZERO
< -30°C

- Increases internal cell resistance
- Reduces available power
- High heating draws



Grid & Infrastructure Topography

Charging network density, remote access and grid integration.



CORRIDOR
5,514 km (east-west)

- Remote fast-charging stations
- Local renewable buffering
- Large distances & sparse population



Renewable Grid Synergy

Clean energy mix and grid integration.



HYDROPOWER
~60%

- Stable and reliable supply
- Supports electrification
- Low carbon footprint



Primary BMS Challenge

Battery management system focus area.



COLD RESISTANCE

- Internal resistance growth
- Heating energy demand
- Power limitation at low T°



PORTUGAL



WARM
15-35°C

- Fast-charging thermal management
- Accelerates cell degradation
- Requires cooling strategies



MESH
118 chargers / 100 km

- Dense urban network
- Smart-grid load balancing
- Peak-shaving strategies



WIND / SOLAR
High integration

- Variable generation
- Requires grid flexibility
- Storage and smart management



FAST-CHARGE DEGRADATION

- Thermal stress management
- Mitigate cell degradation
- Optimize charging profiles



Different conditions. Complementary strengths. Shared engineering solutions.



Batteries are like humans...

Different personalities. Same basic needs. Handle them well for a longer, healthier life.



Cleaner Energy.
Smarter Systems.
Greater Impact.

Just like humans, batteries...



Hate being **OVERCHARGED**

Excessive voltage accelerates degradation and can be unsafe.



Are sensitive to **EXTERNAL PRESSURE**

Mechanical stress can damage cells and reduce performance.



Don't like **TEMPERATURE EXTREMES**

Too hot or too cold speeds up aging and reduces capacity.



Are **DIVERSE** in chemistry, size, and shape

Different batteries have different strengths and limitations.



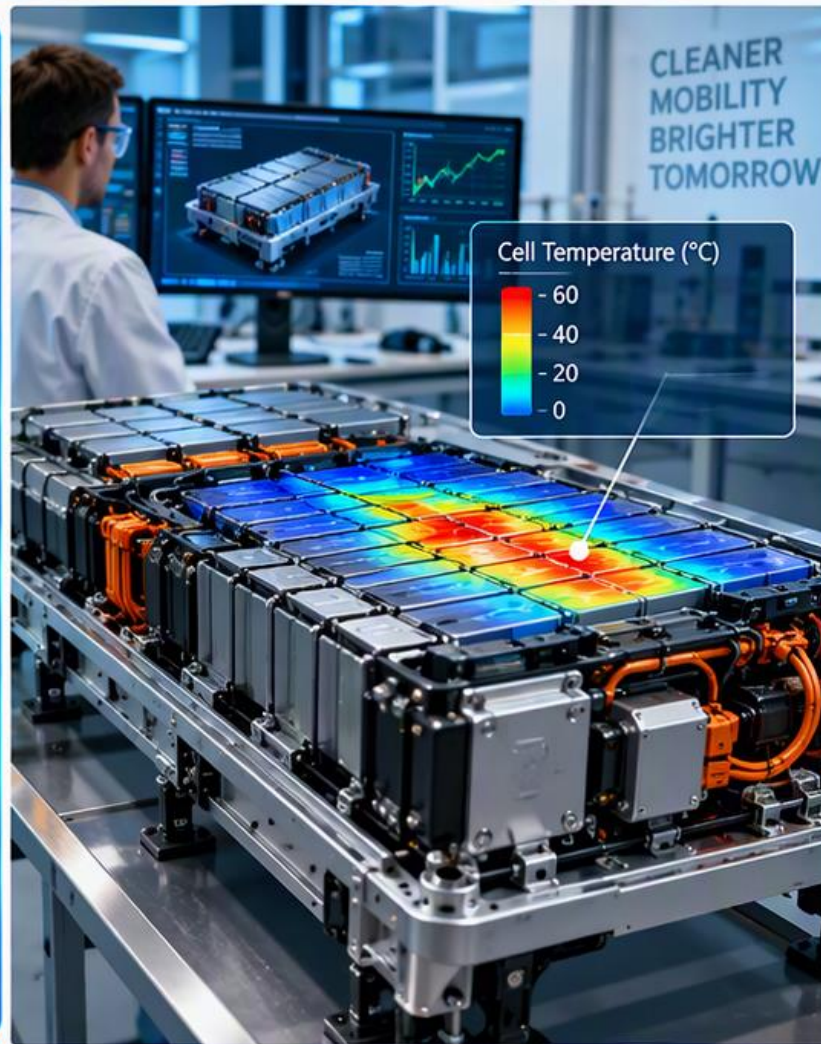
Are statistically **DEFECTIVE**

A small percentage will fail, even when well made.



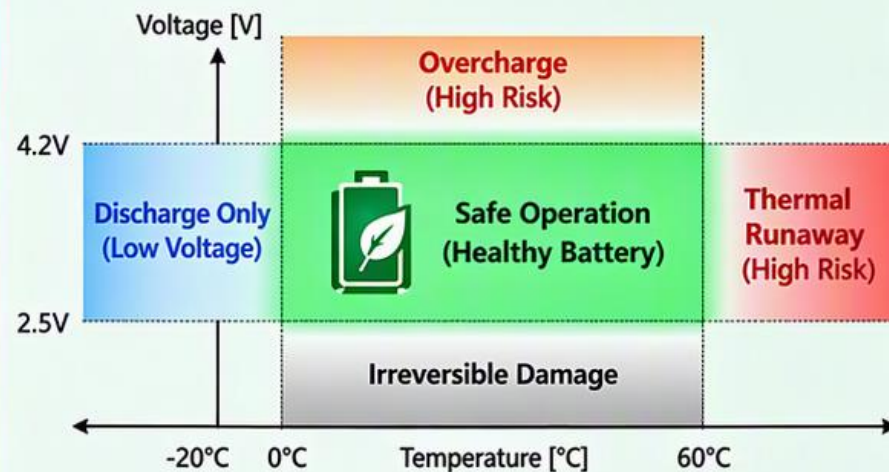
All cells must **DIE** someday...

They age over time and lose their ability to store energy.



The Battery Comfort Zone

Keep batteries within their safe operating window for reliable, long-lasting performance.



Treat them well and they'll take you further.



Use proper charging limits



Manage temperature



Minimize mechanical stress



Choose the right chemistry for your application



Cleaner Planet



Innovative Technology



Skilled Engineers



A Sustainable Tomorrow



Energy
for a Better
Tomorrow



Case Study: Off-Road e-Commander EV in Cold Environments

1 Vehicle Platform Architecture

e-TESC Lab 4WD e-Commander
(Total mass: 857 kg)

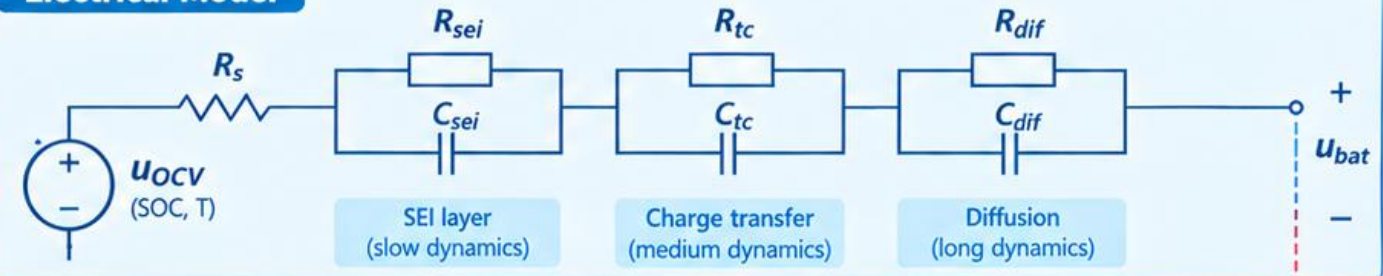


 **48 V**
8 kW
Induction Machine (IM)

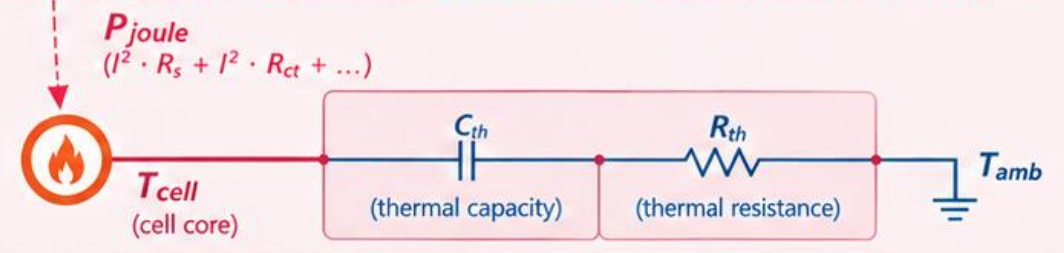
 **5.79 kWh**
Li-ion Battery Pack
(12S48P LG Chem ICR2 cells)

2 Electro-Thermal Battery Equivalent Circuit Model (ECM)

Electrical Model



Thermal Model



3 Key Data & Parameters


857 kg
Total mass
(e-Commander)

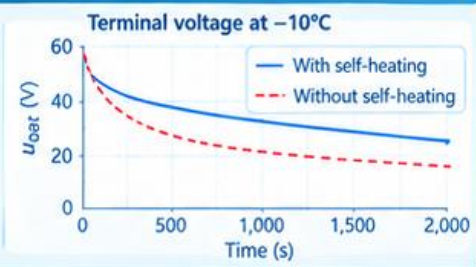

48 V • 8 kW
Induction Machine
(IM)


5.79 kWh
Li-ion Battery Pack
(12S48P LG Chem ICR2)

4 Subzero Battery Behavior

 **-10°C**
Operating temperature

- R_s increases significantly
- Severe terminal voltage drops (u_{bat}) under heavy current demand



5 Electro-Thermal Self-Heating Effect

 **+1.8°C**
Cell core temperature rise
(at -10°C)

- Increases pack voltage slightly
- Postpones inverter voltage saturation beyond 1,200 s

6 Video Demonstrations



- ✓ 4WD off-road dynamic maneuvers in deep snow
- ✓ Real-time telemetry
 - u_{bat}
 - i_{bat}
 - cell temperature rise



REAL-WORLD CONDITIONS + ADVANCED MODELLING + SMART ENERGY MANAGEMENT = RELIABLE E-MOBILITY IN EXTREME CLIMATES

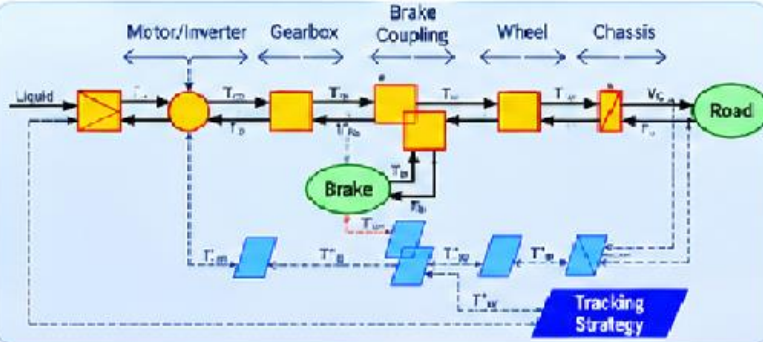


Single-Module EMR Powertrain Modeling, HIL Simulation & Experimental Validation

From real-time control to real-world performance — all in one integrated platform

A

EMR Control Synoptic (Powertrain Chain + Control)



B

Hardware & HIL Setup (Opal-RT + Power Supply)



Opal-RT
Real-Time Simulator



Bidirectional Power Supply
ITECH 6000c



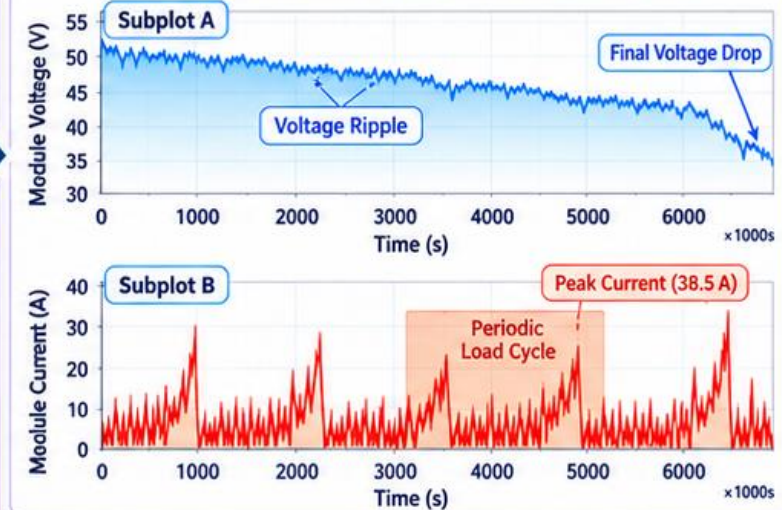
EMR Module
(1 Module)

C

Experimental Validation (Voltage & Current)



MODULE ELECTRICAL PERFORMANCE ANALYSIS



A

EMR Control Synoptic (Powertrain Chain + Control)



- ✓ Models the physical drivetrain from motor/inverter, gearbox, brake coupling, wheel, and chassis to the road interface.
- ✓ Driven by an integrated EMR control structure with a unified braking strategy.



B

Hardware & HIL Setup (Opal-RT + Power Supply)



Emulates a single battery module using an Opal-RT OP4200 Real-Time Simulator coupled with an ITECH 6000c Bidirectional Power Supply.



C

Experimental Validation (Voltage & Current)



Validates real-time performance over a 6,000-second dynamic test cycle, capturing real-time battery module discharge (Voltage drop from 50 V to ~35 V) and transient current demands (peaking near 40 A).



Higher Accuracy



Real-Time Control



Scalable Architecture



Reliable Validation



Accelerated Development

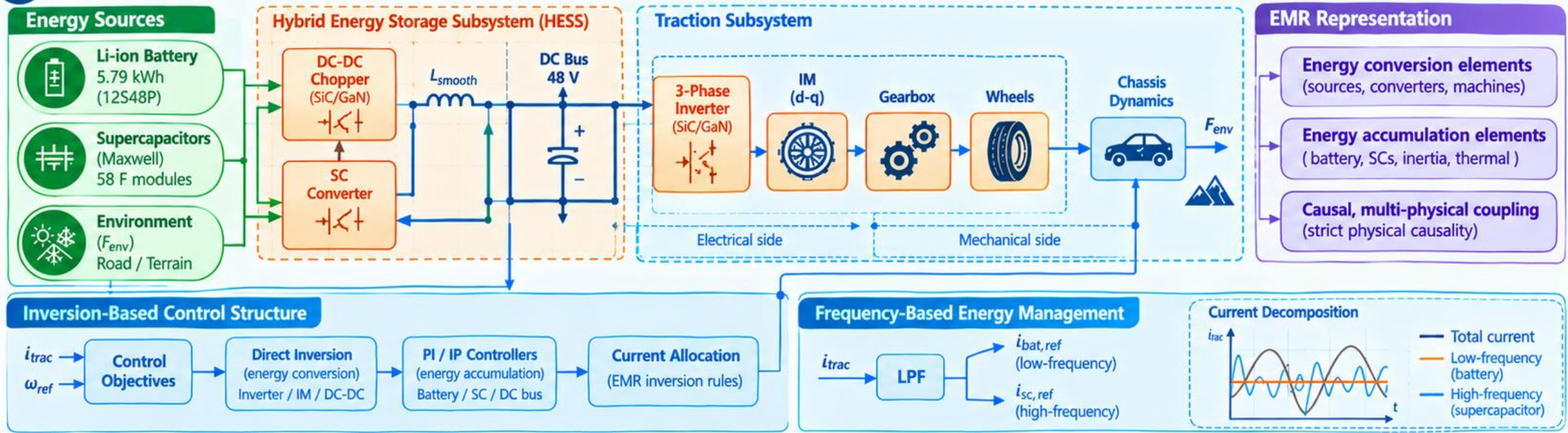


EMR Modeling & Inversion-Based Control Architecture

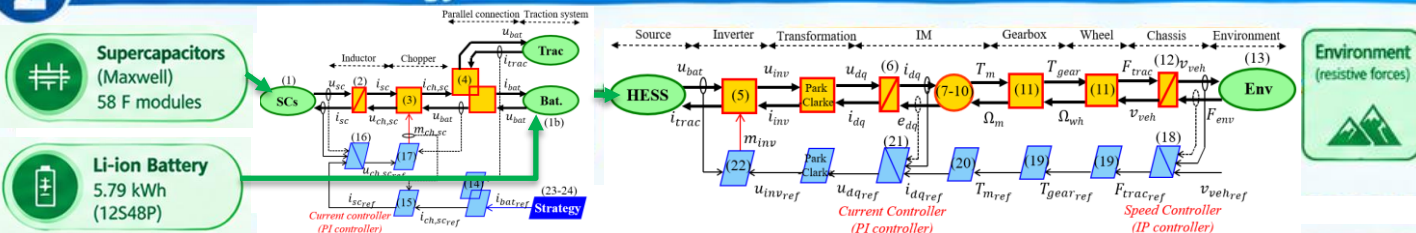


e-TESC 4WD
Total mass: 857 kg
48 V / 8 kW IM
5.79 kWh (12S48P)
+ Maxwell SCs (58 F)

1 EMR Synoptic Diagram (Physical System Model)



2 EMR Elements & Energy Flow



3 Key Control & EMS Features

- ✓ EMR formalism with strict causality
- ✓ Direct inversion control architecture
- ✓ LPF-based current allocation (f_c adjustable)
- ✓ HESS with semi-active DC-DC converter
- ✓ Optimal energy distribution & efficiency

4 Benefits

- ⚡ **Lower peak currents** (→ longer battery life)
- 🛡️ **Improved energy efficiency** (→ reduced losses)
- ❄️ **Robust performance** (including cold conditions)



EMR + Inversion =

Systematic | Physics-based | Optimal Control



Toward Smarter, Cleaner,
More Resilient E-Mobility



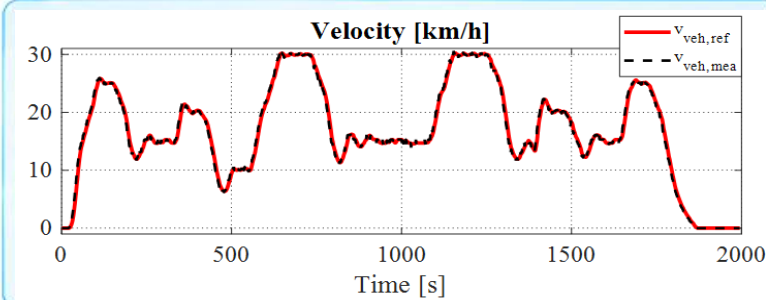
e-TESC 4WD Platform
Real-World Validation

Hybrid Energy Storage System (HESS) Sizing & Performance Comparison



Cleaner Energy.
Smarter Fleets.
Longer Batteries.

1 Hardware & Test Setup



System Components & Specifications



Battery Pack (LG Chem ICR2)

- 2,500 mAh (cell)
- 12/48 Ns/Np
- 51 V (max voltage)



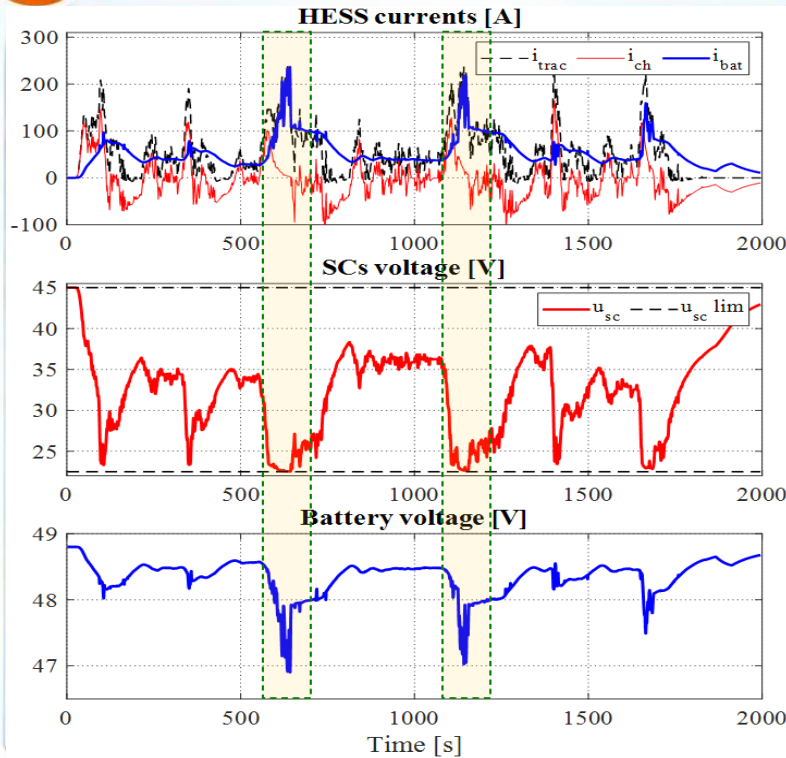
Supercapacitors (Maxwell BMOD0058)

- 58 F (module)
- 15 V (nominal)
- 95% efficient DC-DC converter

HESS Case Study Matrix

Parameter	Case 1 (3 × 3 SC)	Case 2 (3 × 6 SC)
SC Matrix	3 × 3	3 × 6
Switching frequency (f_c)	20 mHz	20 mHz
Total SC capacitance	Baseline	2× (higher)
Performance focus	RMS current reduction & depletion events	Peak current elimination & smoother response

2 Case 1: 3 × 3 SC Array ($f_c = 20$ mHz)



Key Performance (Case 1)

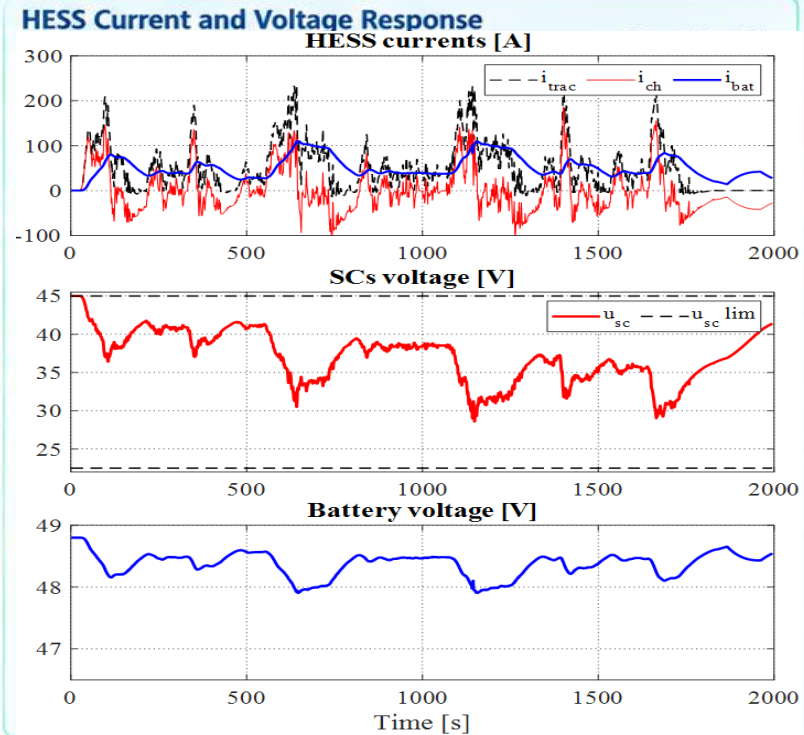
↓ 12.5%
reduction in $i_{bat,rms}$
(compared to battery-only)

⚠ SC Depletion Events

- 635 s: SCs reach 100%
- 1,148 s: SCs reach 100%

→ Battery handles full peak traction current alone → steep voltage drops.

3 Case 2: 3 × 6 SC Array ($f_c = 20$ mHz)



Key Performance (Case 2)

-53.4%
peak battery current
(compared to Case 1)

-11%
 $i_{bat,rms}$
(compared to Case 1)

+52.6%
 Δu_{bat} (battery voltage variation)
(compared to Case 1)

✓ No SC depletion or overcharging.

Peak currents eliminated.

Smoother battery response.



Optimized Hybrid Storage



Improved Battery Health



Higher Efficiency



Sustainable Mobility

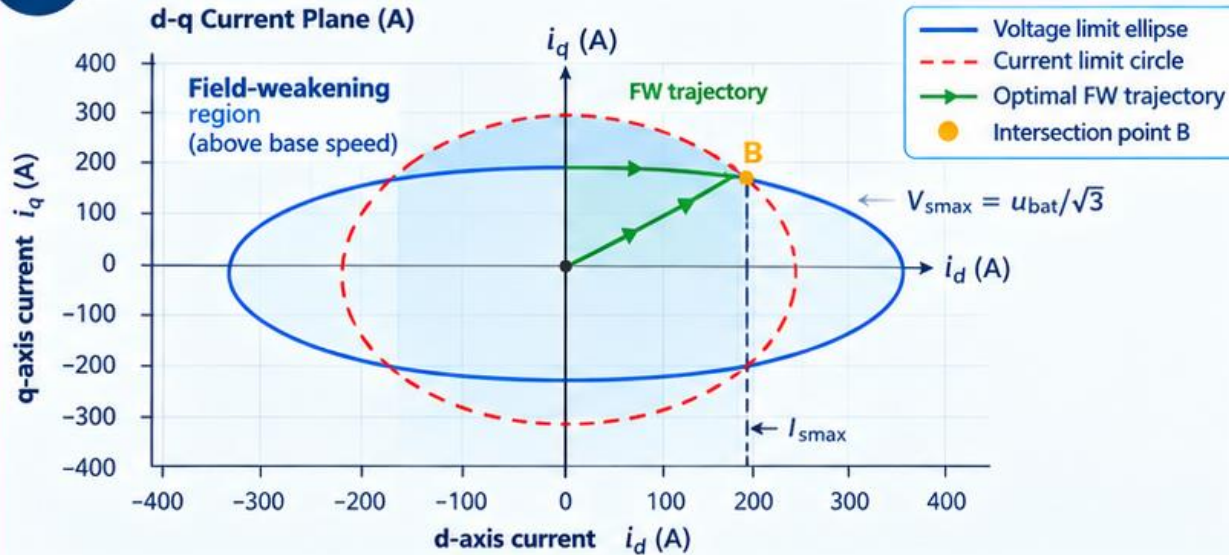


Advanced Control: EMR Formalism, Optimal Flux-Weakening & HESS

More range.
Better efficiency.
Stronger protection.



1 Optimal Flux-Weakening (FW) Strategy



Key Concepts

- 1 Voltage Limit**
Inverter voltage constraint:
 $V_{smax} = \frac{u_{bat}}{\sqrt{3}}$
- 2 Current Limit**
Maximum stator current: I_{smax}
- 3 Optimal Point (B)**
Intersection of voltage ellipse and current circle
→ optimal (i_d^*, i_q^*) references
- 4 Result**
 - Operation above base speed
 - Maximum torque under voltage limits
 - Improved efficiency

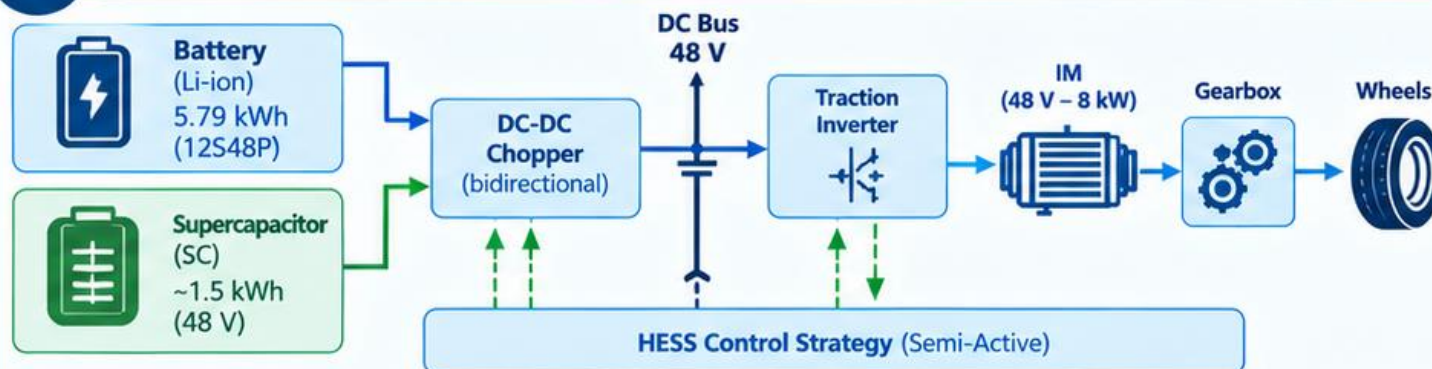
Optimal FW Trajectory

i_d^* (negative)
 i_q^* (positive, reduced)

Benefits

- ✓ Higher top speed
- ✓ Maintains torque capability
- ✓ Efficient use of DC bus voltage

2 Semi-Active HESS (Battery + Supercapacitors)



Performance Improvement

Peak Battery Current
↓ 53.4%
(i_{bat_max})

Voltage Drop Smoothing
↓ 52.6%
(Δu_{bat})



Why It Matters

Protects the Li-ion battery during cold and high-torque maneuvers.



Main Control Actions

- Allocate high power peaks to SCs
- Limit battery current
- Maintain DC bus stability



Result

Better efficiency | Longer battery life
Improved vehicle performance

Real Opportunities for Future Engineers & Final Takeaways

Innovative Technologies

Global Collaboration

A Sustainable Future



Cleaner Energy.
Smarter Systems.
Greater Impact.

1 Thermal & Battery Engineering



Temperature-dependent electro-thermal BMS models



Active pre-heating systems



Cold-climate fast-charging algorithms



e-Commander (4WD)

857 kg | 48 V / 8 kW | |
5.79 kWh (12S48P) Li-ion | 58 F Maxwell SCs

2 Power Electronics & HESS Hybridization



Smarter Power. Longer Life.

Multi-source hybrid storage (Battery + Supercapacitors + Fuel Cell) with semi-active DC-DC converters (SiC, GaN)

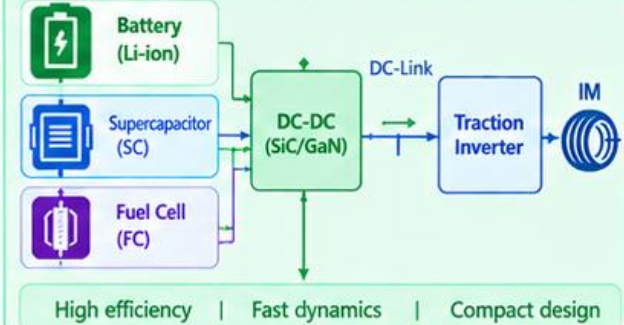


New wide-bandgap semiconductors (SiC, GaN) for higher efficiency, smaller size and faster control



Extend battery lifespan

HESS Topology with SiC/GaN DC-DC Converters



3 Grid-to-Vehicle Integration

Clean Energy. Smart Grids. Reliable Charging.



Hydropower (Canada) & wind/solar (Portugal)



Resilient charging infrastructure



Smart load management & peak shaving



Climate-Resilient
Sustainable
E-Mobility

4 International Collaboration Networks

Shared Knowledge. Stronger Engineers. Global Impact.

UNIVERSITÉ DE SHERBROOKE

L2EP
Laboratoire d'électrotechnique et d'électronique de puissance de Lille

INESCC
Institute for Systems Engineering and Computers at Coimbra



Cross-border education → Interdisciplinary skills → Global innovation



Cleaner Planet



Innovative Technology



Skilled Engineers



A Sustainable Tomorrow



Questions & Discussion

Thank you — Research, Collaboration & Future Mobility



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