Optimal Design of Electrified and Automated Vehicles

Candidate: Pier Giuseppe Anselma
Department of Mechanical and Aerospace Engineering (DIMEAS)
Tutor: Prof. Giovanni Belingardi
XXXIII cycle
A.Y. : 2018/2019
Mail: pier.anselma@polito.it

OUTLOOK

Optimal Design of Electrified and Connected Vehicles

Lines of research

1. Rapid prediction of the fuel economy capability of HEVs
2. Integration of on-line control in the design of HEVs
3. Optimal design of automated electrified vehicles
4. Prediction of battery lifetime in the design of HEVs

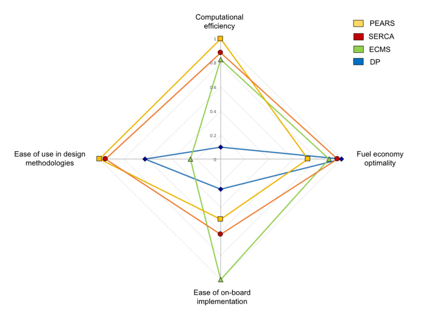
HEV = hybrid electric vehicle

REFERENCES

1. P.G. Anselma, G. Belingardi, “Next generation HEV powertrain design tools: roadmap and challenges”, *SAE Technical Paper* 2019-01-2602, 2019.
2. P.G. Anselma, Y. Huo, J. Roeleveld, G. Belingardi, A. Emadi, “Slope-weighted Energy-based Rapid Control Analysis for Hybrid Electric Vehicles”, *IEEE Transactions on Vehicular Technology*, vol. 68, no. 5, pp. 4458 - 4466, 2019.
3. P.G. Anselma, Y. Huo, J. Roeleveld, G. Belingardi, A. Emadi, “Integration of On-line Control in Optimal Design of Multimode Power-split Hybrid Electric Vehicle Powertrains”, *IEEE Transactions on Vehicular Technology*, vol. 68, no. 4, pp. 3436-3445, 2019.
4. P.G. Anselma, G. Belingardi, “Enhancing Energy Saving Opportunities through Rightsizing of a Battery Electric Vehicle Powertrain for Optimal Cooperative Driving”, *SAE International Journal of Connected and Automated Vehicles*, In press, 2019.
5. S. Ebbesen, P. Elbert, L. Guzzella, "Battery State-of-Health Perceptive Energy Management for Hybrid Electric Vehicles“, *IEEE Transactions on Vehicular Technology*, vol. 61, no. 7, pp. 2893-2900, 2012.

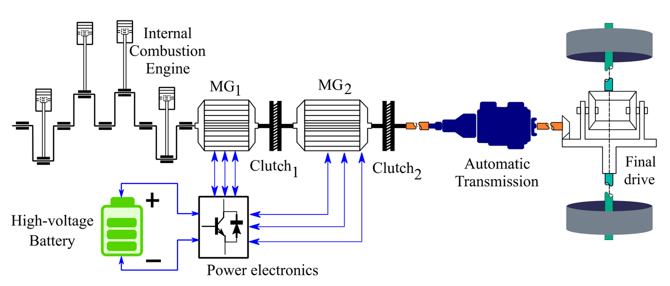
1. RAPID PREDICTION OF THE FUEL ECONOMY CAPABILITY OF HEVs

- Off-line control allows to estimate the ideal fuel economy capability of HEVs ➔ fundamental step to be implemented in HEV design methodologies.
- State-of-the-art of current off-line HEV energy management strategies [1]:
  - Dynamic Programming (DP)
  - Equivalent Consumption Minimization Strategy (ECMS)
  - Power-weighted Efficiency Analysis for Rapid Sizing (PEARS)

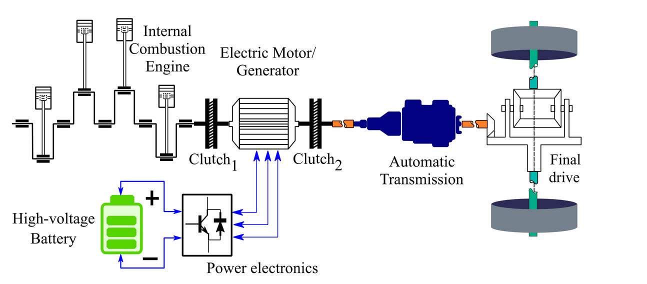


- Introduction of a novel algorithm: **Slope-weighted Energy-based Rapid Control Analysis (SERCA)** [2]
- Successful application of SERCA to various HEV powertrain types:

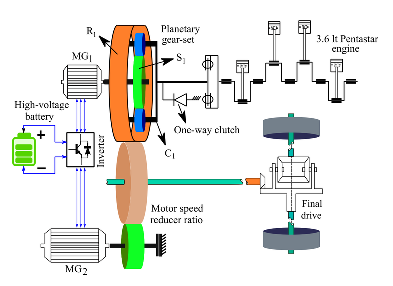
1. Series-parallel (P1P2)



2. Parallel (P2)

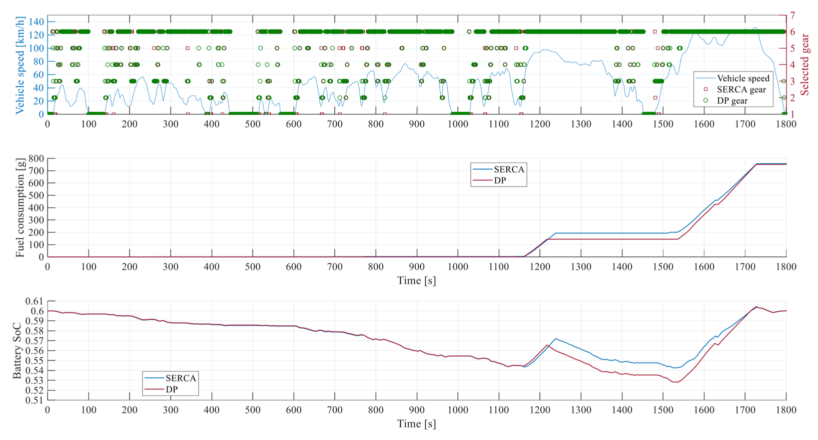


3. Power-split (PS)



EFC = estimated fuel consumption
CT = computational time

	P1P2		P2		PS	
	EFC [l/100 km]	CT	EFC [l/100 km]	CT	EFC [l/100 km]	CT
WLTP (DP)	3.81	399.3 min	4.40	14.9 min	5.20	357.2 min
WLTP (SERCA)	3.82 (+0.26 %)	6.42 min (-98.39 %)	4.46 (+1.57 %)	3.8 s (- 99.57 %)	5.23 (+0.5 %)	283 s (- 98.67 %)



- **What’s next**: integration of the developed algorithm (SERCA) in computer-aided engineering (CAE) tools for designing HEV powertrains.

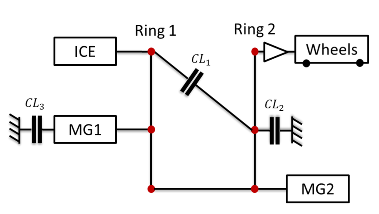
2. INTEGRATION OF ON-LINE CONTROL IN THE DESIGN OF HEVs

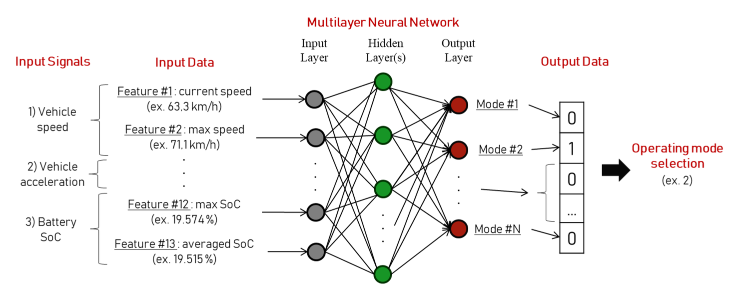
Motivation:

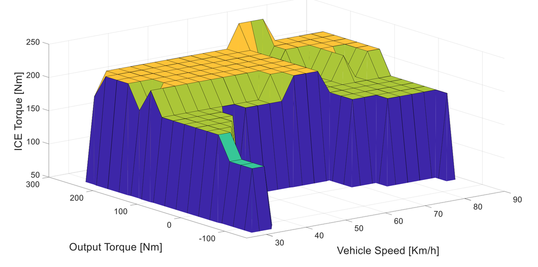
- In HEV design, selection of the powertrain architecture and on-board controller implementation are usually considered in a sequential order ➔ constraints from previous decisions.
- Development of a nested procedure to simultaneously design both the HEV powertrain architecture and the related control logic in early design phases.

Methodology:

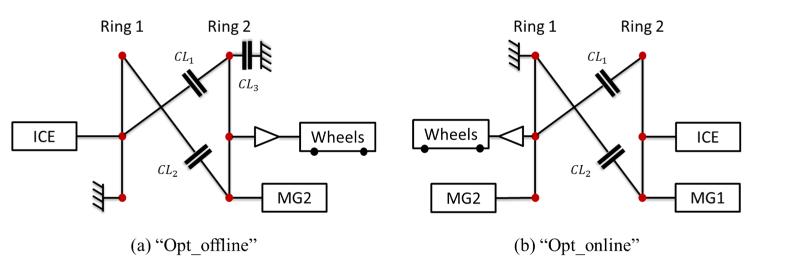
- Multimode power-split HEV powertrains.
- On-line control logic both near-optimal (EFC) and easy to be automatized in HEV design processes.
- 2 levels of control: 1) Power-split ➔ efficiency-based look-up tables
  2) Mode selection ➔ supervised machine learning (neural networks) trained with off-line optimized data







- Integration in an HEV design procedure ➔ **different identified optimal HEV architectures** [3].



	“Opt_off-line”	“Opt_on-line”
WLTP fuel consumption Off-line (iPEARS) [g]	903.9	922.1
WLTP fuel consumption On-line [g]	907.9	905.8
WLTP fuel consumption Off-line (DP) [g]	892.4	899.9
$n_{neurons}$	20	30
n_{layers}	1	1
ΔZ [s]	8	3

What’s next:

- Refining the on-line control strategy (e.g. adaptive power-split, neural network structures).
- Refining the algorithm for exploring the design space.
- More detailed HEV model.

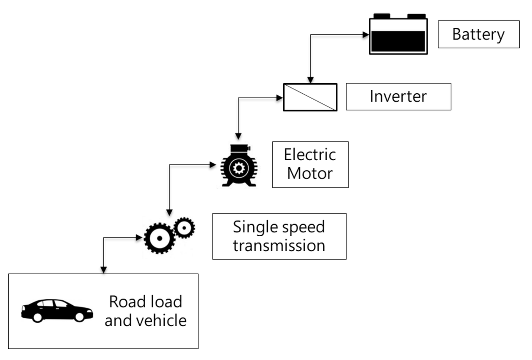
3. OPTIMAL DESIGN OF AUTOMATED ELECTRIFIED VEHICLES

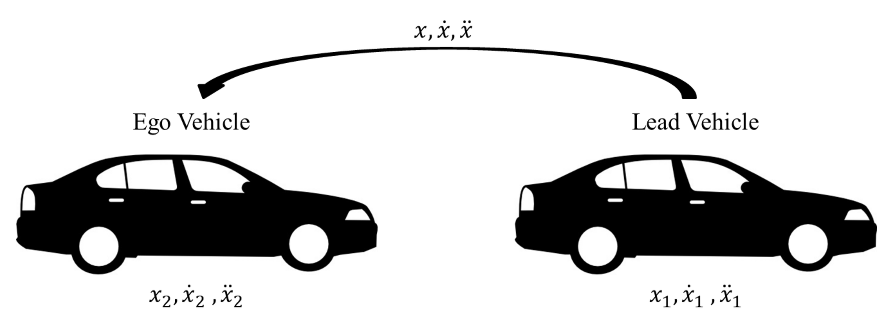
Motivation:

- Current advances in connected and automated mobility claim to change driving scenarios worldwide.
- The impact of automated mobility on the design of vehicle powertrains still need exhaustive assessment.

Methodology:

- Battery electric vehicle (BEV) powertrain.
- Vehicle-to-vehicle (V2V) driving scenario with off-line optimal driving management of Ego Vehicle.

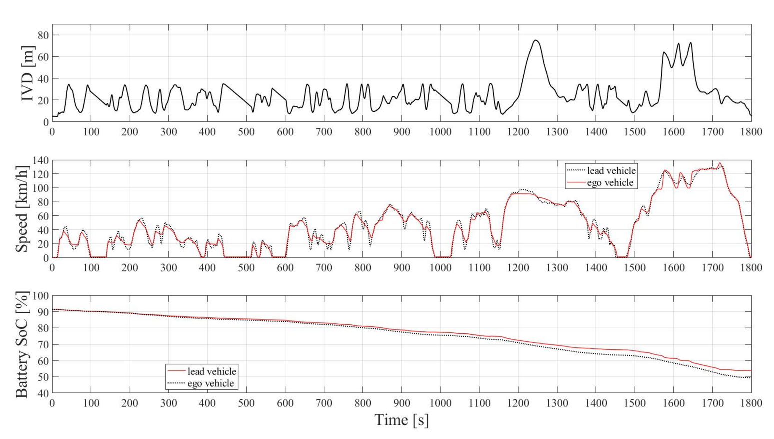


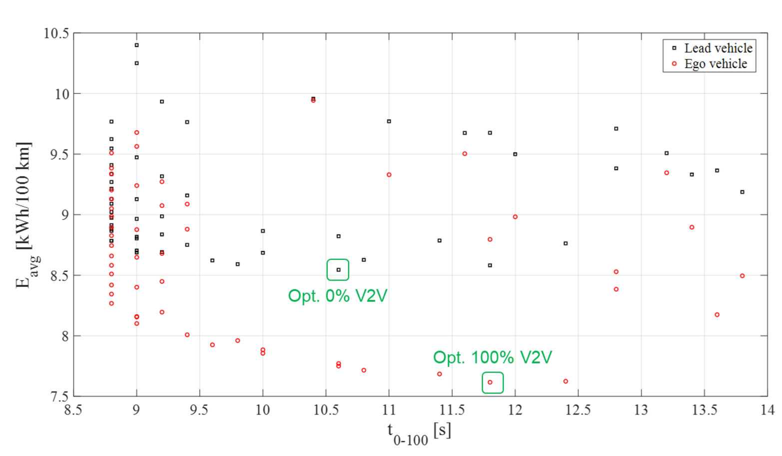


- DP formulation for optimal off-line control in V2V driving for BEVs:

$$J_{DP} = \int_{t_0}^{t_{end}} [e_{batt}(\dot{x}_2, \ddot{x}_2, t) + \alpha_{jerk}]\, dt \qquad U = \{\ddot{x}_2\} \qquad X = \begin{Bmatrix} x_1 - x_2 \\ \dot{x}_2 \end{Bmatrix}$$

- BEV design methodology including V2V driving ➔ **different identified optimal BEV design options** (electric motor size, transmission ratio) [4].





What’s next:

- Development of an on-line controller for optimal V2V driving for BEVs.
- More detailed modelling approach, further driving scenarios.
- Extension to different electrified powertrain architectures (HEVs).

4. PREDICTION OF BATTERY LIFETIME IN THE DESIGN OF HEVs

Motivation:

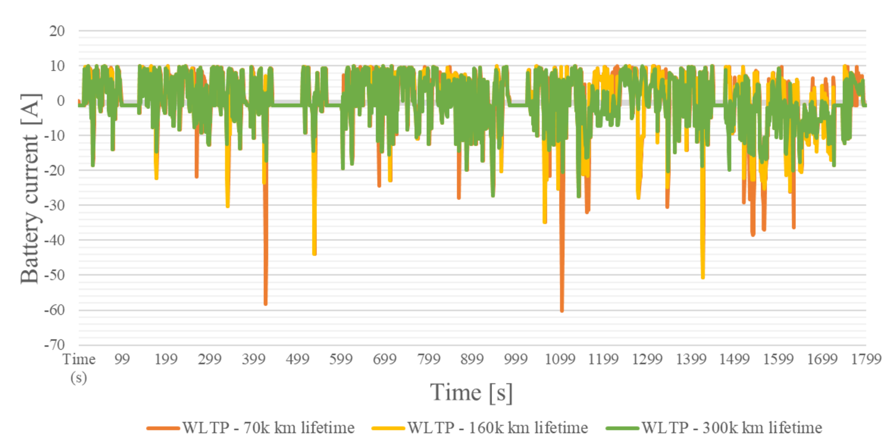
- Accounting for battery lifetime optimization in early design phases of HEVs.
- Numerical models for battery ageing at vehicle level in HEVs exist, but few experimental validation activities have been carried so far.

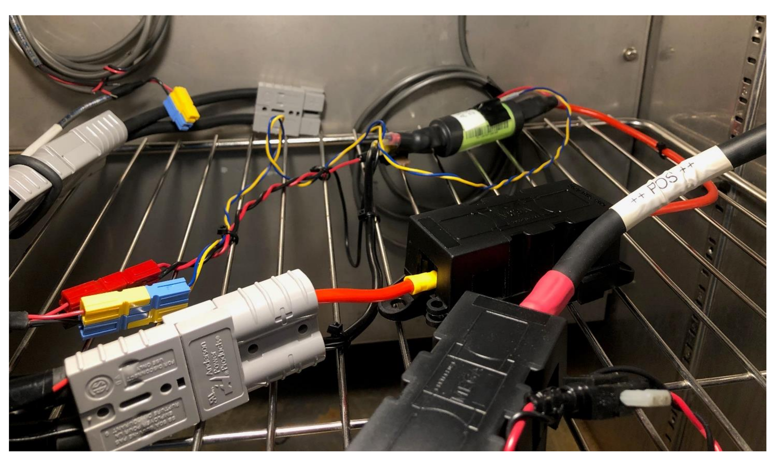
Methodology:

- Power-split HEV powertrain.
- HEV off-line control strategy sensitive to battery state-of-health (SoH).
- Vehicle level battery ageing numerical model from [5].
- DP formulation with a dual-term cost function:

$$J = (m_{fuel} + m_{fuel\_start}) \cdot \$_{fuel} + \lambda_{battery} \cdot \$_{battery} \cdot \alpha_{battery}$$

- Extraction of three battery current profiles with predicted battery lifetime (WLTP).





What’s next:

- Experimental validation of the predicted battery lifetime through ageing tests (to be conducted at McMaster University, Canada).