



E-mobility in India, case of fuel-cell vehicle

E-mobility International Workshop 2026:

challenges and opportunities

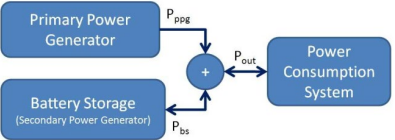
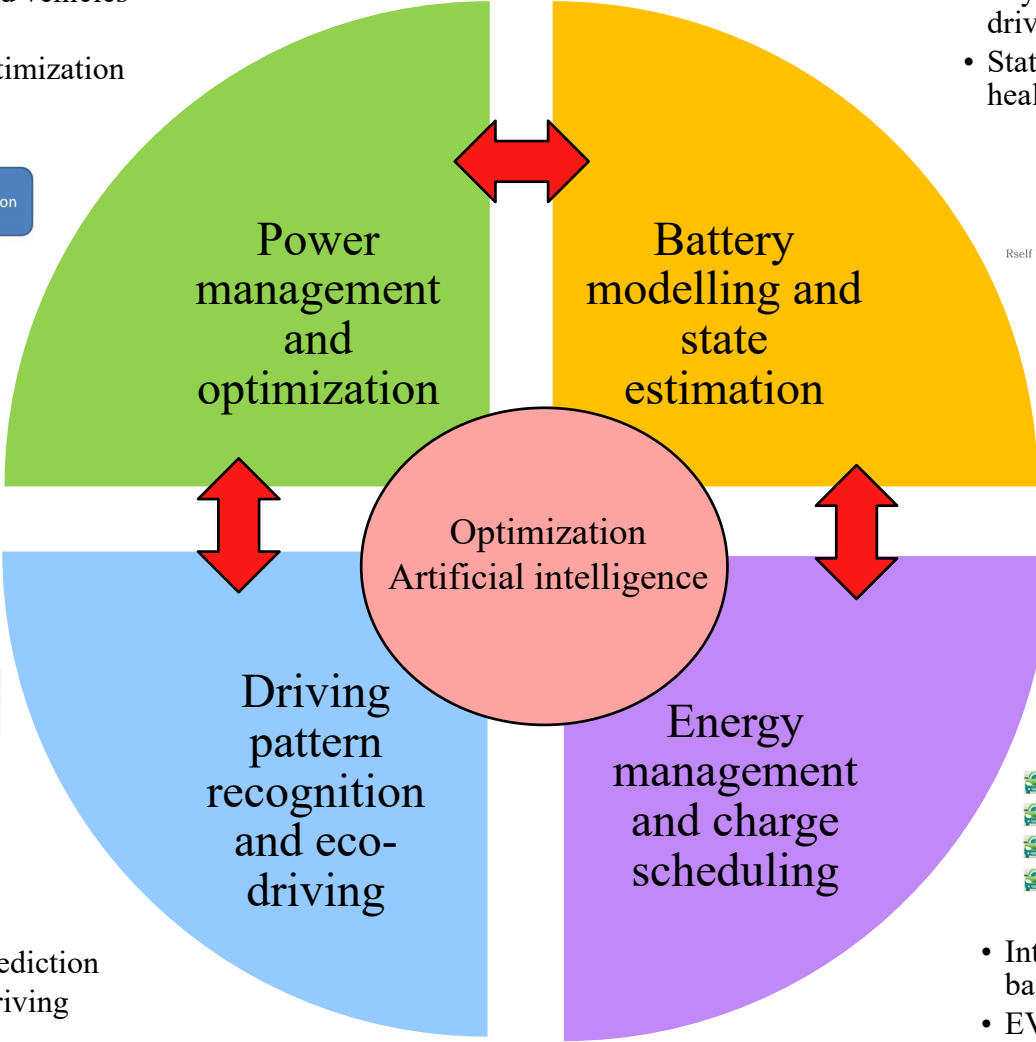
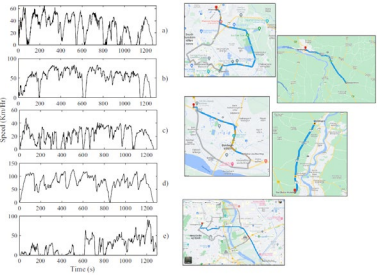
Dr. Bedatri Moulik

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Amity University Uttar Pradesh, Noida, India**



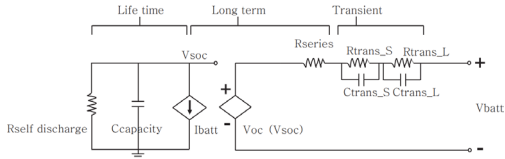
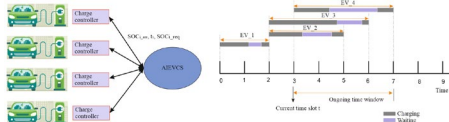
Main research directions

- Modelling of hybrid vehicles
- Power split control
- Multi-objective optimization



- Speed and traffic prediction
- Safe and efficient driving

- Physics-based and data-driven modelling
- State of charge and state of health estimation



- Integrated renewable-based energy systems
- EV charge scheduling

Outline

Introduction

- Environmental concerns
- Problems in India > Need for change
- Recent initiatives

Fuel cell vehicles

- Working of a fuel cell
- Fuel cell hybrid vehicle (FCHEV)
- Scope within global and Indian context

Use case

- EMR and control of a FCHEV
- Power management and optimization
- Simulation results

Introduction

Environmental concerns

Pollution due to transportation sector

- ❑ Harmful emissions, significant contributor of green house gases,
- ❑ Scarcity, rising costs of fossil fuels

Traffic congestion: increase in number of cars



carlosromero.com



www.pininterest.com



www.uksusa.org

Everybody wants to have a car

- ❑ Decreased dependency on public transport
- ❑ Car congestion on weekdays
- ❑ Most of the seats unoccupied

Why do people prefer personal transport? > Convenient timings and flexible destination; To avoid overcrowding

carwale.com



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Problems in India – Need for change

How can alternatives be introduced?

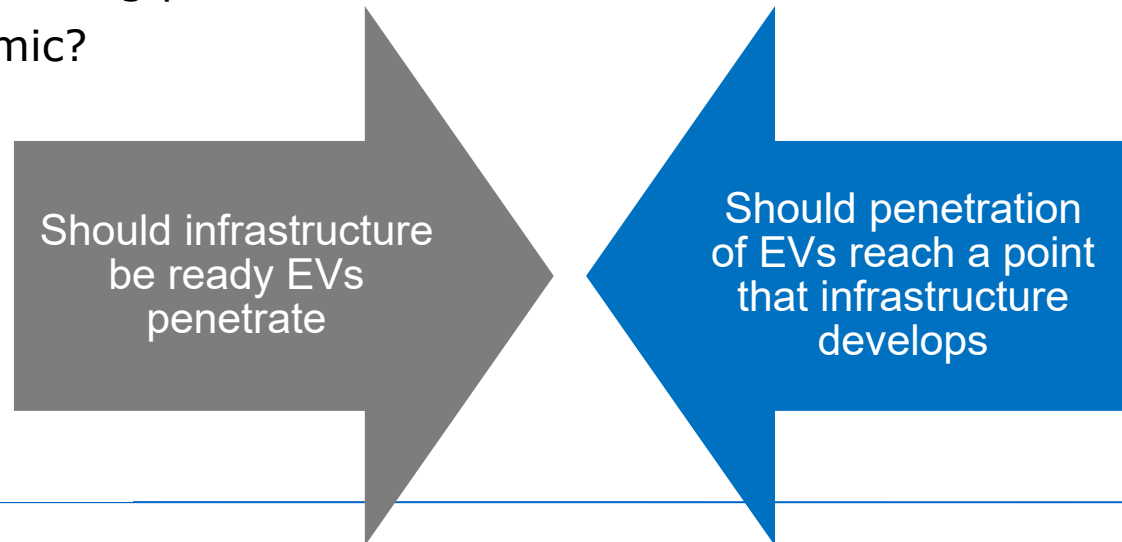
- ❑ Available public transportation options: Mass >> buses
- ❑ Need for smaller passenger carrying vehicles in certain zones
- ❑ Electric vehicles as a substitute

SMALL, SHARED, ELECTRIC

Questions remain.....

- ❑ Charging time depends on input power, battery type, capacity, and control system
- ❑ How much can the grid supply capacity be stretched?
- ❑ Can renewables (Solar, wind,..) support the grid during peak demands?
- ❑ How can electricity pricing model be made dynamic?

- ➔ Driving smaller vehicles
- ➔ Mass transportation
- ➔ Driving electric vehicles



Recent initiatives

Faster Adoption and Manufacturing of Electric Vehicles

NEMMP
2020 •2012

→ FAME I •2015

→ NITI
Aayog •2017

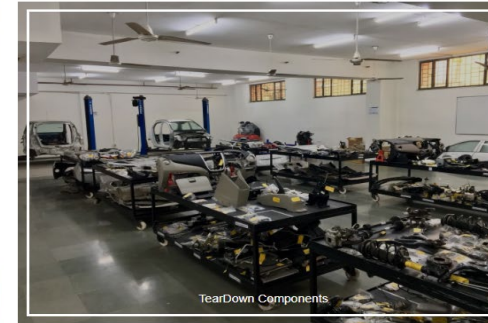
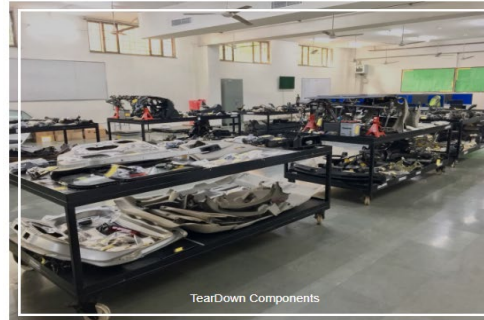
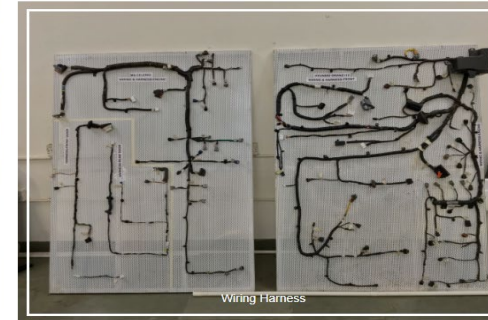
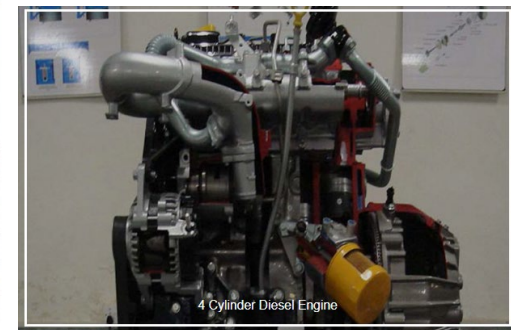
→ FAME II •2019

→ PLI
scheme •2021

→ PM E-
DRIVE •2024

→ IEMI •2025

Industry-academia collaboration



- ❑ Amity Institute of Technology > joint initiative with Tata Technologies Ltd.
- ❑ Training "future-ready" engineers with practical skills rather than just theory
- ❑ Specialized labs run by Tata Technologies
- ❑ Bachelor, master, PhD in automobile, aeronautical, and EVT

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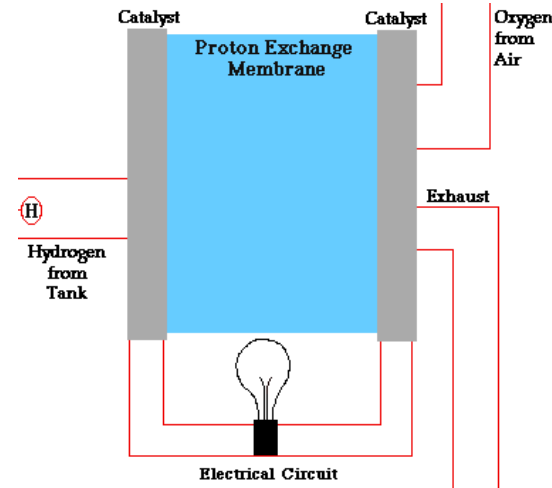
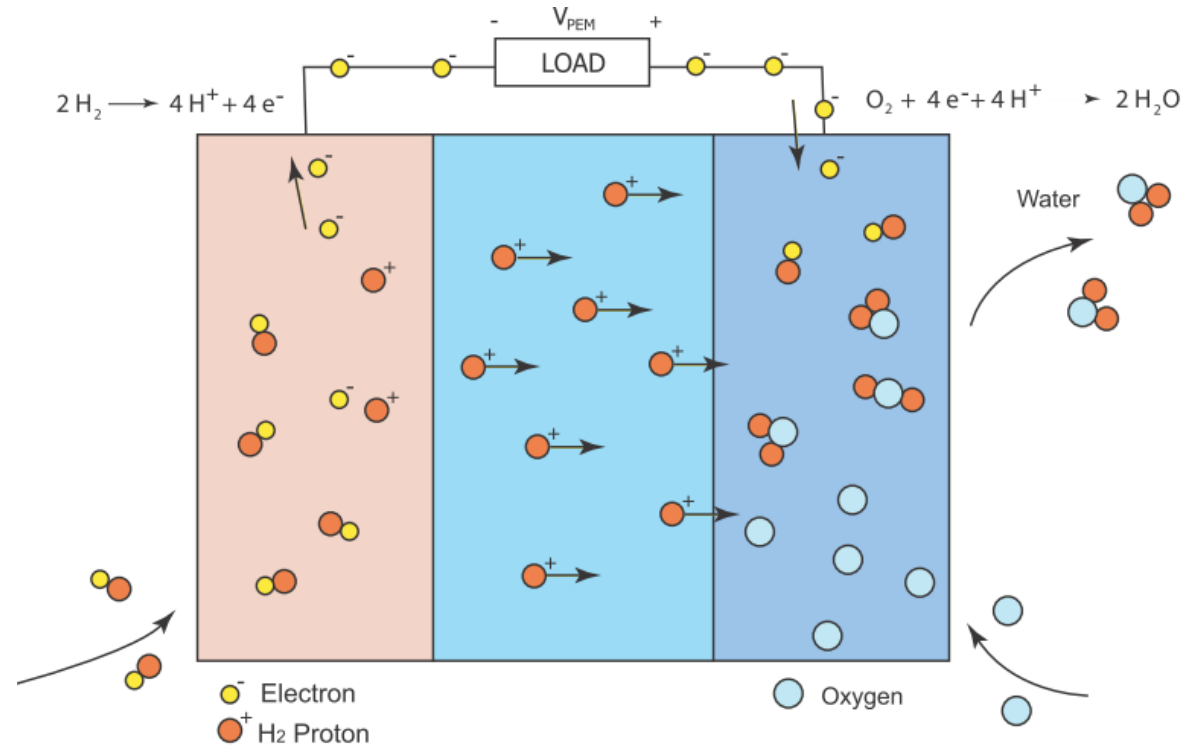
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Fuel cell vehicles

Working of a fuel cell

Basic operation of a fuel cell

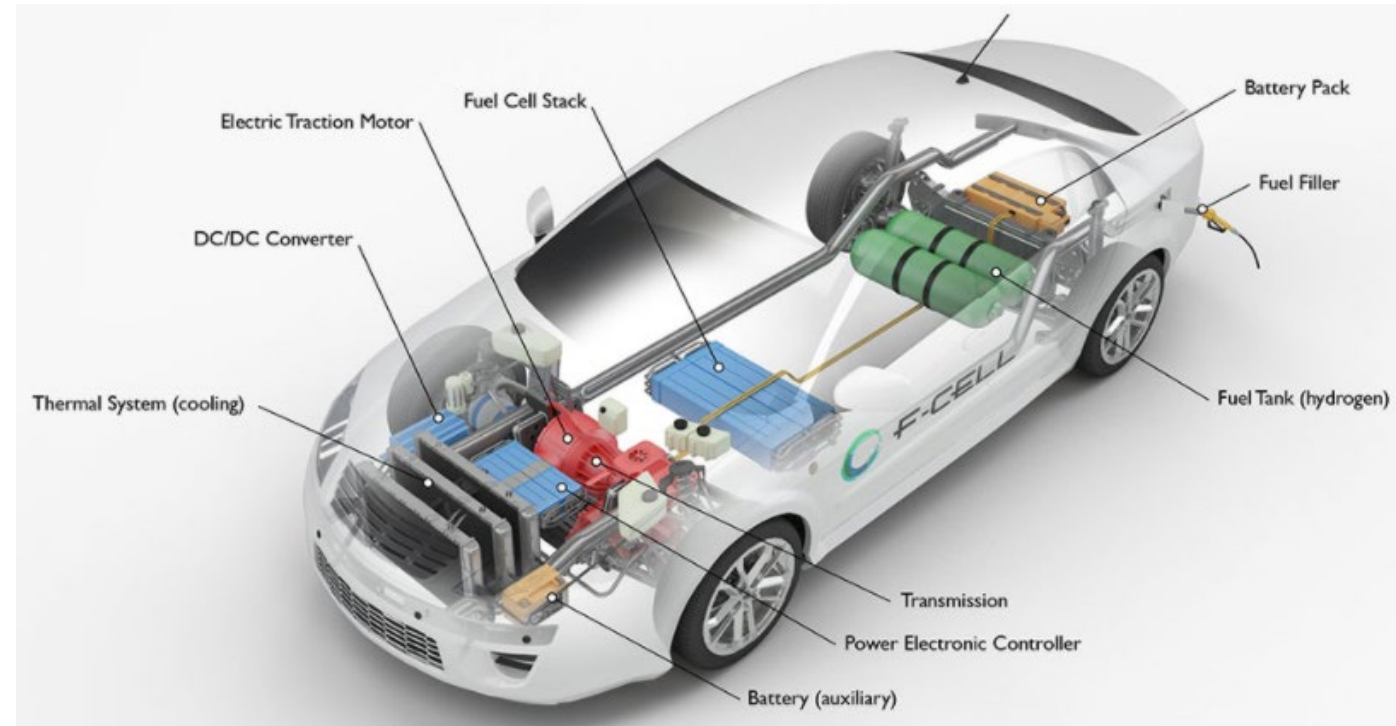
- ❑ Chemical energy of hydrogen into electricity through an electrochemical reaction, producing water and heat
- ❑ Anode (Negative Electrode): hydrogen enters.
- ❑ Cathode (Positive Electrode): oxygen (from the air) enters.
- ❑ Electrolyte: lets only specific ions pass through.
- ❑ Catalyst: material speeds up chemical reactions.



➔ Unlike battery, fuel cell does not need recharging as long as fuel and oxygen are supplied

Fuel cell hybrid vehicle (FCHEV)

- ❑ Primary Power Source: polymer electrolyte membrane (PEM) fuel cell
- ❑ Secondary storage: fuel cells react slowly to sudden power shifts, battery/supercap as additional source
- ❑ Regenerative Braking: captures kinetic energy during deceleration, recharging of the secondary storage



afdc.energy.gov

➔ FCHEVs offer extended driving ranges, benefit from better energy and power density

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Scope within global and Indian contexts

- ❑ First hydrogen fuel cell bus developed in Pune with support from CSIR and KPIT
- ❑ Adani Enterprises launched first hydrogen fuel cell-powered truck for industrial logistics



maritimegateway.com

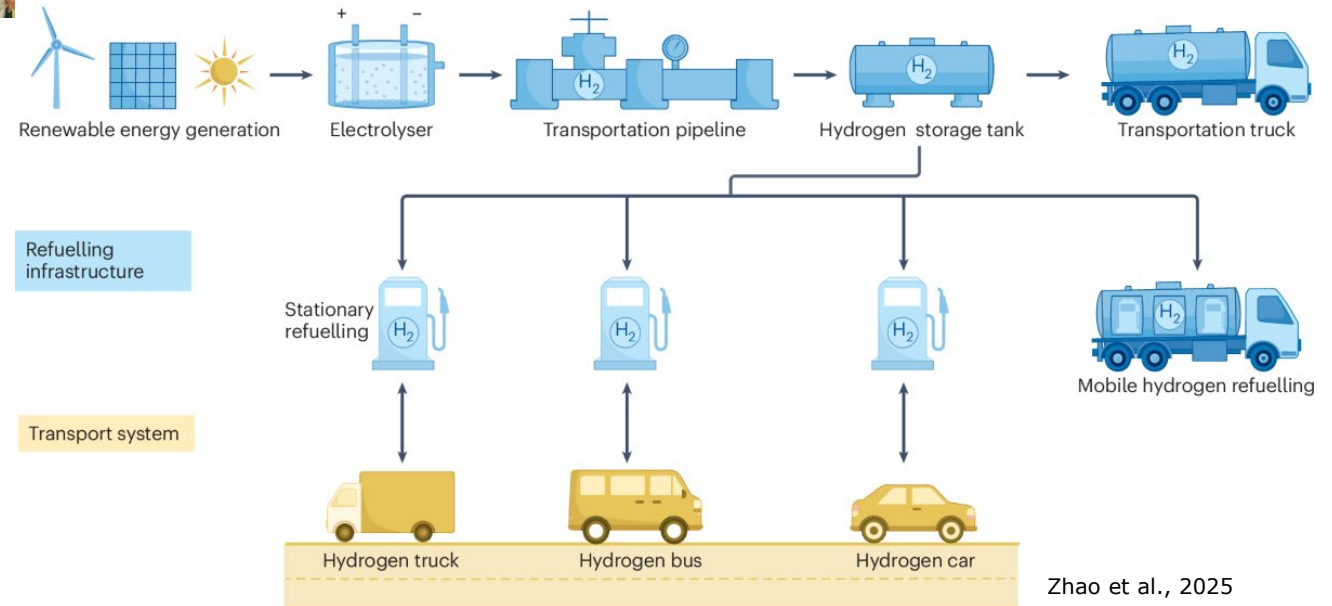


facebook.com

- ➔ Passenger cars in exploratory stage in India
- ➔ High cost of hydrogen production
- ➔ limited number of hydrogen re-fueling stations

- ❑ Highest-potential for heavy duty transport
- ❑ Infrastructure, regulations, economic benefits, technical feasibility, and consumer market
- ❑ Integrated approach: hydrogen production, storage, and distribution investments

➔ GHG emissions associated hydrogen production



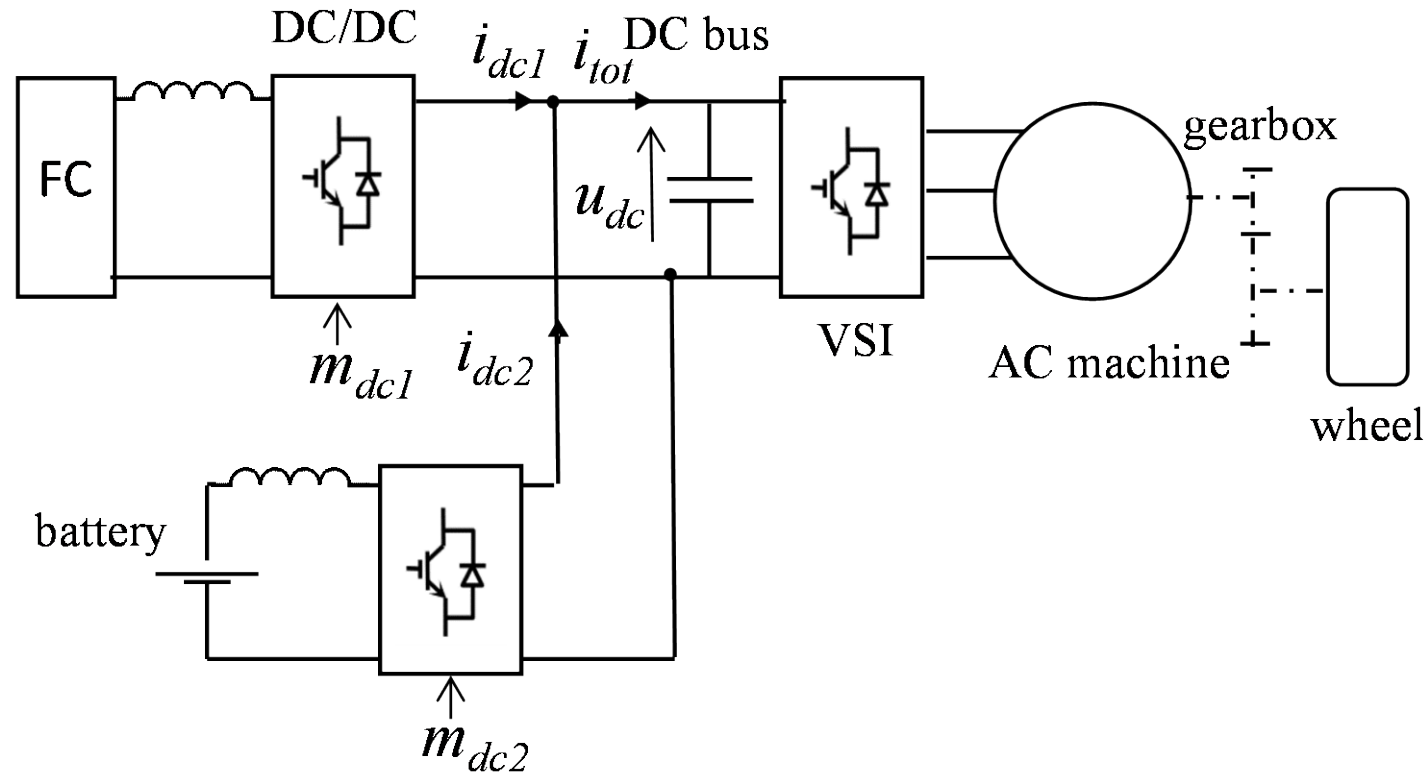
Zhao et al., 2025

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Use case

EMR and control of a FCHEV

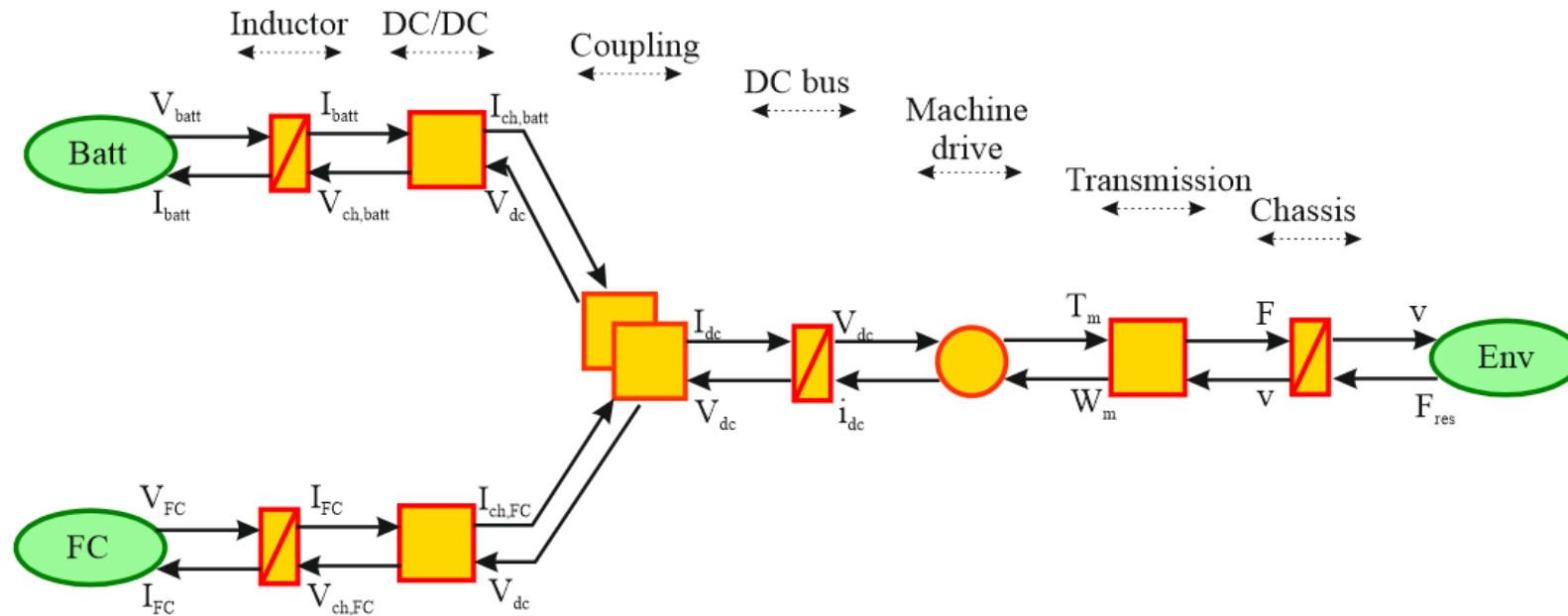
Structural description



➔ Hybrid parallel topology with battery as secondary source

EMR and control of a FCHEV

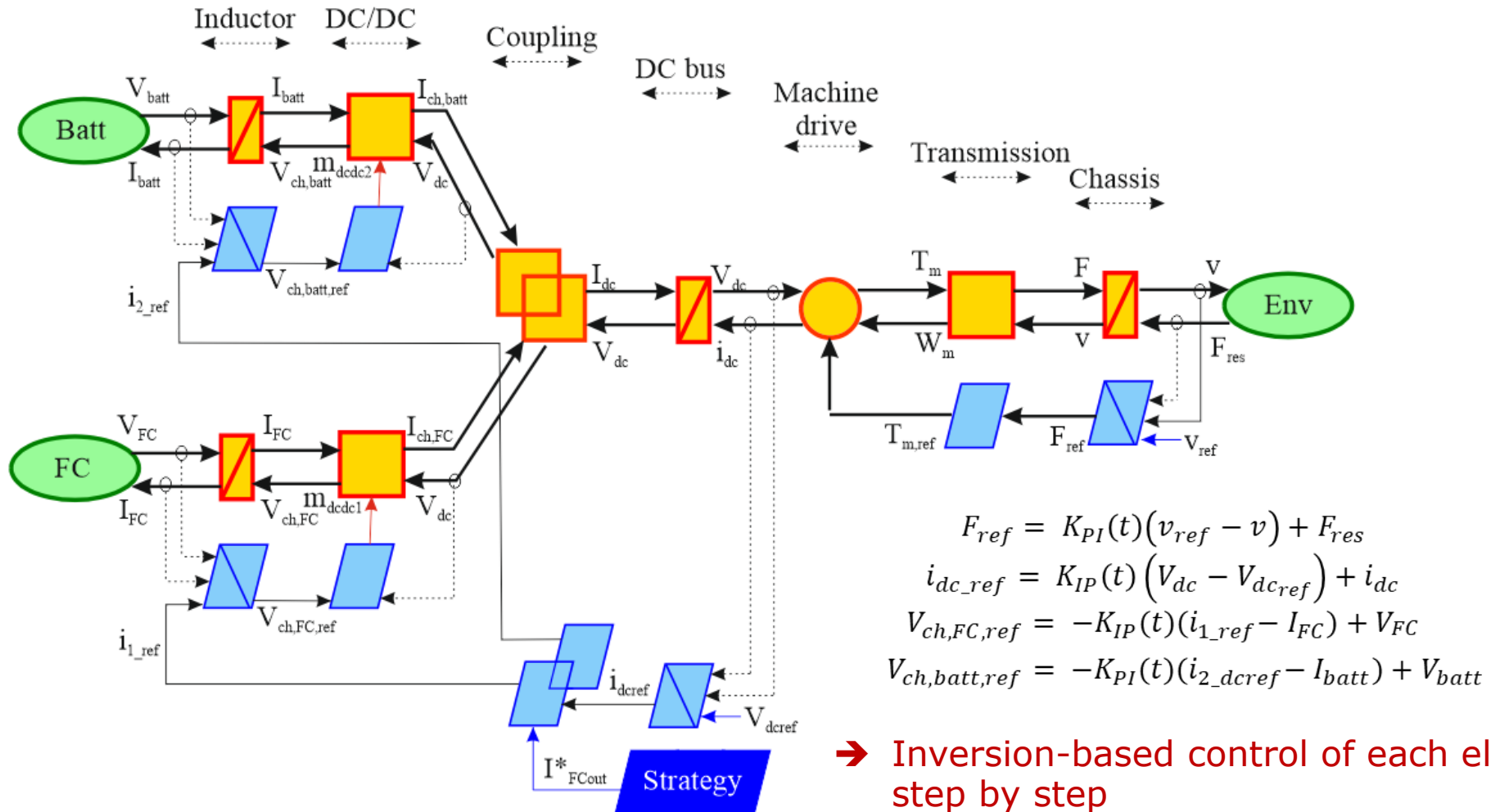
Functional representation



- ➔ Functional description using EMR
- ➔ Consideration of causal, dynamic models, forward simulation to respect energy properties

EMR and control of a FCHEV

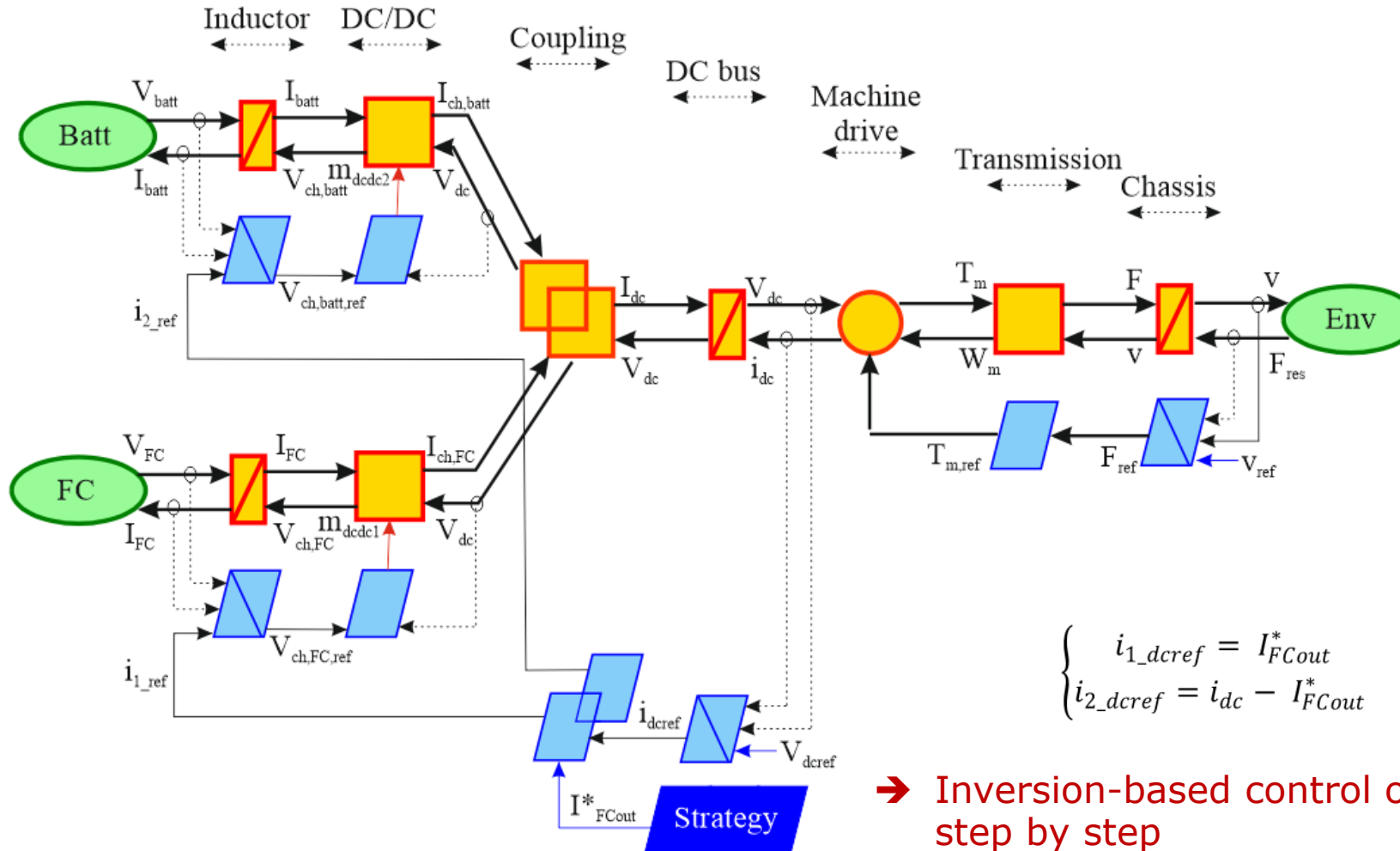
Functional representation



→ Inversion-based control of each element step by step

EMR and control of a FCHEV

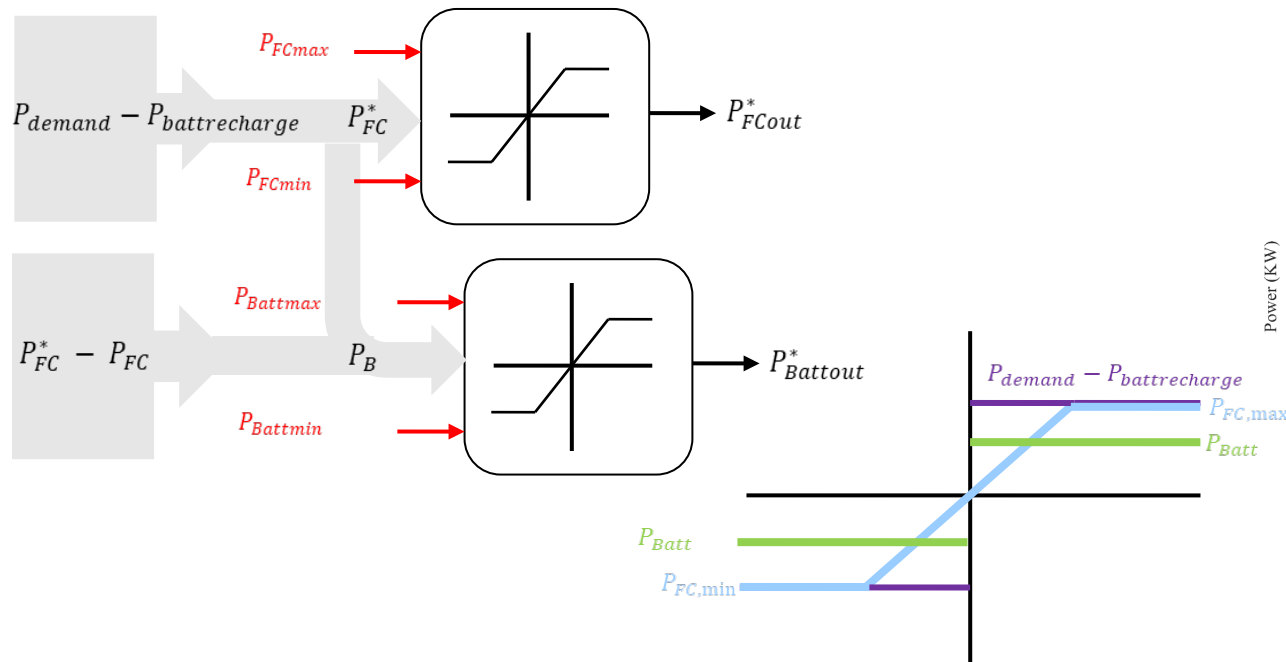
Functional representation



Power management and optimization

Dynamic rate limitation and saturation for fuel cell hybrid vehicle (FCHEV)

- Limits of saturation and rate limitation are varied according to driving cycle



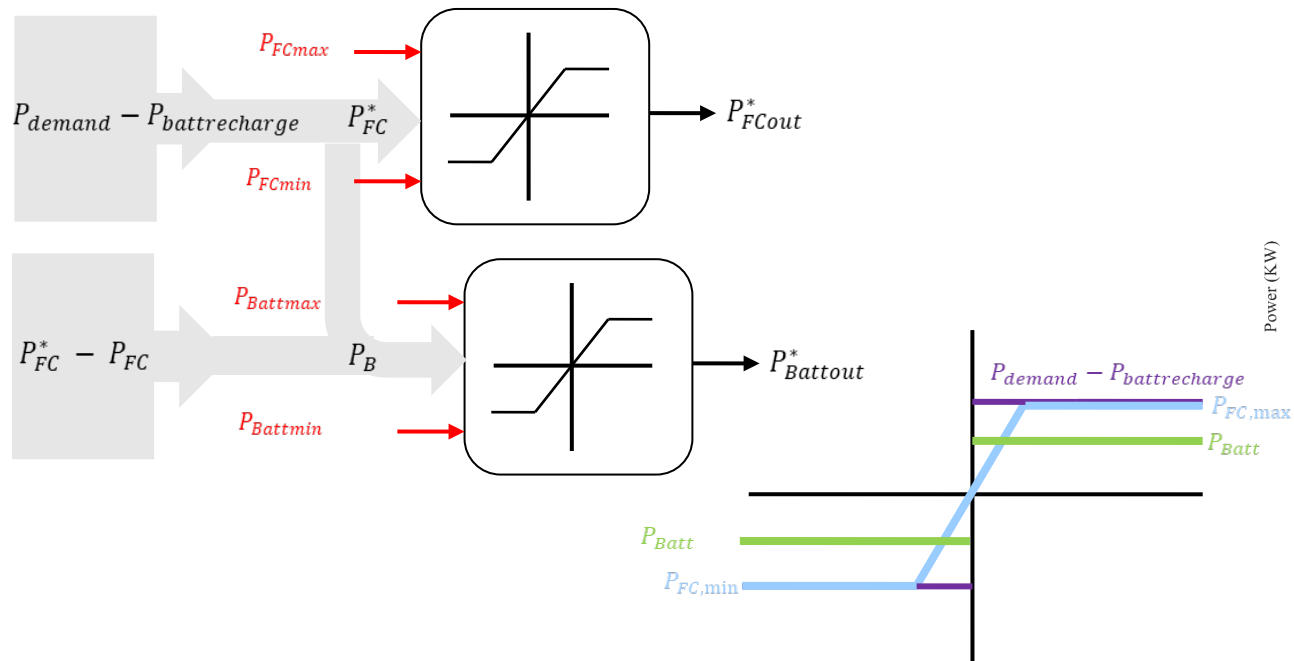
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- ➔ Operation of battery & fuel cell governed by individual dynamics
- ➔ Rate limitation to control current growth rate in a fuel cell, saturation to restrict operation of battery within pre-defined bounds

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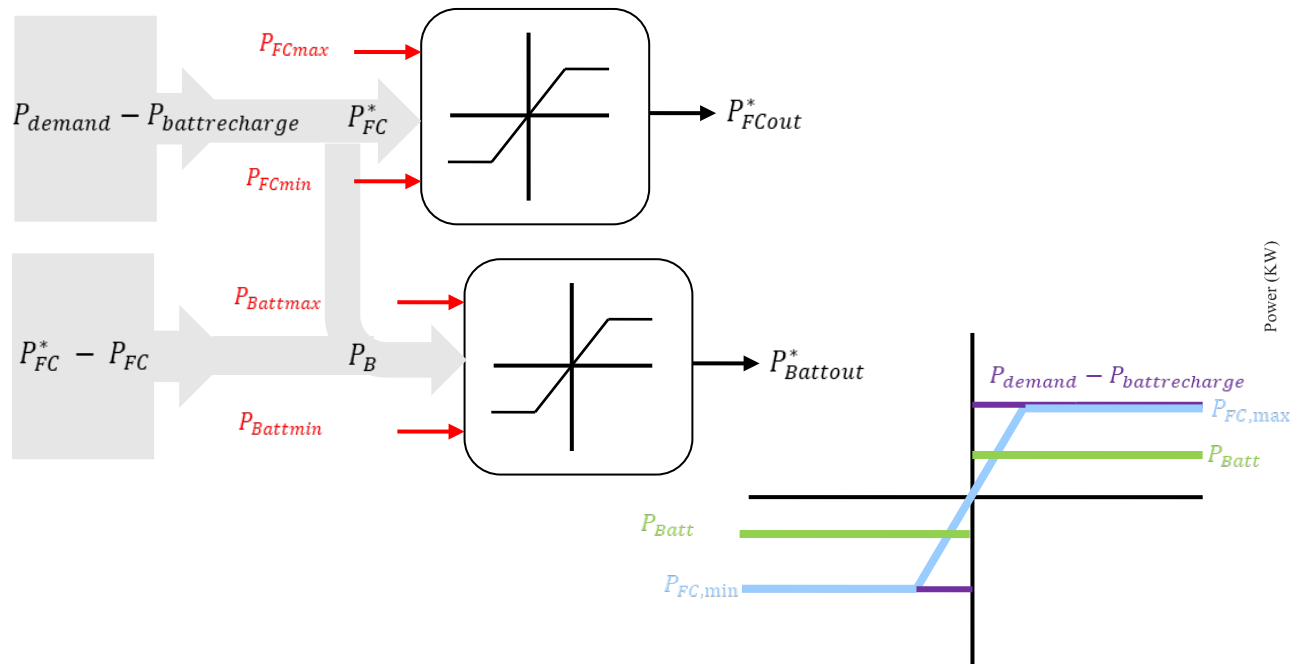
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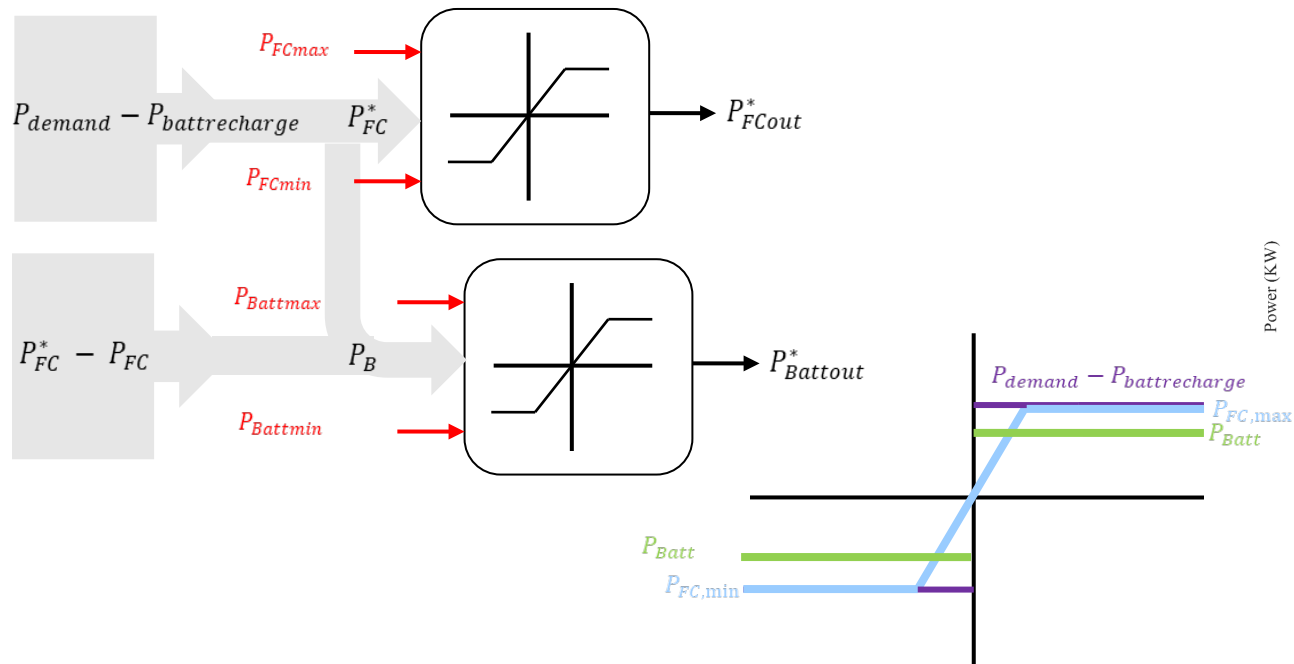
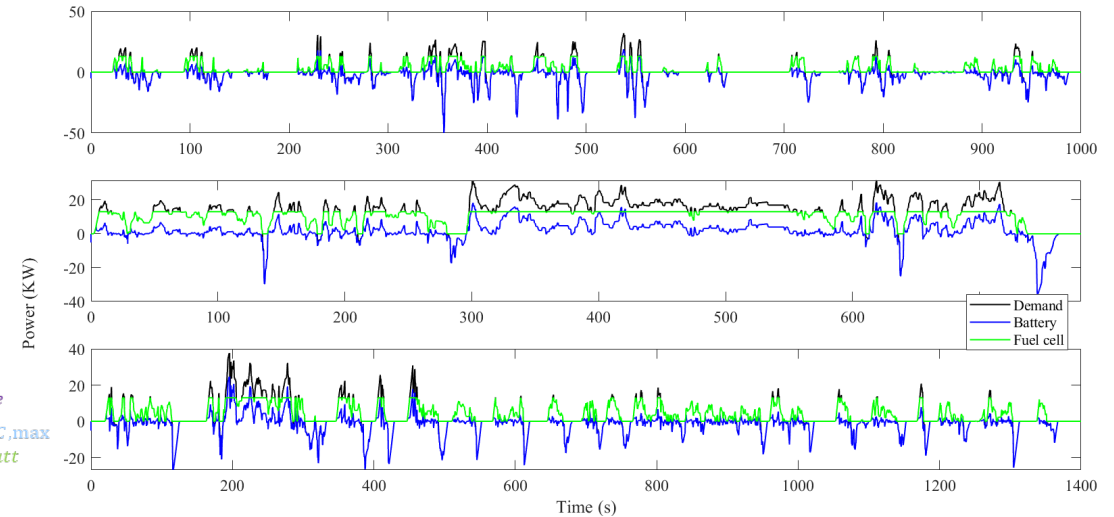
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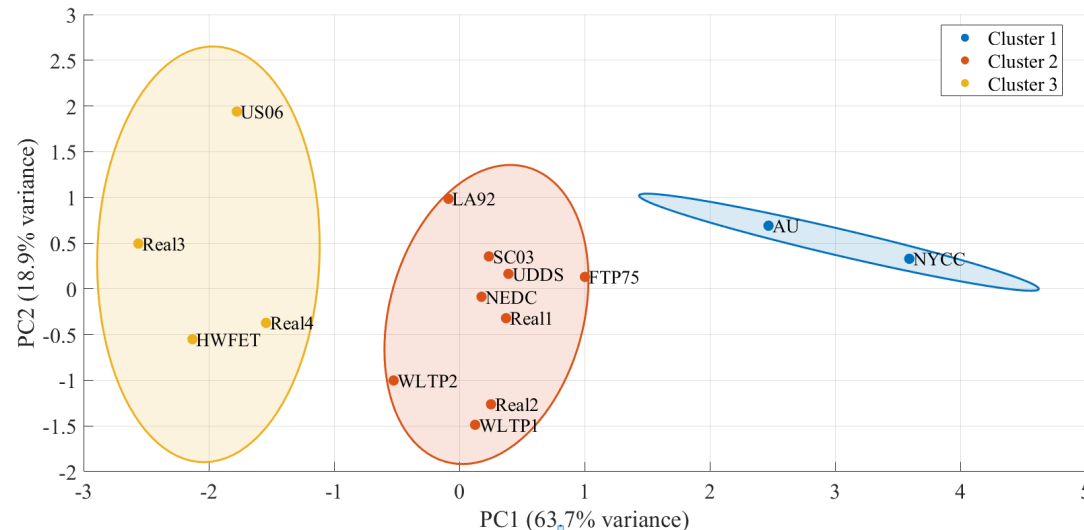
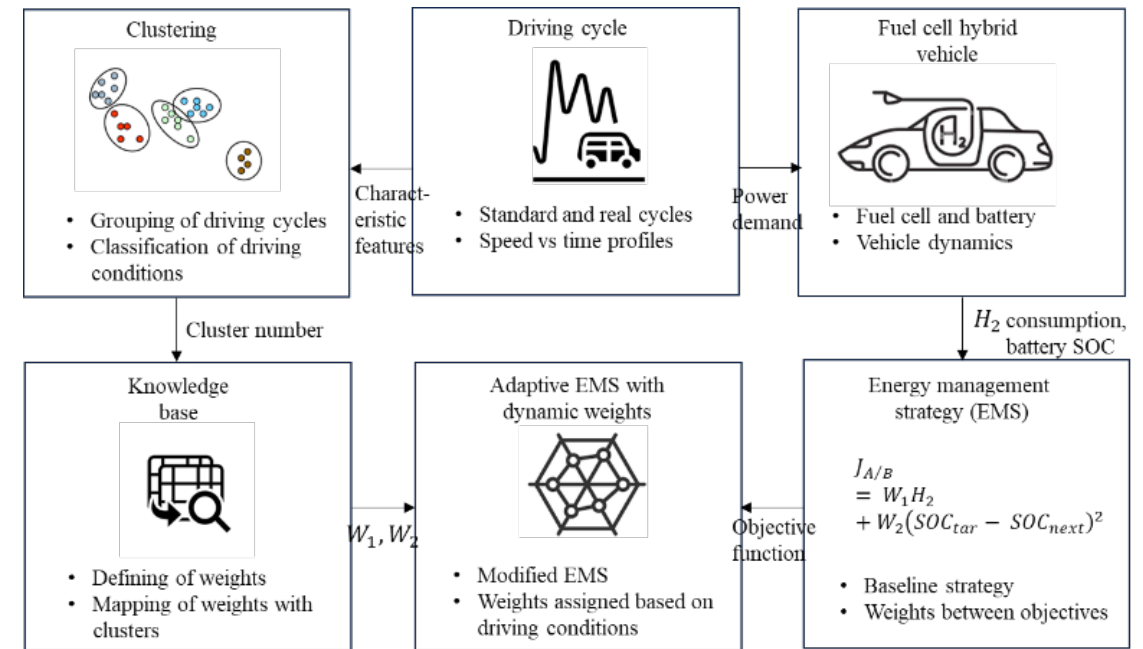
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Power management and optimization

Selection of optimized power management for fuel cell hybrid vehicle based on clustering

- Based on selected cluster, weights for minimization of objectives



Mukhopadhyay, A., Moulik, B., et al. *Optimized Energy Management Strategy of a Hybrid Vehicle with Dynamic Weight Adjustment Between Objectives* IETE Journal of research (2026), submitted.

- Cluster groups are formed representing city, urban, highway driving conditions
- Knowledge base for defining weights based on cluster

Summary and conclusion

Summary

- ❑ A fuel cell hybrid vehicle can combine the advantages of hybrid sources by employing an energy management strategy to optimally split the power between the sources
- ❑ An organized deduction of control structure involving both local and global control is feasible through EMR
- ❑ Optimization of maximum and minimum boundaries of fuel cell and battery operation can dynamically split the power between the sources and also respect the system constraints
- ❑ Multi-objective optimization can be used with prioritization between objectives
- ❑ First simulation results demonstrate the interest of the proposed EMS

Thank you