Optimization of Electric actuation systems

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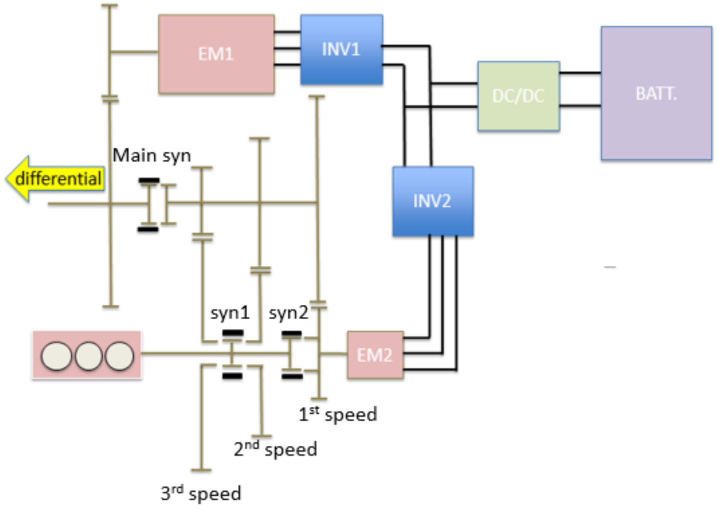
Research context and motivation

Hybrid electric vehicles (HEVs) are combined hybrid and electric vehicles that combine the best features of internal combustion engines (ICEs) and electric motors (Ems). This capability basically is due to: the ability of the rechargeable storage system to recover energy during braking phases (regenerative braking), and the fact that an additional degree of freedom is available to satisfy the power demands from the driver, since power can be split between thermal and electrical paths.

ELdor IHT project introduce a new clutch-less Integrated Hybrid Transmission (IHT) configuration having three energy sources: 2 Ems and an ICE for HEV system. Which allows to operate in both PHEV and SHEV modes, and also can be driven in pure EV mode since ICE can be completely decoupled from electrical part. This novel configuration requires investigation about:

- Checking the feasibility of IHT requirements
- Transmission gearbox design
- IHT vehicle model on Simulink
- Preliminary Torque split strategy

- ECMS for mode decision and Torque split
- Integrated Thermal model of ELDOR_IHT system
- Engine fuel enrich strategy during the transient



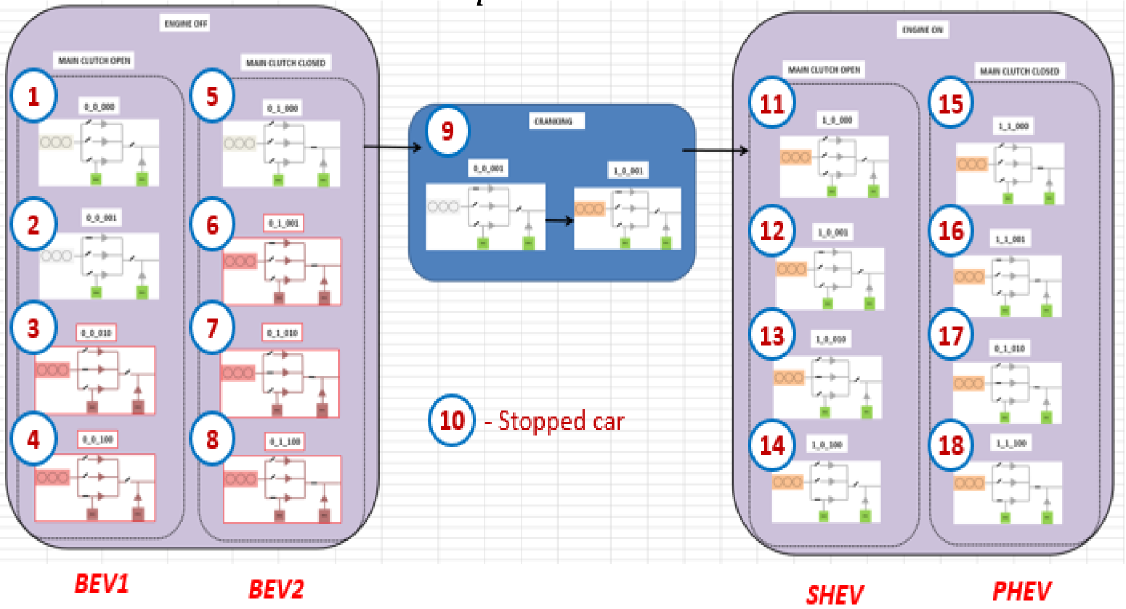
Addressed research problem1

Mode selection based on ECMS

The mode selection system can adjust the driving mode of the HEV according to different road conditions to obtain the optimal use of fuel. The ELDOR_IHT configuration allows the following possible combinations of operation modes as shown in figure (#). There are 4 main operation modes: BEV1, BEV2, SHEV and PPHEV. As well as, each of these modes has 4 sub-modes inside depending on the gear's engagements. Using ECMS (equivalent fuel consumption minimization strategy) best operation mode and gear ratio is selected at each instant. Objective ECMS is to minimize equivalent fuel consumption rate which is sum fuel consumption rate by ICE ($\dot{m}_{ice}$) and equivalent fuel consumption rate of battery ($\dot{m}_{equ}$):

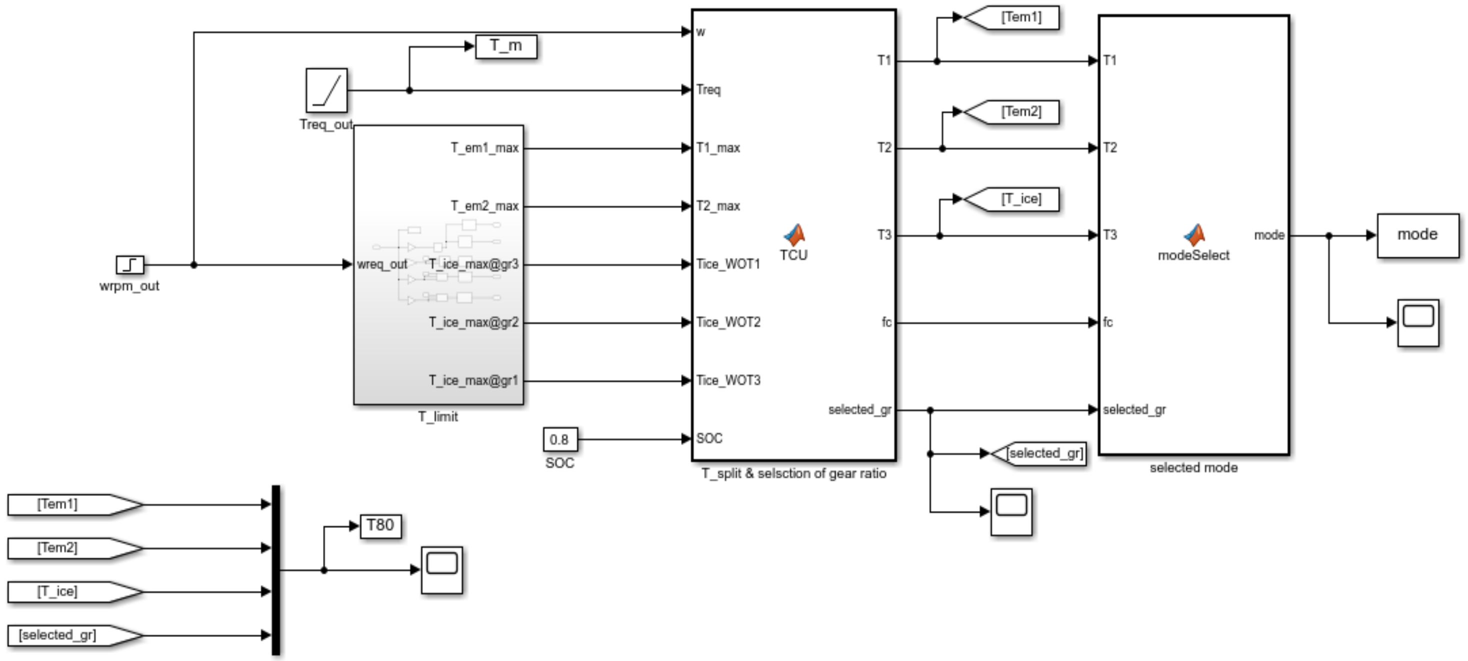
$$FC_{tot} = \dot{m}_f + P(SOC) * \dot{m}_{efc}$$

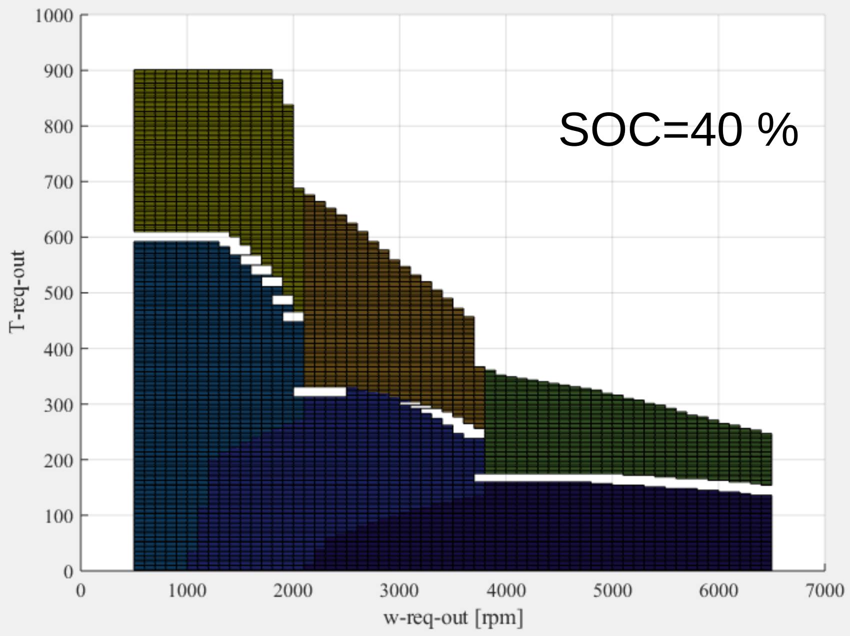
$$\dot{m}_{efc} = \frac{P_{dc}}{Q * \eta_{ice} * \eta_{inv} * \eta_{bat} * \eta_{dcdc}} = \frac{P_{dc}}{Q} * \text{sdis}$$

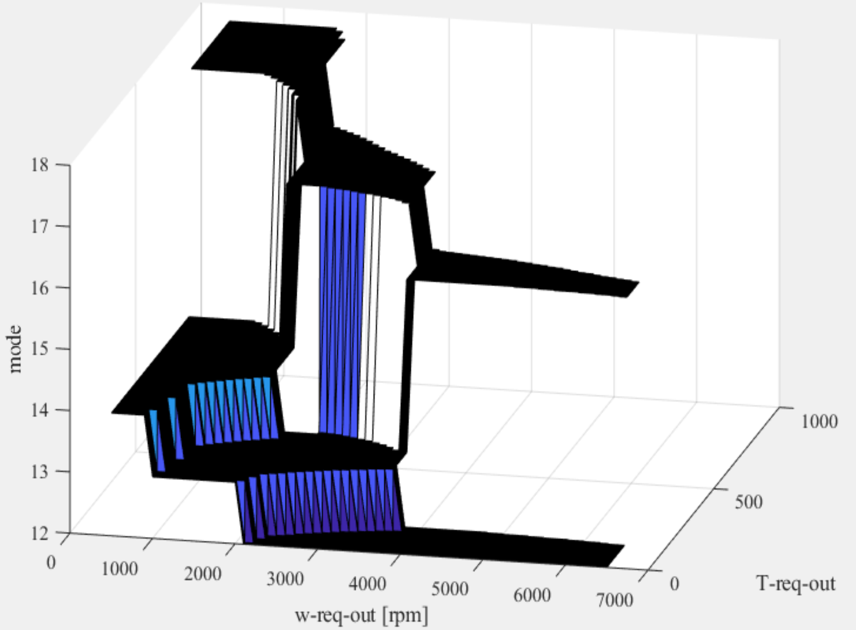


Where:
$\dot{m}_f$ – fuel consumption rate of engine
$\dot{m}_{efc}$ – equivalent fuel consumption rate of electric power
Q – lower heating value of gasoline($4{,}4e4\ \frac{J}{g}$)
P_{dc} – electric power in Inverter
η_{ice} –engine efficiency

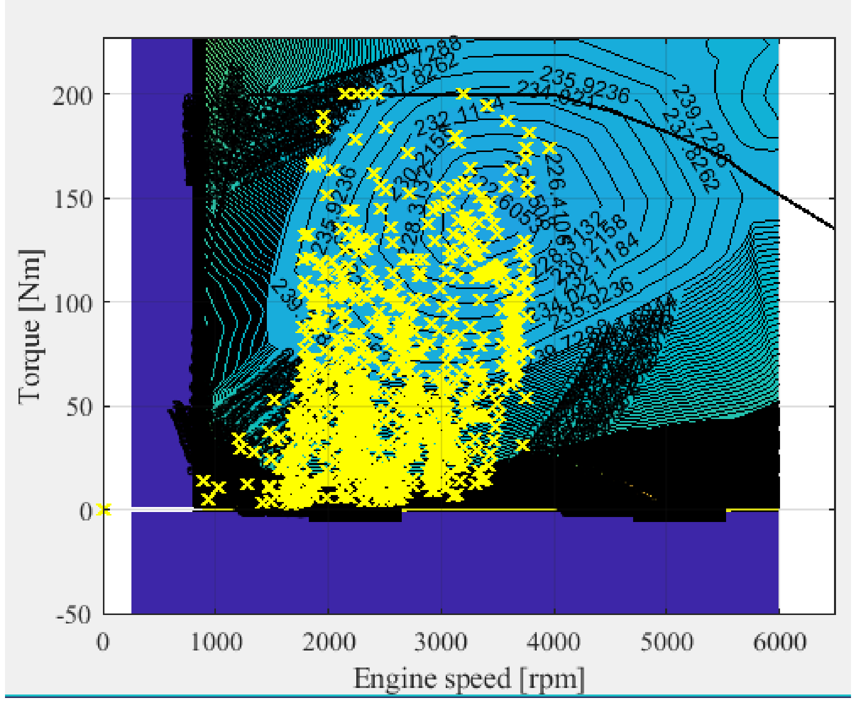
Simulink model of mode decision for a given speed [rpm] and T=[0, 900]Nm

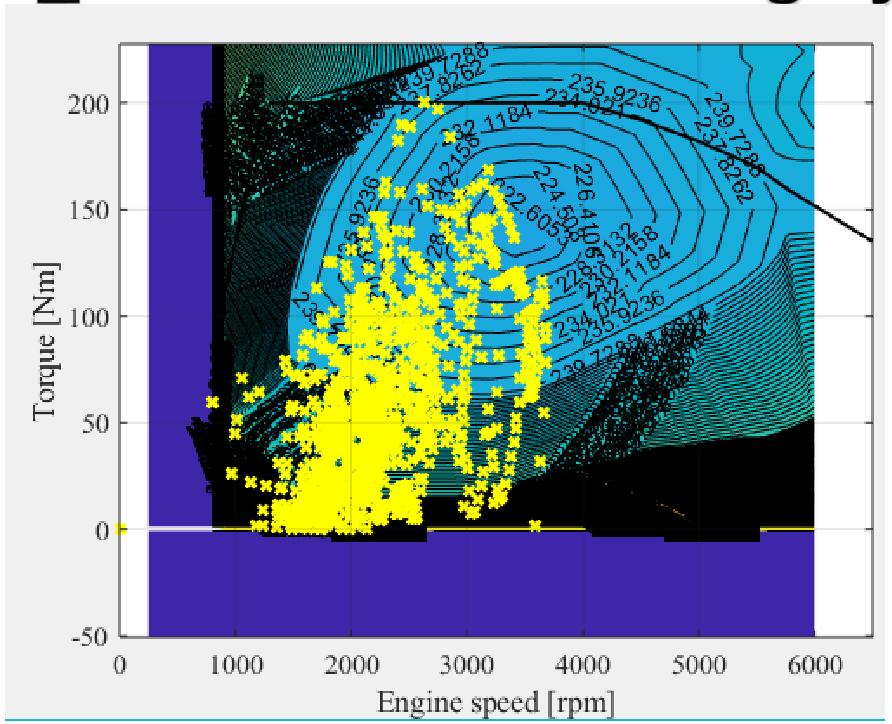






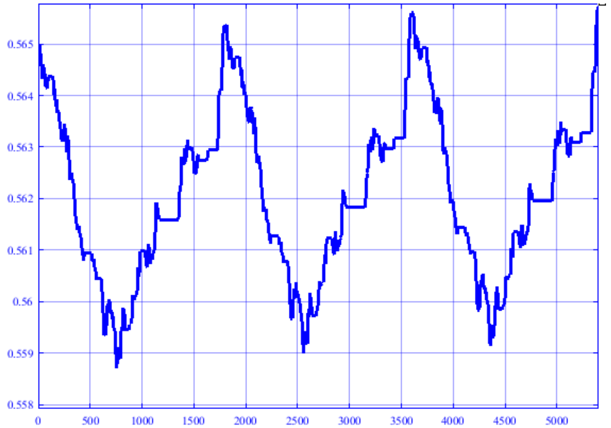
Simulation results on ECMS for ELDOR_IHT on WLTP driving cycle





ELDOR_IHT vehicle in charge sustaining mode: fc=4,505 l/100km

$$eff = \frac{5{,}074 - 4{,}505}{5{,}074} = 10\ \%$$

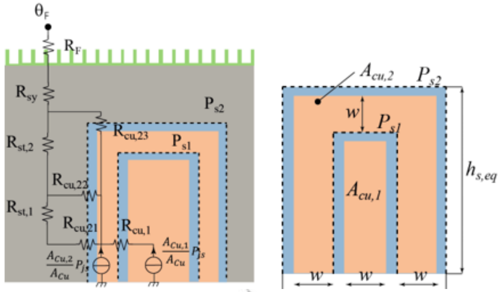


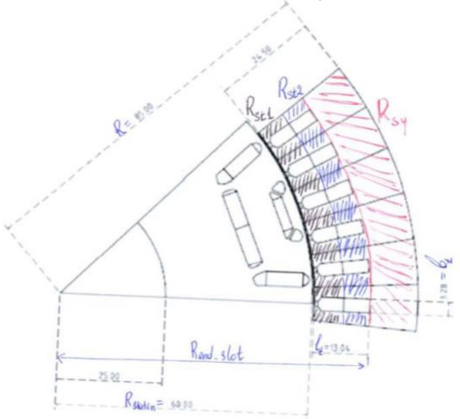
Conventional 5speed vehicle: fc=5,074 l/100km

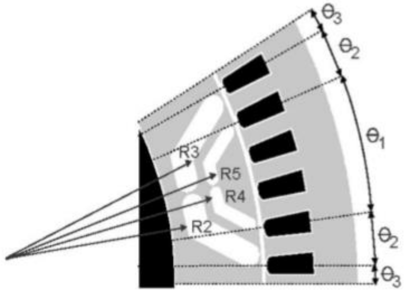
Addressed research problem2

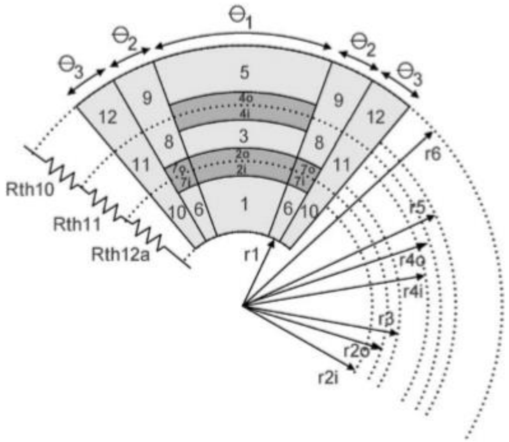
Thermal Modelling

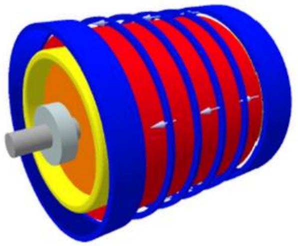
The lumped parameter thermal model in 2D (radial and axial direction) has been successfully developed for thermal analysis of all components of ELDOR_IHT system including: EMs (rotor, stator, air gap, helical cooling jacket…), Inverters, DC/DC converter and battery thermal model. Using thermal and geometric parameters of each component Equivalent Thermal circuit(RC) was developed according to their constructions. Obtained results are validated with the results of MOTOR/CAD software.

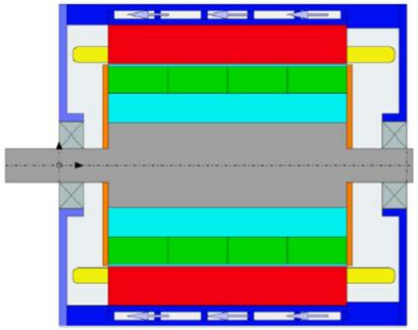


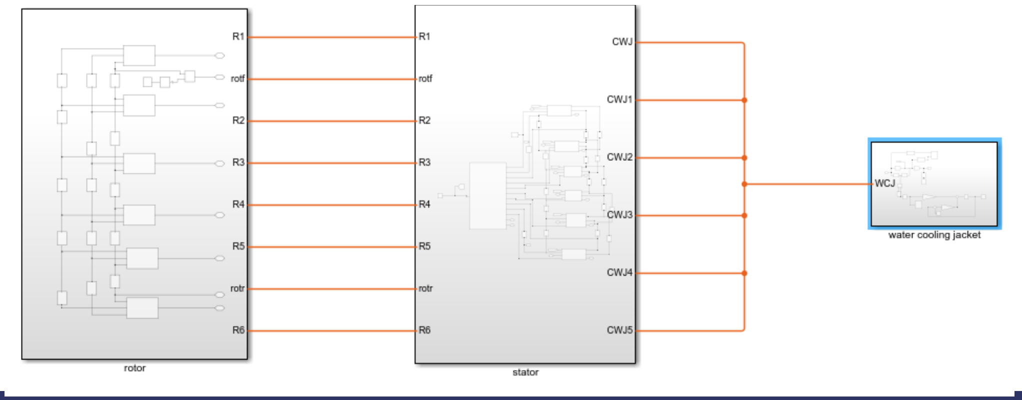




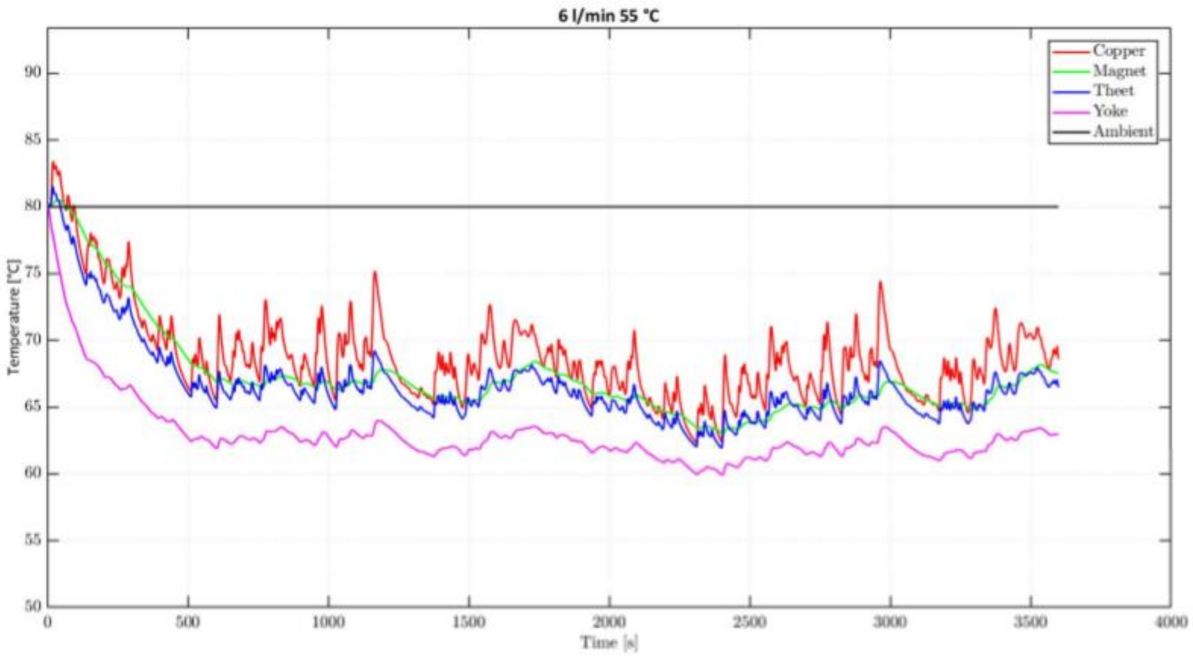


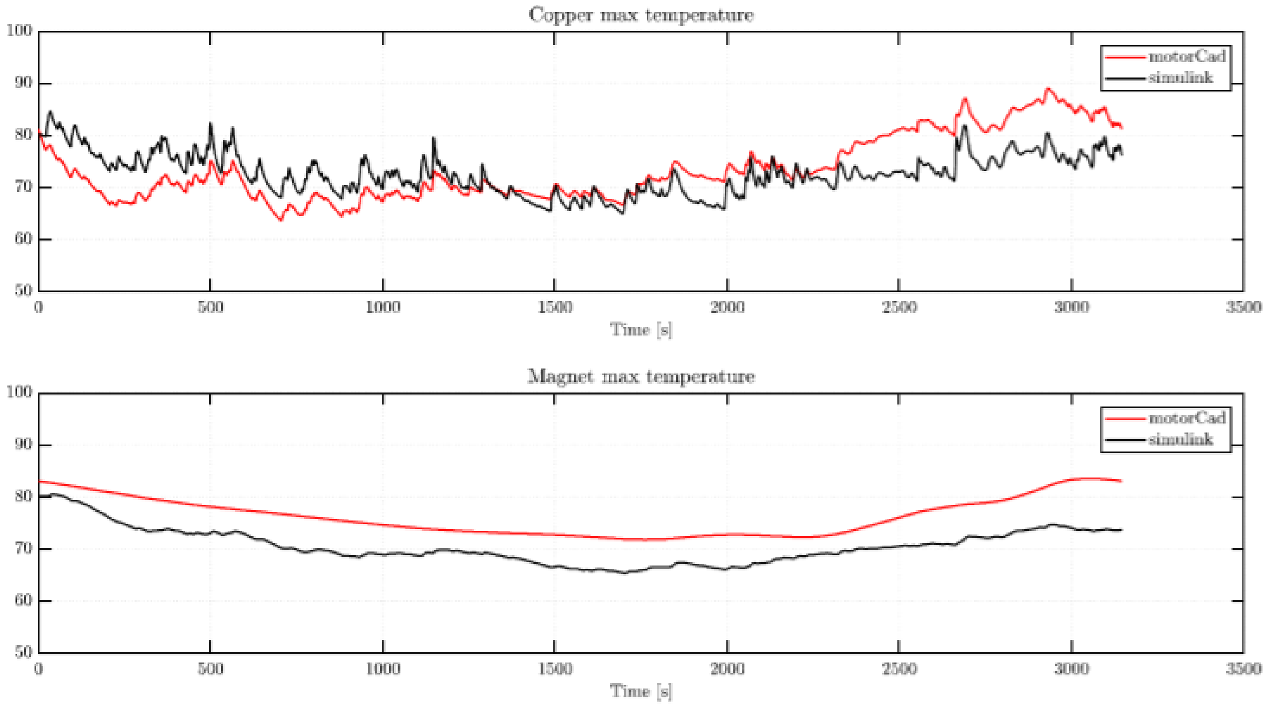






Motor/CAD vs Simulink results for WLTP cycle



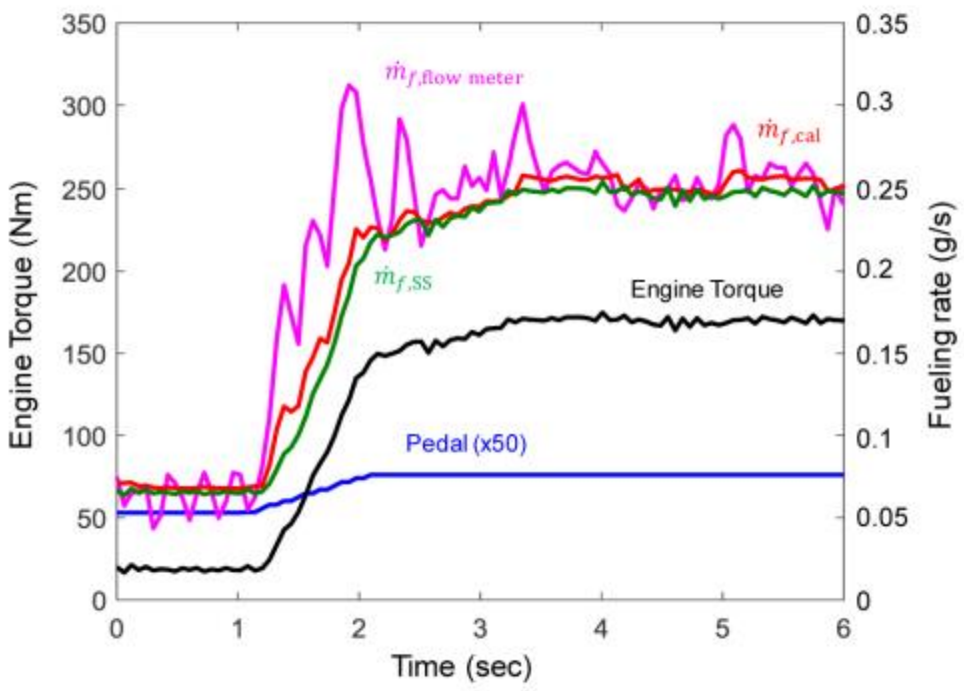


Ongoing work

Engine transient fuel consumption model

A simple model based only on a steady-state fuel map will yield fuel consumption and GHG emissions lower than what is measured during a chassis dynamometer test due to a variety of factors present during transient operation of ICE.

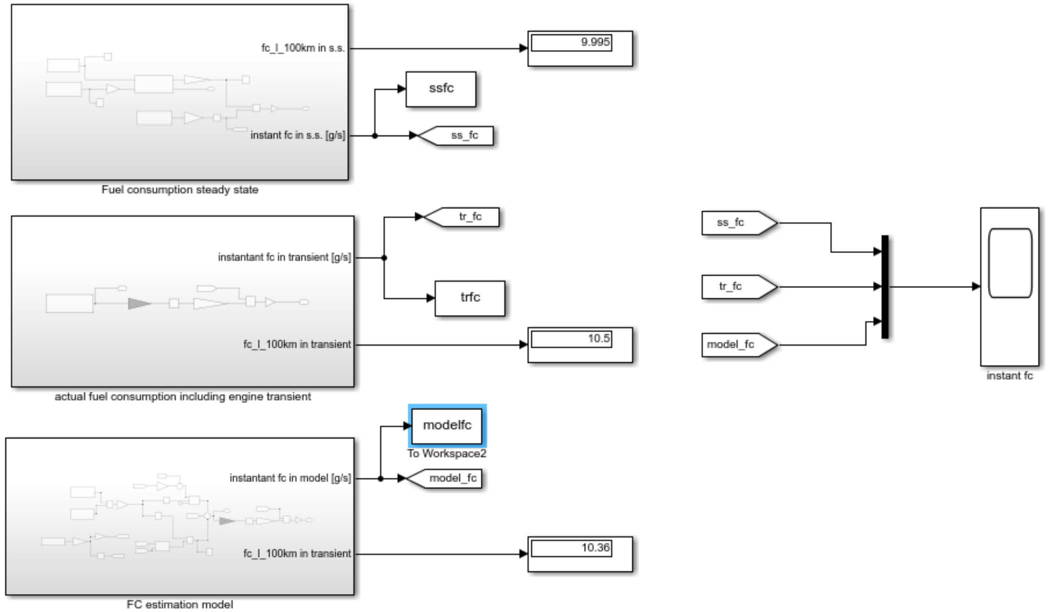
a.



b.

Table 5. Fuel consumption breakdown over drive cycles from ALPHA simulation

Vehicle	Drive Cycle	Steady-State Map Fuel Mass (g) / %	Power Rate Transient Adj. Fuel Mass (g) / %	Transmission Shifting Adj. Fuel Mass (g) / %	CDA Transition Adjustment Fuel Mass (g) / %	Post DFCO Adjustment Fuel Mass (g) / %	Total Fuel Mass (g) / %
Chevrolet Silverado	UDDS	995.03 / 97.68	11.87 / 1.17	7.12 / 0.70	2.90 / 0.28	1.75 / 0.17	1018.67 / 100
	HWFET	932.99 / 98.19	9.00 / 0.95	2.48 / 0.26	3.67 / 0.39	2.03 / 0.21	950.17 / 100
	US06	1167.95 / 96.48	29.02 / 2.40	4.92 / 0.41	4.06 / 0.34	4.65 / 0.38	1210.60 / 100
Ford F-150	UDDS	830.11 / 98.04	8.07 / 0.95	5.98 / 0.71	N/A	2.53 / 0.30	846.71 / 100
	HWFET	807.57 / 98.73	5.08 / 0.62	1.48 / 0.19	N/A	3.79 / 0.46	817.92 / 100
	US06	1052.23 / 96.61	28.46 / 2.61	3.02 / 0.28	N/A	5.46 / 0.50	1089.17 / 100



Future works

- Full ECMS control model for ELDOR_IHT including thermal limitations and engine transient behavior.

- Comparison of ELDOR_IHT parallel/series vs Toyota Prius power split

Thank You !