Design and Control Methodologies for Electrified and Intelligent Vehicles

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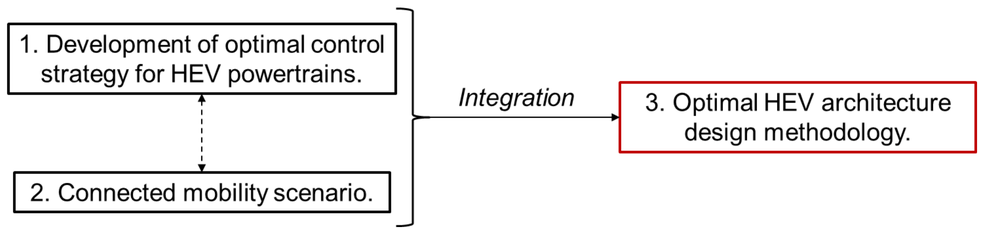
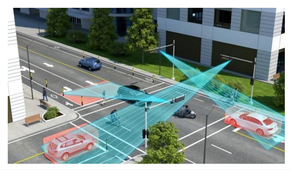
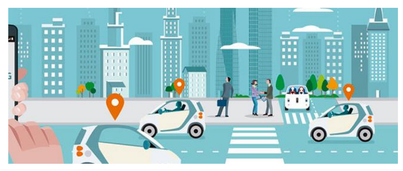
MOTIVATION

- Transportation electrification vision currently represents the leading path in society and automotive industry.
- Control strategy is considered a crucial issue in the design of hybrid electric vehicles (HEVs).
- Finding an energy management strategy that guarantees optimal fuel economy, light computational burden and ease of on-board real-time implementation still represents an open research question.
- Smart, connected, autonomous and shared mobility represents a novel opportunity to develop dedicated and improved approaches for designing and controlling vehicle systems.

RESEARCH PLAN







1. OPTIMAL CONTROL STRATEGIES FOR HEV POWERTRAINS

HEV control

Offline

- Vehicle speed profile known a priori.
- Generally employed in powertrain design (prediction of fuel economy capability).
- Not representative of vehicle operation in real world.

Fuel economy / Rapidity

- Dynamic Programming (DP)
- Pontryagin's Minimum Principle (PMP)
- Power-weighted Efficiency Analysis for Rapid Sizing (PEARS)

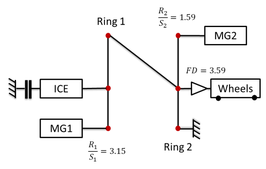
Real-Time

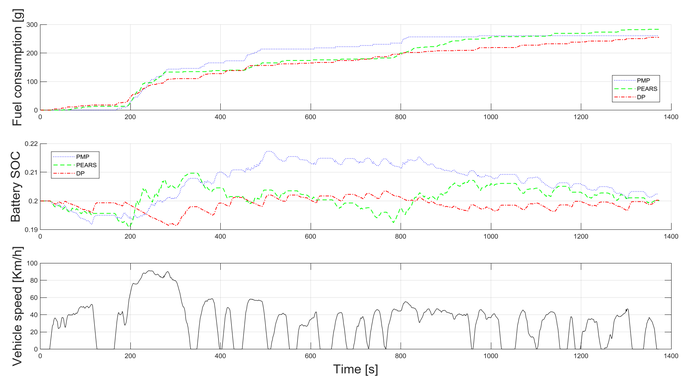
- Future road profile and vehicle speed unknown.
- Difficult to implement in powertrain design.
- Representative of vehicle operation in real world.

Fuel economy / Implementation

- Rule-based
- Equivalent Consumption Minimization Strategy (ECMS)
- Machine learning

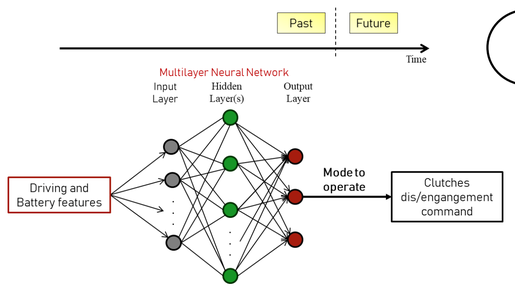
1





Control strategy	UDDS fuel consumption [g]	Computational time* [minutes]
DP	258	5
PMP	261	4
PEARS	284	2

3



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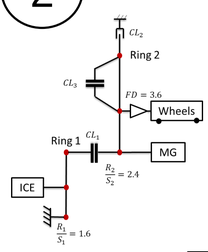
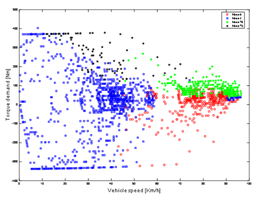
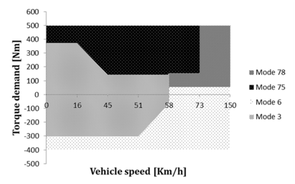


Offline statistics by PEARS (UDDS, HWFET)



Lookup table for real-time control



	Rule-based strategy (real-time)	Improved PEARS (offline)	Increase
WLTP fuel consumption [g]	898	892	0.67 %

What's been done:

- Quasi-static approach with analytical equations and lookup tables (MATLAB©).
- Benchmark study of different offline control strategies [1].
- Detailed study of PEARS [2].
- Development of near-optimal rule-based real-time control strategy [3].
- Implementation of machine learning based real-time control strategy.

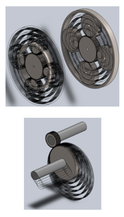
What's next:

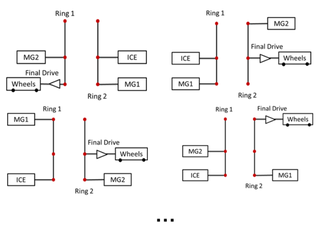
- Validation with more accurate simulation approach.
- Usage of real-world driving data ➔ control strategies refinement.

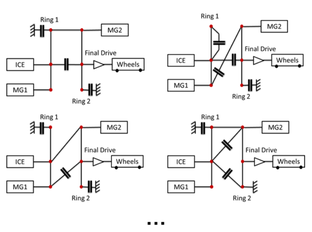
3. OPTIMAL HEV ARCHITECTURE DESIGN METHODOLOGY

- Design space for 2 planetary gear (PG) sets multimode power-split HEV:

1. Gear ratios × 2. PG nodes – power components connections (144 possibilities) × 3. Clutch connections location (7280 possibilities) = Millions of possible transmission designs → Billions of possible designs if component sizing is included

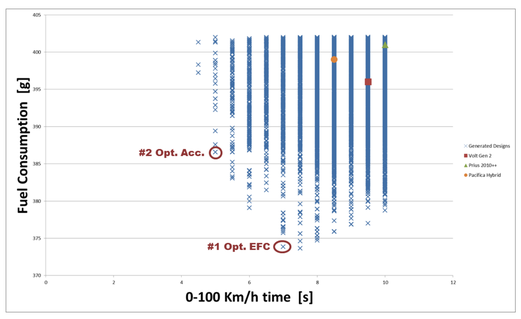


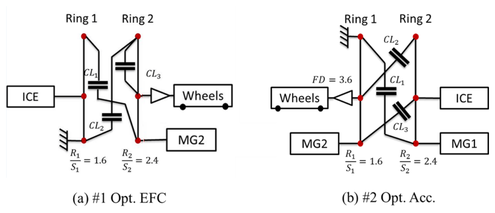




What's been done:

- Clutch connections represent a discrete highly non-linear optimization parameter ➔ design exploration using brute force method and PEARS as offline control strategy [4].
- Designs are assesses based on fuel economy prediction (standard drive cycles) and acceleration capability.





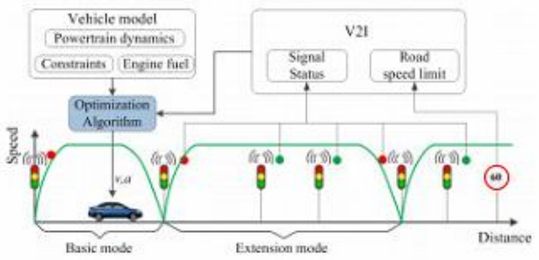
(a) #1 Opt. EFC

(b) #2 Opt. Acc.

What's next:

- Integration of further optimization criterion (real-world emissions, mode-shifting feasibility,…)
- More efficient exploration algorithm for the design space.

2. CONNECTED MOBILITY SCENARIO



State-of-the-art:

- Studies of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications on the fuel economy of traditional engine vehicles [5].
- Developments of personalized eco-driving for intelligent electric vehicles.

What's next:

- Development of control algorithm (energy consumption minimization) for various traffic scenarios including electrified vehicles in connected mobility.
- Integration of connected mobility scenario in the design of vehicle systems (powertrain, brakes, …).

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