Which Hybrid Architecture and Control for a 44-ton long-haul truck?

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Abstract

This poster illustrates the work done in the framework of the **SIA Student Challenge 2020**. Our team worked during **6 weeks** on this hybrid truck to design and optimize an architecture that fulfill the specifications.

Subject input data

The SIA gave the truck **mechanical specifications**, available **ICE characteristics** (8L and 13L engine) and **three cycles** that the truck must do (urban, regional, highway).

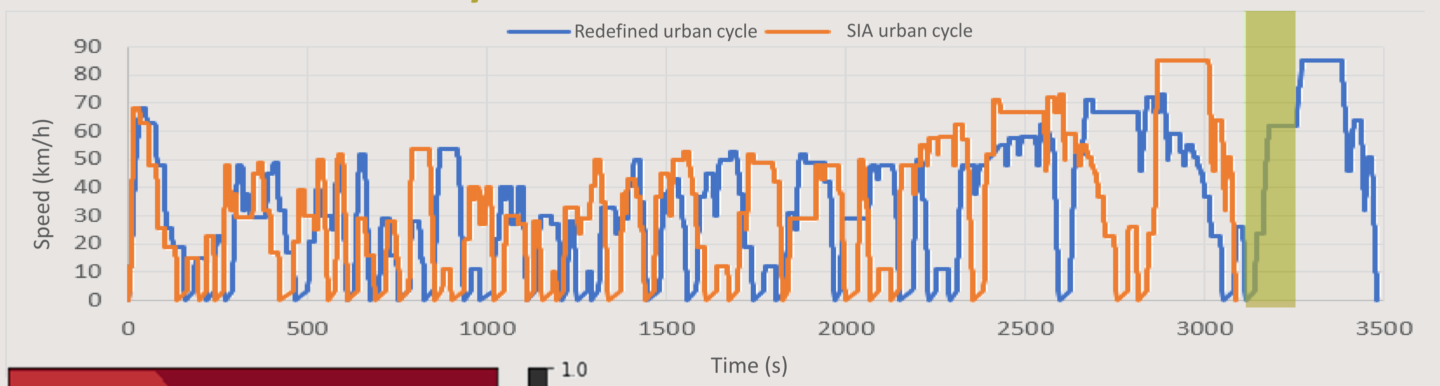
Weight	44000	kg
Crr	5	kg/T
SCx	5.3	m²
Wheel radius	0.5265	m²
Rho diesel	0.845	kg/l
$\eta_{transmission}$	0.95	

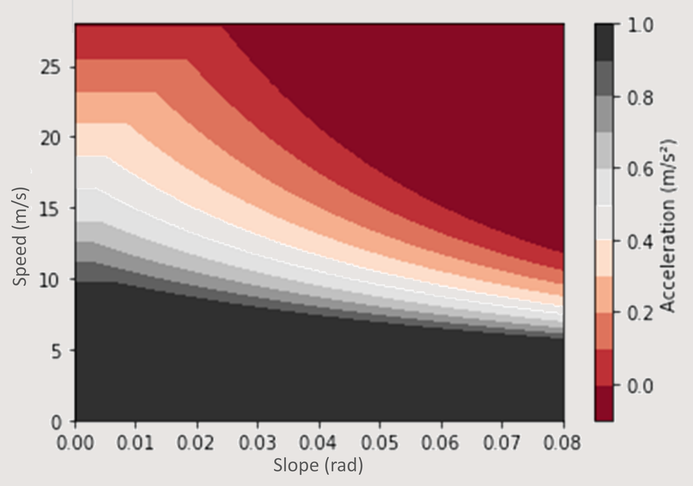
Truck Requirements :

- perform **two** urban cycles in fully electric mode
- carry out the **highway** and **regional** cycles
- **start** electrically on a 12% slope and reach 10km/h
- **drive** at 50km/h on a 5% slope

Redefined cycles for the study

The first calculations we made show us that the cycles **can not** be made by the actual 13L-engine 44T truck. Therefore, we redefined the cycle accelerations in order to achieve the **same cycles** but with **lower** accelerations.



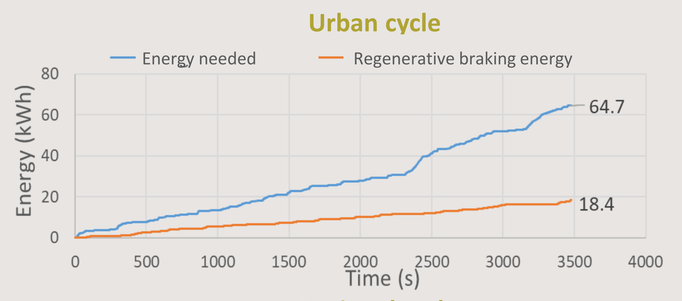


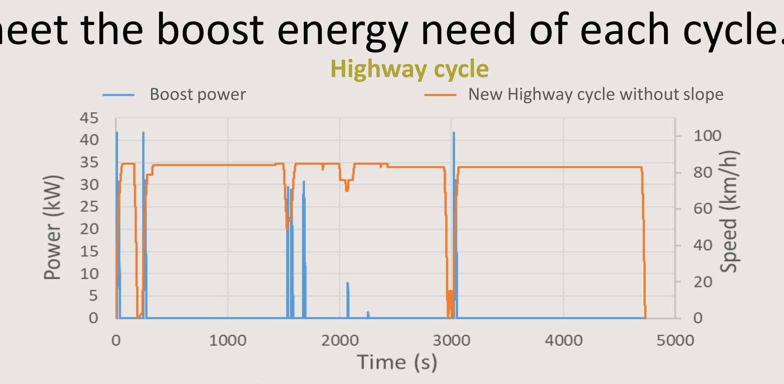
- The original cycles are unrealistic due to **excessive accelerations** ⇨ New acceleration profile depending on **speed** and **slope**
- The new cycle is **6min30s** longer
- Approximately same speed profile

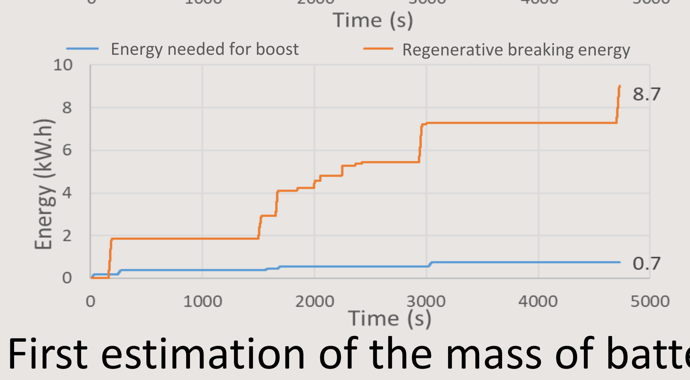
Cycles analysis

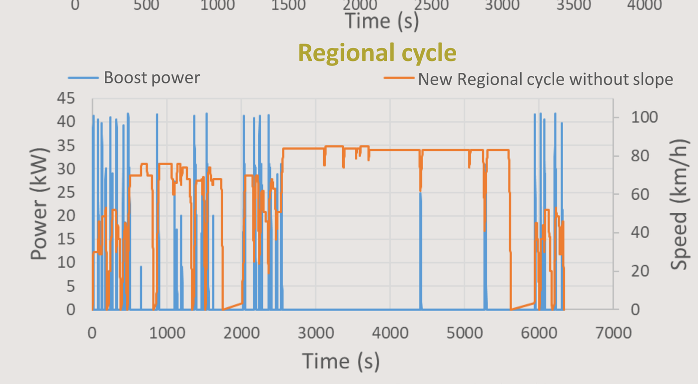
Regenerative energy represent almost **30%** of the energy needed for the urban cycle.

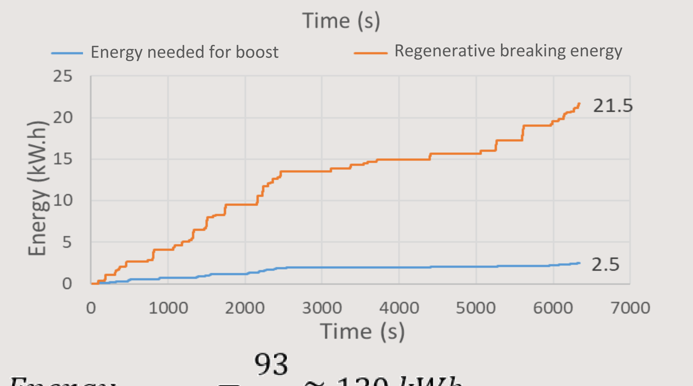
⇨ **93kWh** are needed to do two urban cycles. On the highway and regional cycle, the regenerative braking is comfortable to meet the boost energy need of each cycle.











- First estimation of the mass of battery: $Energy_{battery} = \frac{93}{0.8} \approx 120\ kWh$

With a depth of discharge (DoD) of 80% of the total battery energy and considering that a 102kW battery from a Tesla Model S weighs around 600kg, our truck's battery mass is estimated to be around **650kg**.

Questioning the requirements

The 13L-engine truck develops 350kW to achieve the urban cycle. With such power, the 44T trucks can do :

0% slope		5% slope		10% slope		12% slope	
Pice (W)	V lim(km/h)	Pice (W)	V lim(km/h)	Pice (W)	V lim(km/h)	Pice (W)	V lim(km/h)
350000	>80	350000	44	350000	25	350000	21

Here is what a 44T truck with 250kW can do:

0% slope		5% slope		10% slope		12% slope	
Pice (W)	V lim(km/h)	Pice (W)	V lim(km/h)	Pice (W)	V lim(km/h)	Pice (W)	V lim(km/h)
250000	>80	250000	36	250000	18	250000	16

The reduction of 100kW does not change the performance of the truck **very much**. The performances with 250kW is **quite acceptable** especially for a **fully loaded** truck. A 250kW electric transmission against a 350kW one will have the advantage of being **cheaper** and **lighter** and it always fulfills the most sizing specifications.

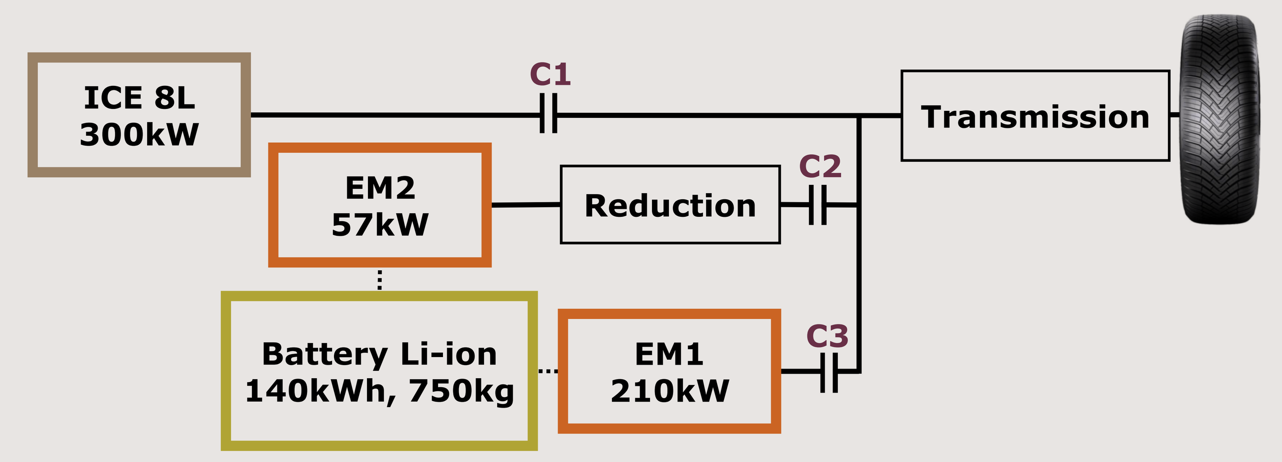
Battery specifications

- Used cell : Lithium ion - Nickel Cadmium Aluminum – Panasonic

U0 cell (V)	Cells		Modules	U0 battery (V)	Energy (kWh)	Estimated Weight
	Number	Serial				
3.925	10521	167	63	655	**140***	**750 kg**

** Considering simulation, transmission efficiency and a safety energy reserve (3min at 50km/h on a 5% slope)*

Hybrid architecture



Hybrid Modes

With the previous architecture, we designed several modes that aim to reduce as much as possible the fuel consumption.

	C1	C2	C3
Full electric	0	1	1
Extra-urban Boost	1	1	0
Recharging via ICE	1	1	1
Regenerative Braking	0	0	1
ICE Optimal Performances	1	1	1
Electric Take-off	0	1	0

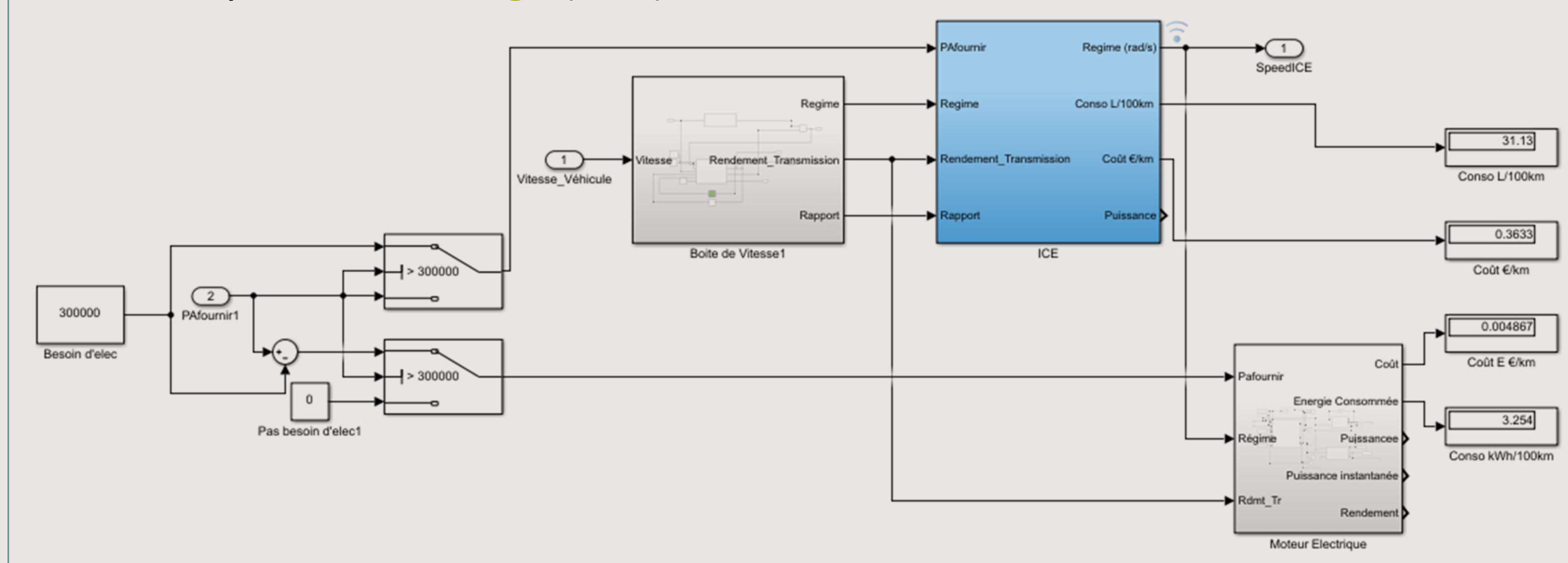
- Full electric mode ensure **maximal performances** on urban cycle
- Electric take-off is possible on a **12% slope**
- **50km/h** on a **5% slope** is carried out with Boost mode

1: Engaged ; 0: Disengaged

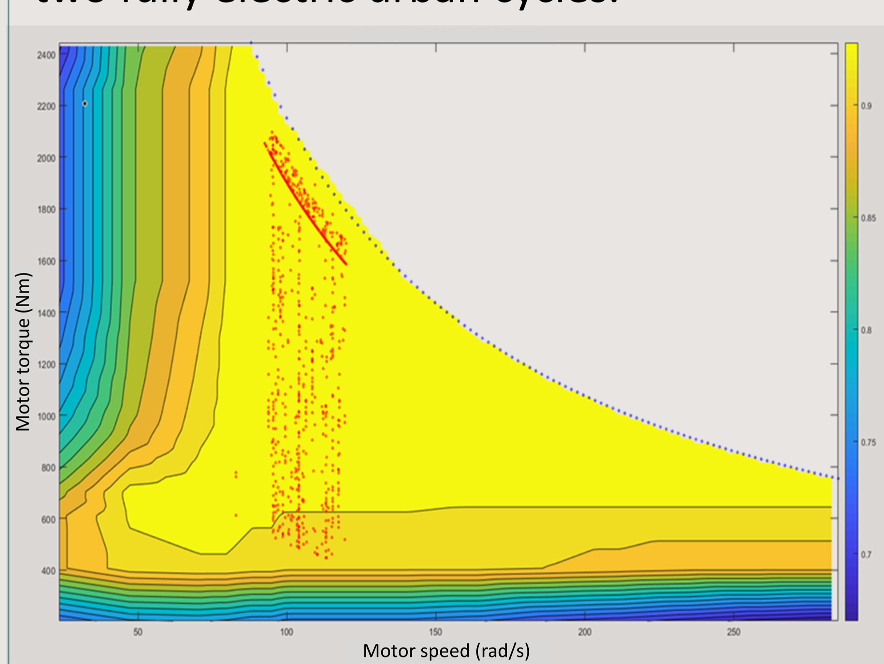
1 means that it depends on the required power

Modelling

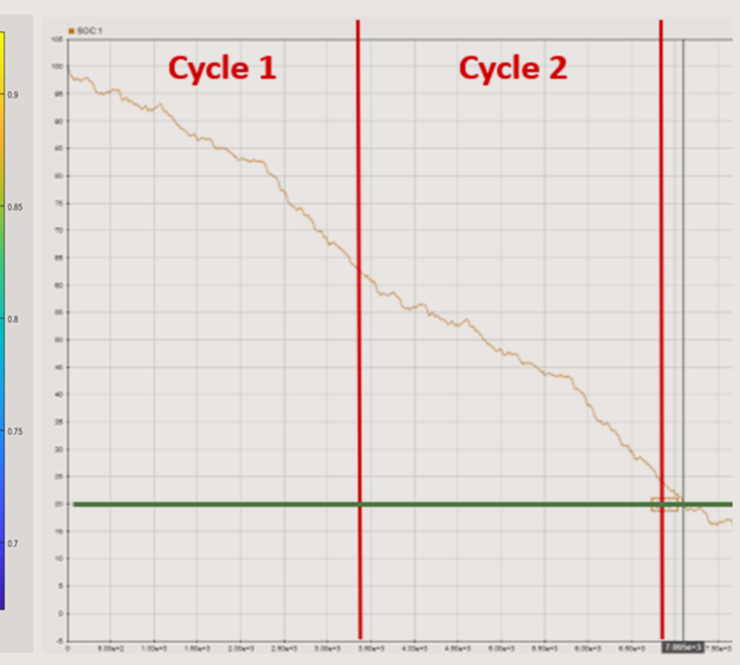
We developed a Matlab-Simulink model to **simulate** the cycles. Input data are cycles and the simulations gives **fuel consumption**, **energy consumption** and the battery **State of Charge** (SOC).



This simulation also specified the **operating points** of the machines and helped us to decide whether one or two machines is suitable. This simulation provided the proof that the chosen **energy of the battery** meets the specification of the two fully electric urban cycles.



210kW EM operating point on urban cycle



2 urban cycles simulation. Final SoC is 24%, 4% still usable after these cycles (safety)

Results

			13L-engine Truck	Hybrid Truck	Gain
HIGHWAY	*Diesel*	L/100km	25.86	25.04	**-3%**
	Electricity	kWh/100km	0	0*	
	Cost	€/100km	33.62	32.55	**-3%**
REGIONAL	*Diesel*	L/100km	29.2	25.26	**-14%**
	Electricity	kWh/100km	0	14	
	Cost	€/100km	37.96	34.94	**-9%**
URBAN	*Diesel*	L/100km	45.69	0	**-100%**
	Electricity	kWh/100km	0	204.6	
	Cost	€/100km	59.40	30.69	**-48%**

** At the end of a highway cycle, the battery is fully recharged thanks to regenerative braking.*

To go further

- Find and use the 8L-engine associated **gearbox**
- Replace the 8L-engine by a **5L-engine**
- **Optimize** the modes on the simulation

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