13TH CIMAC CASCADES

Title: Intelligent Energy Management in Hybrid-Electric Vehicles: How Deep Learning is Shaping the Future

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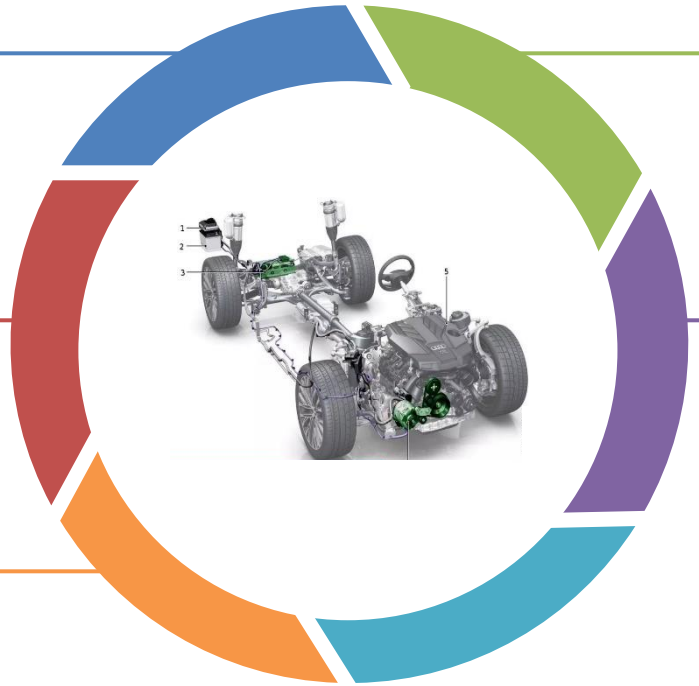
Overview

Hybrid-Electric Powertrains: A Rapid Solution to Energy and Environmental Challenges

Overview of the Markov Decision Process and Deep Reinforcement Learning (DRL)

Application of Reinforcement Learning in Energy Management System

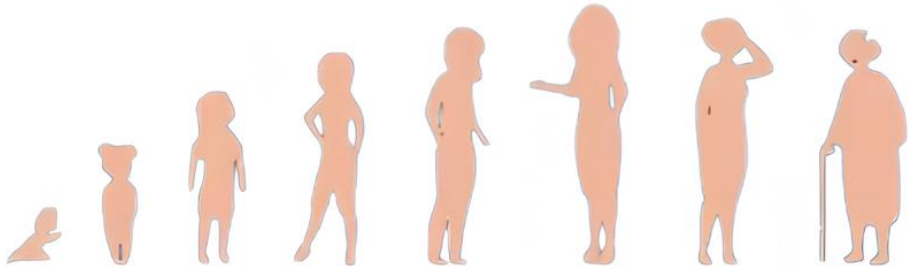


Objective: Optimizing Hybrid-Electric Powertrains with Deep Reinforcement Learning for Intelligent Energy Management Systems

Working Principle of Reinforcement Learning in Energy Management System

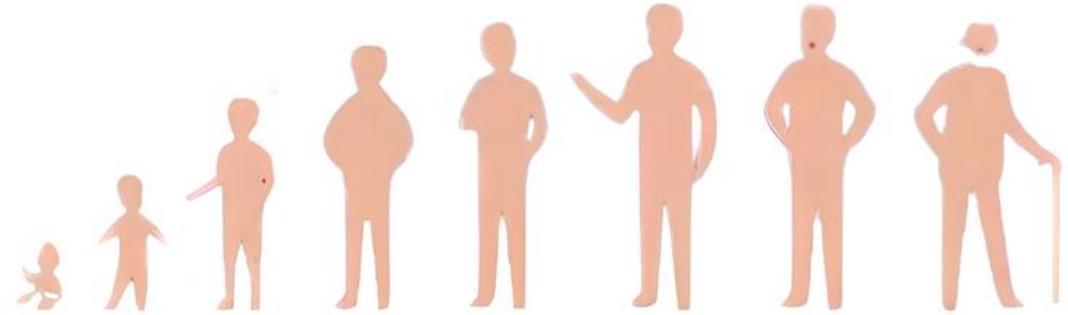
Reinforcement Learning: Brief Recap

Reinforcement Learning:



Human Learns through this

A learning Mechanism:



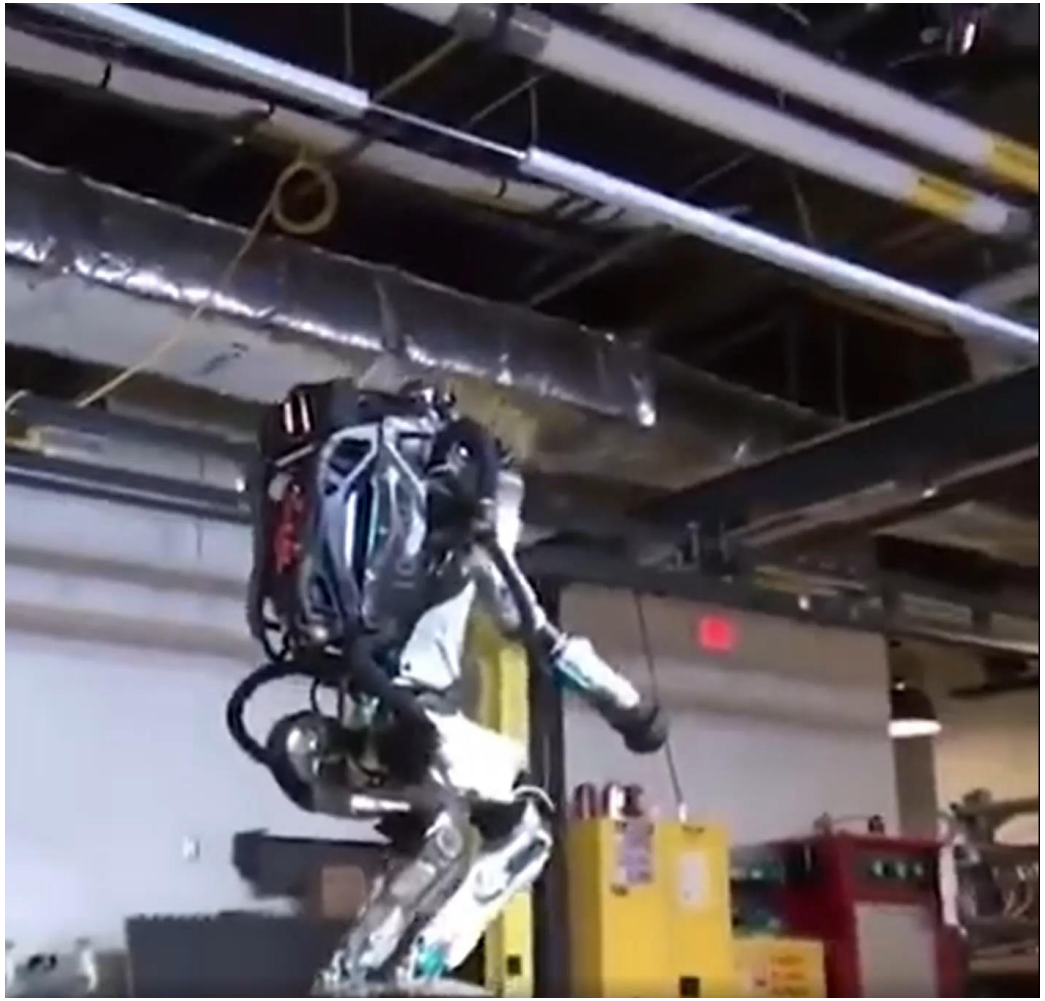
Decision making improves with more experience

One of the Foundation of AI:

Advanced Application of Reinforcement Learning

When we are still in a Naïve stage

Advanced Application of Reinforcement Learning



Decision making improves with more experience

Introduction of Conventional and Electrified Powertrain

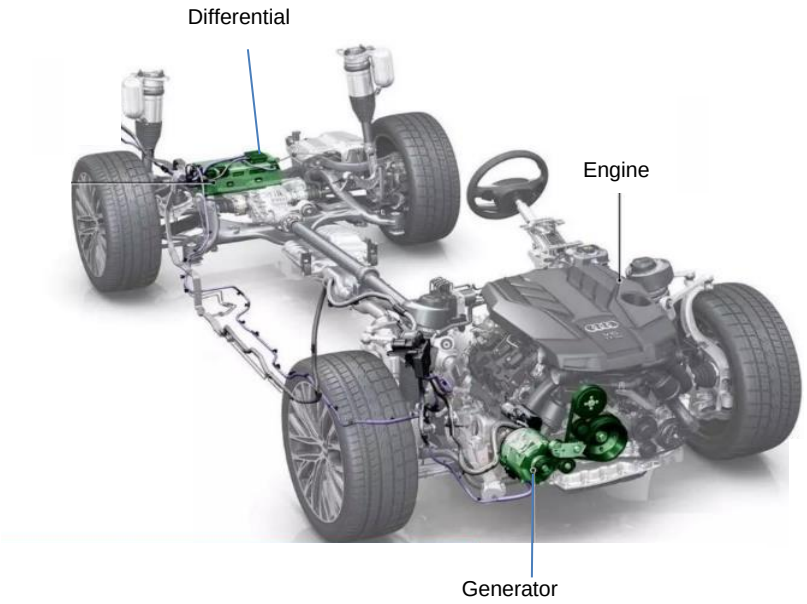
Conventional Powertrain

Edges over all-electric power train:

- Minimum refueling time
- Reasonable initial cost
- No compromise on performance

Drawbacks:

- Emission of toxic gases
- Inefficient driving
- Fuel consumption is very high



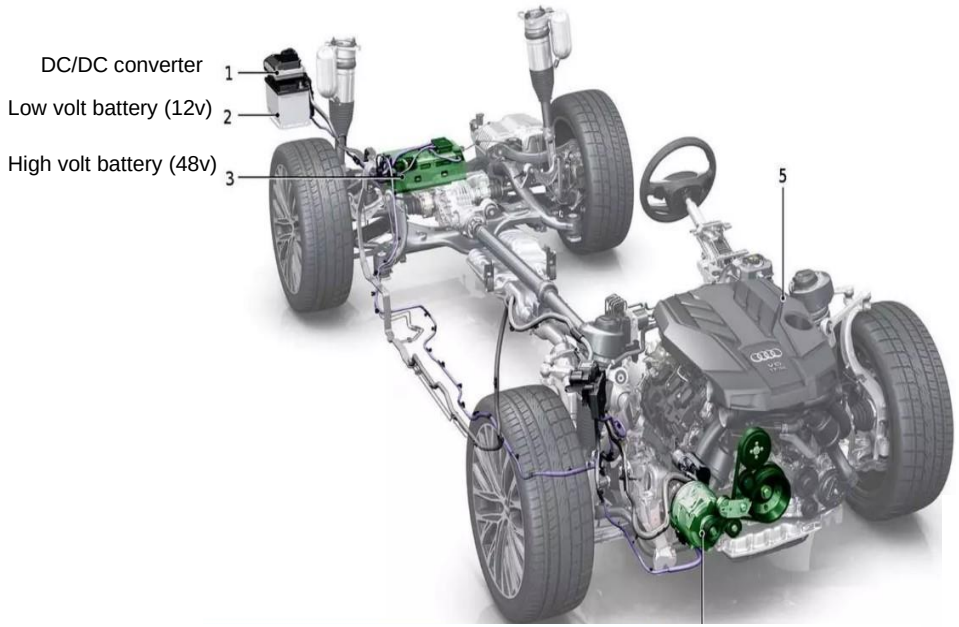
Fully Electric Vehicle

Edges over ICE-based vehicle:

- No emissions
- Highly efficient driving
- Regenerative braking

Drawbacks:

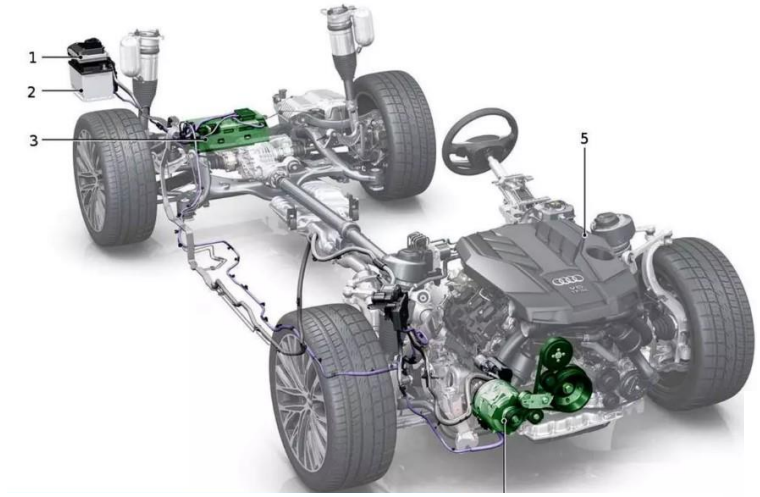
- Charging infrastructure
- Range Anxiety
- People's perception



Introduction of Hybrid Electric Powertrain

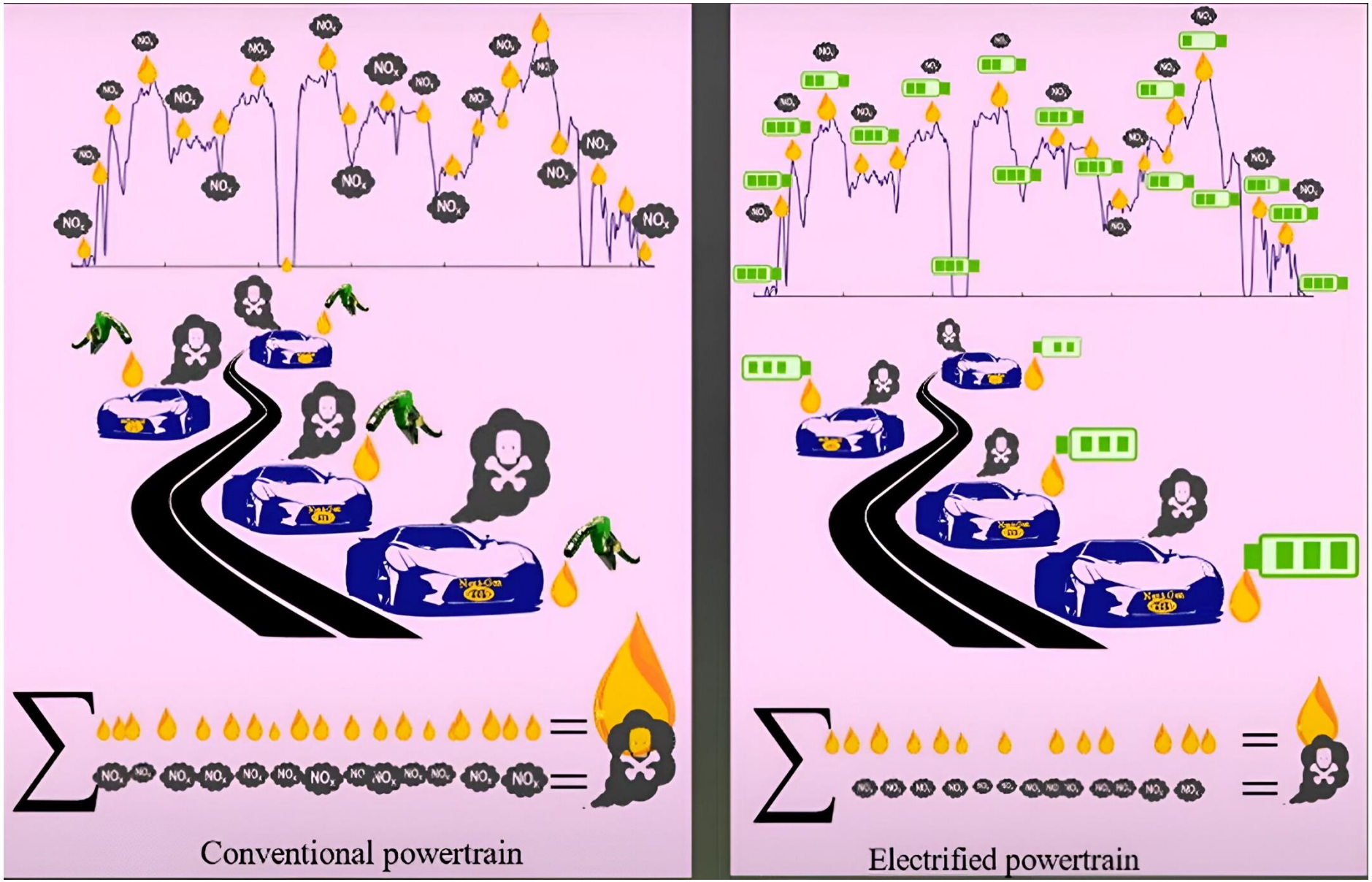
Benefits of all electric powertrain

Benefits of all conventional powertrain



However hybrid brings control complexity

Energy Management System: Fundamental Objectives



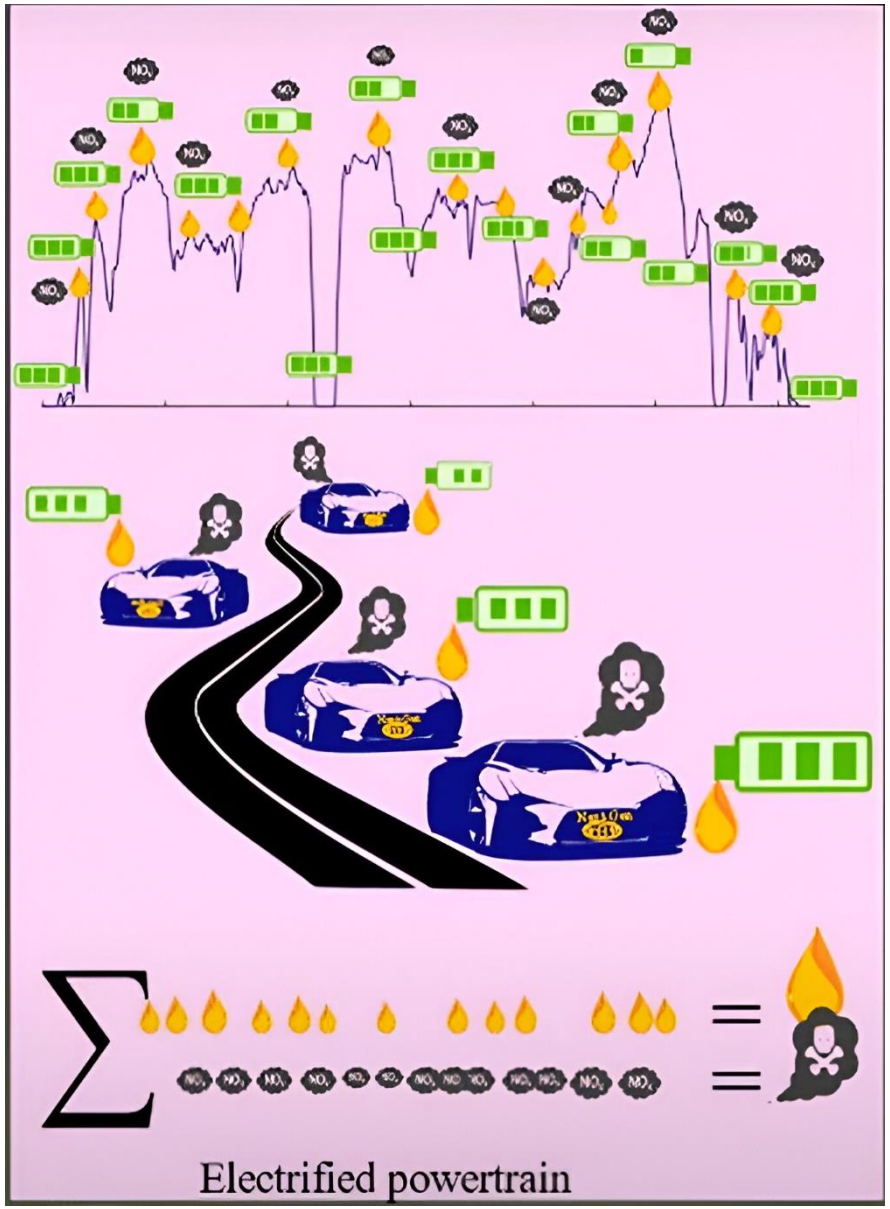
Energy Management System: Industry's Perspective

Industry's need from an EMS:

- Real time implementable ✗
- Optimal fuel consumption and GHG emissions ✓
- Computationally cheap ✗
- Charge sustaining for hybrid powertrains ✓

Global optimization based control:

- Not real time implementable
- Guaranteed global optimality
- Computationally expensive
- Charge sustainability guaranteed



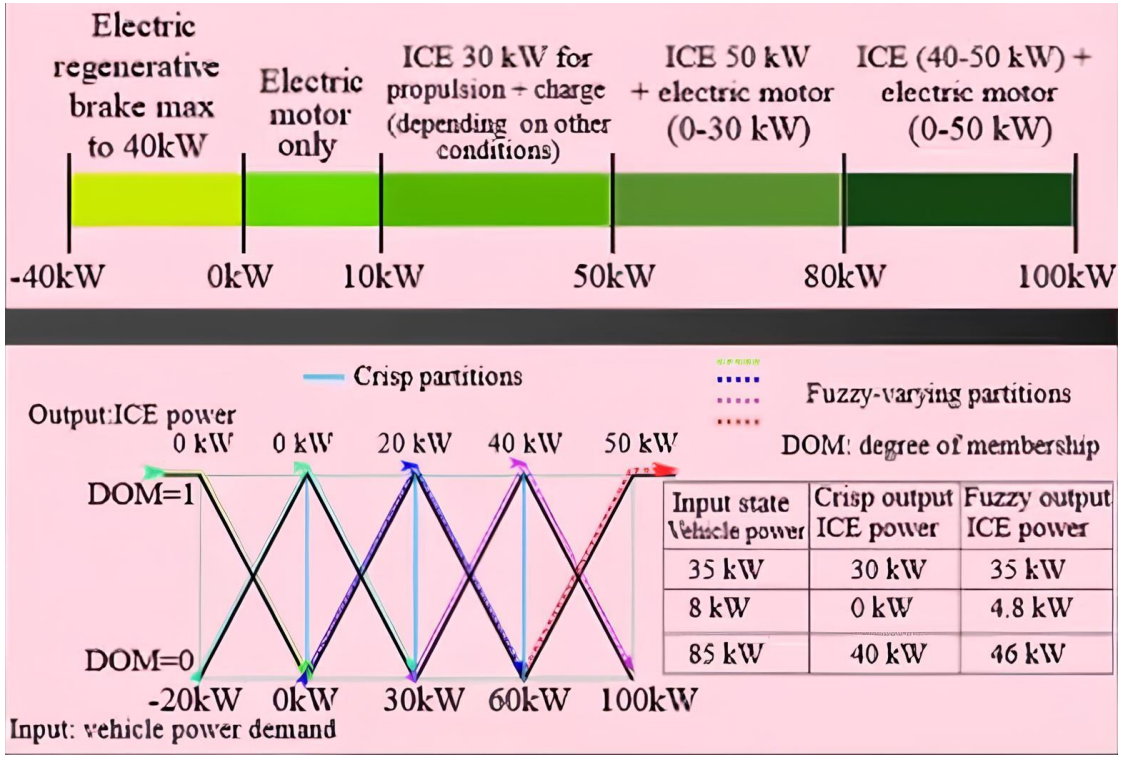
Energy Management System: Industry's Perspective

Industry's need from an EMS:

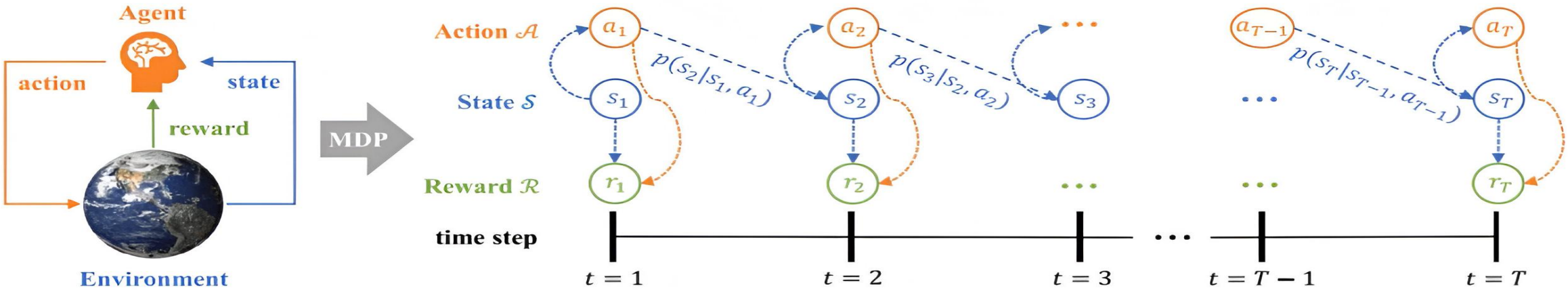
- Real time implementable ✔
- Optimal fuel consumption and GHG emissions ✖
- Computationally cheap ✔
- Charge sustaining for hybrid powertrains ✖

Rule based control:

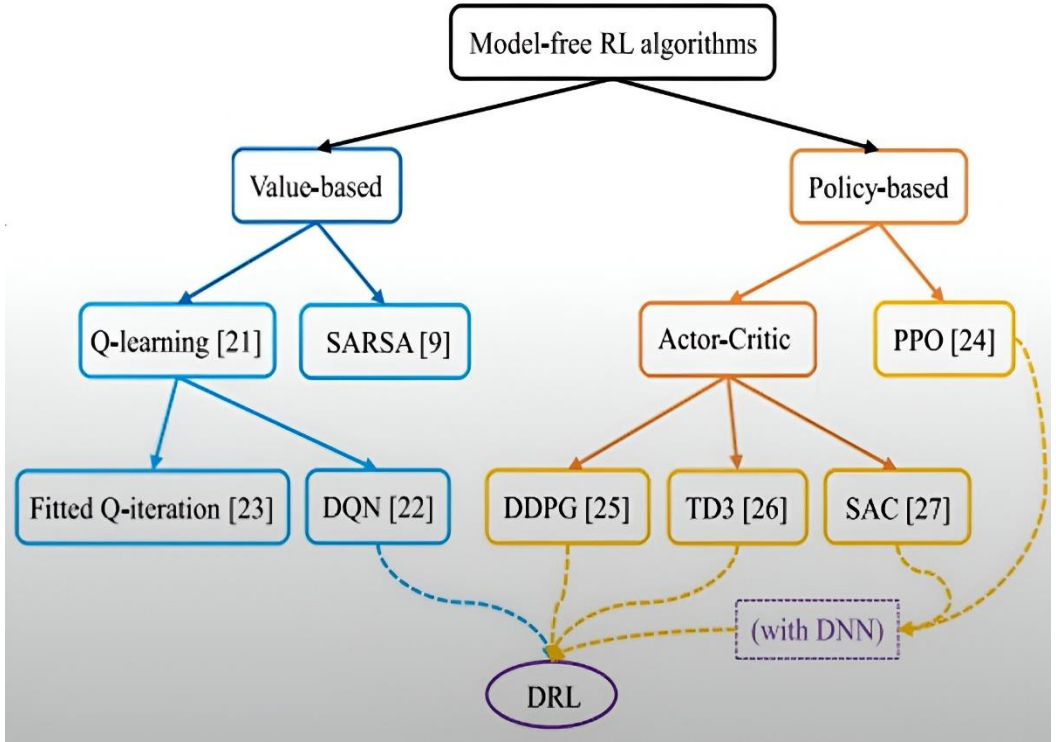
- Real time implementable
- Optimality not Guaranteed
- Computationally very simple
- Charge-sustainability not guaranteed



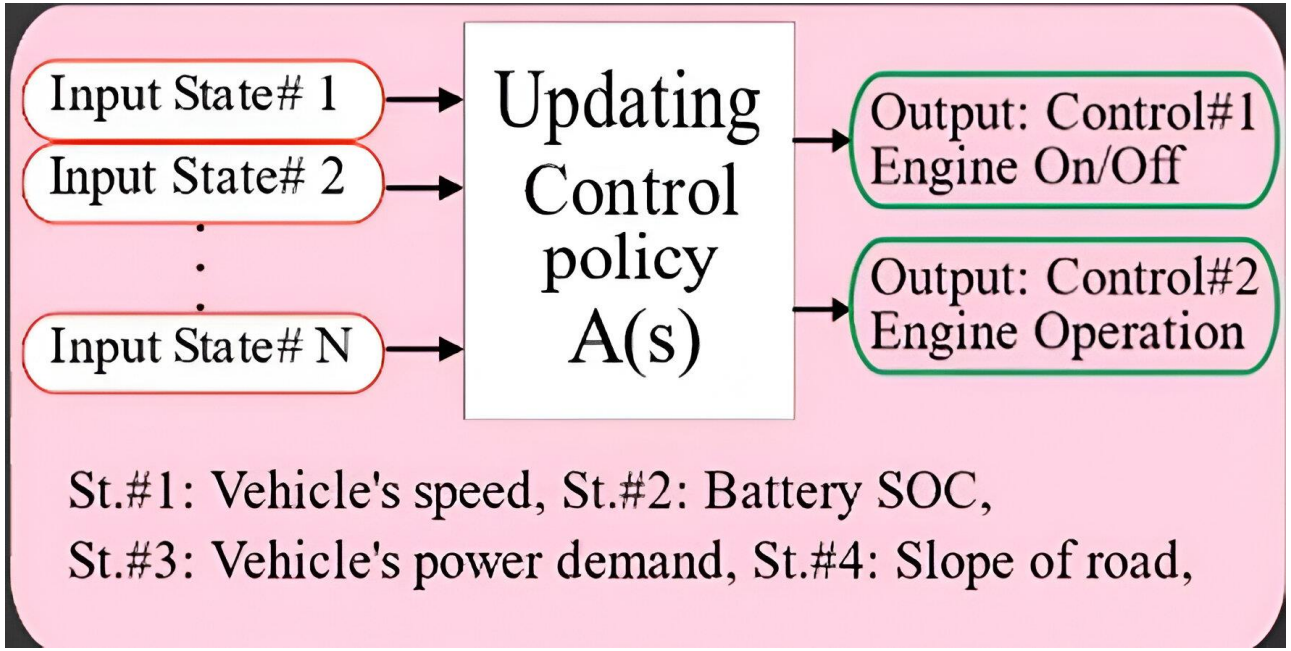
Reinforcement Learning in Energy Management System



Agent–environment interaction and the process of Markov decision process.



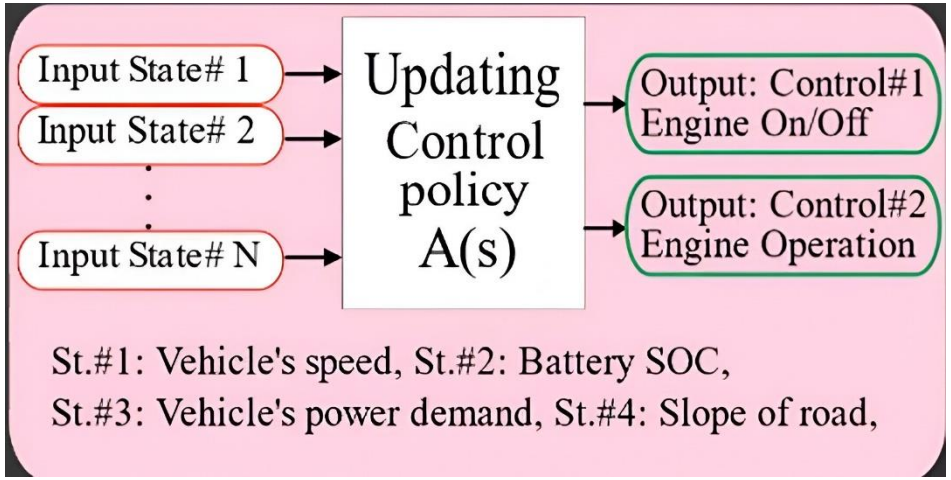
Application of Reinforcement Learning in Energy Management System



Lets develop a learning based-control strategy whose

- **Rules for choosing the optimal control changes periodically**
- **There is a specific algorithm for changing the "Rule"**
- **Charge sustaining for hybrid powertrains**
- **Computationally cheap**

Working Principle of Reinforcement Learning in Energy Management System



Start

The Reinforcement learning-based EMS does not have any idea of the entire drive cycle

Sensors data (speed, SOC, acc, Pedal pos.., etc.) are fed as input to EMS as vehicle runs

Reinforcement learning-based EMS decides control action based on arbitrary rule

RL based EMS observes the immediate consequence and predicts long term

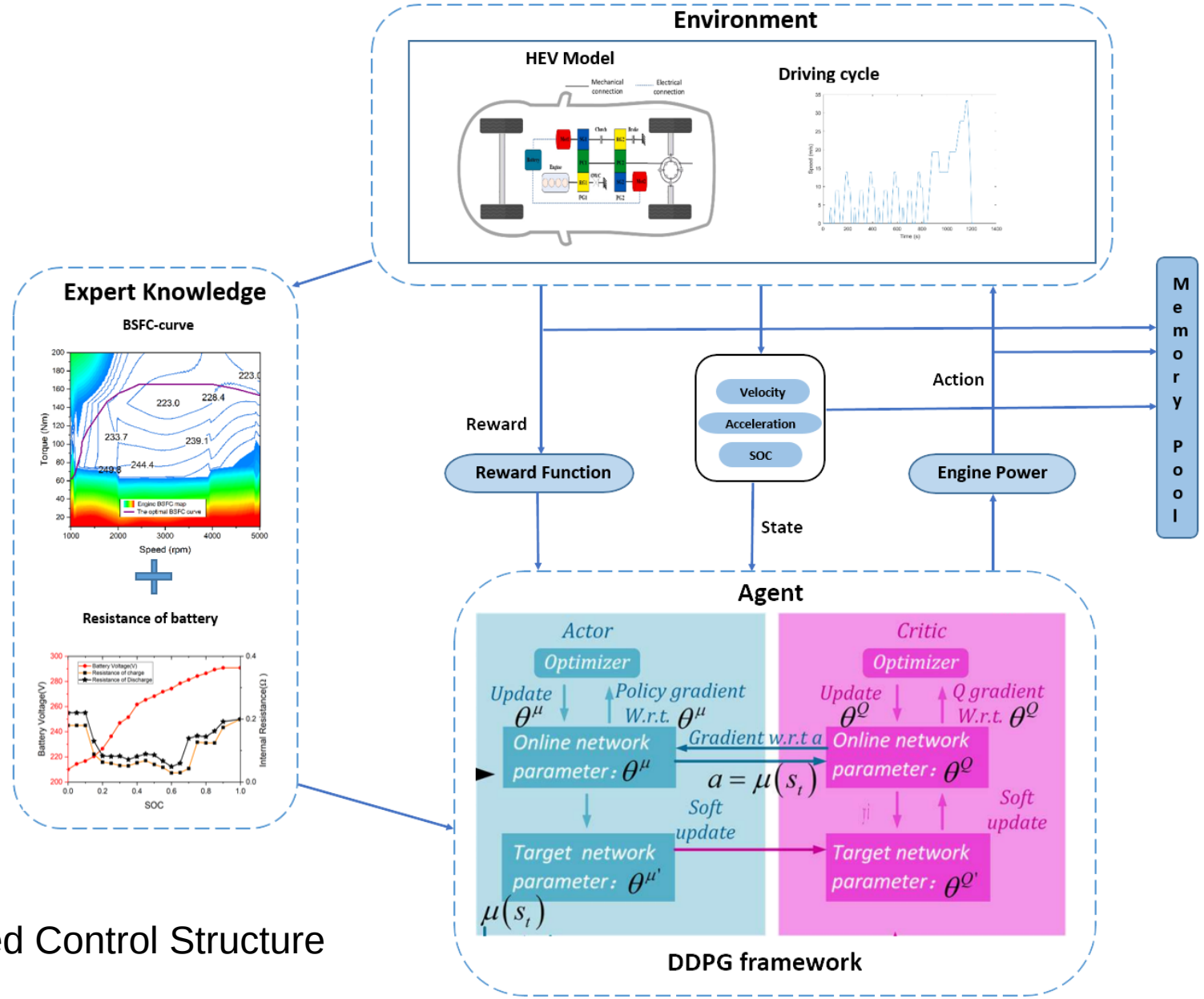
Based on predicted long-term consequences, the learning Algorithm updates the control rules

Control rule is no more arbitrary. But exploitation-exploration ratio maintained

Next time step

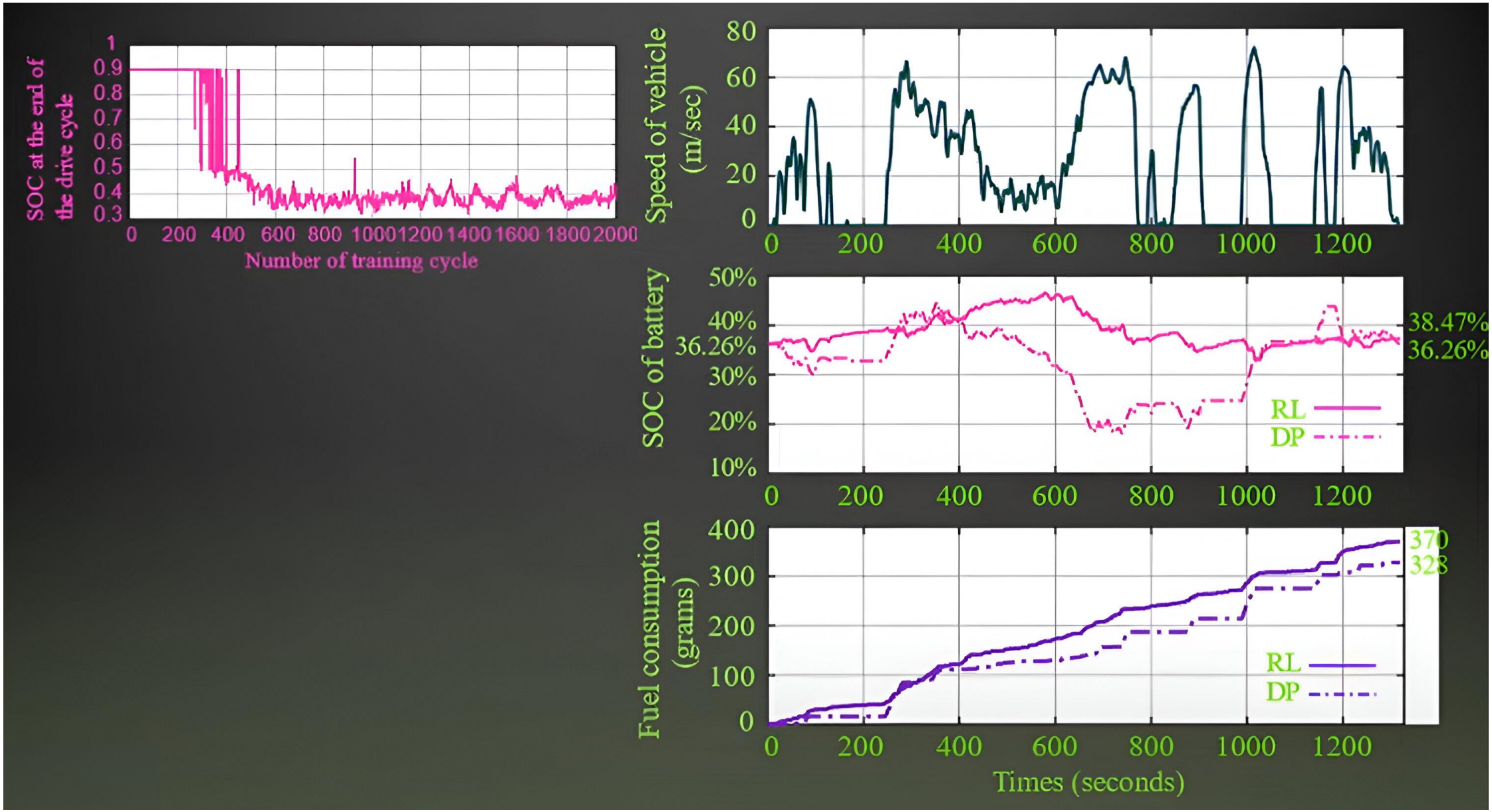
Vehicle enters into the next time step

Deep Reinforcement Learning (DRL)-Enhanced knowledge -Driven EMS Implementation



DDPG based Control Structure

Results of Reinforcement Learning in Energy Management System



Thank you