MECAPROM

E-Tract project
Deliverable 2.1 - Adaptors

1. System concept

1.1. Aim of the system

The design is aimed to create a fully mechanically integrated electric traction system for electrification of minibus and light duty vehicles.
The system shall be embedding high speed motor coupled with multi-ratio innovative three-axes transmission with synchro-meshes and electro-hydraulic actuation for on-line optimization of overall system efficiency and exploitation.
The transmission fit in both passenger cars and 4.2 tons applications.
The system is flexible, efficient, cost effective, compact and mechanically simple.
Figure 1 summarizes the transmission key points at a glance.

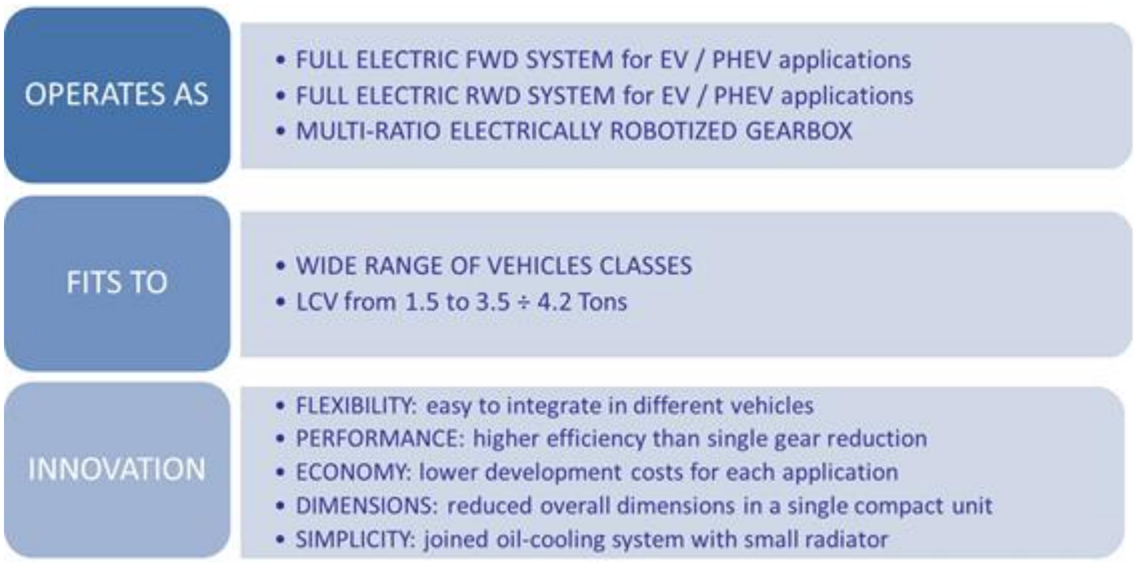


Figure 1 – Transmission key points.

1.1. Mechanical concept

Fulfilling the aim of flexibility leads to the requirements that the system can be supported on the chassis and suspension assembly. Proposed design is depicted in Figure 2-a) where the innovative transmission, consisting in electric motor coupled to gearbox, is directly connected to axle by means of an embedded differential gear-set.

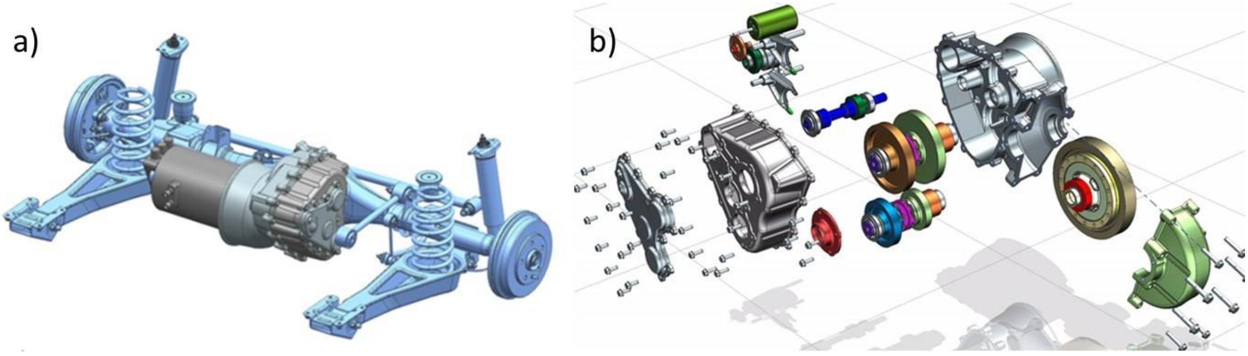


Figure 2 – Installation and parts explosion.

Main gearbox shaft (blue) is coupled with 2 secondary shaft (bronze) which are connected to planetary gear (gold). This solution allows for a sequential gear disposal with an integrated open differential targeting for performance and economy aims. Indeed, provided four gear system ensure fitting the power unit in different applications possibly depopulating some gear ratio. This allows for scale economy and consequently and efficient cost reduction making the system affordable for a business consisting in several different applications whit limited number of pieces for year. Moreover, the system itself can be more efficient considering the possibility of selecting different motor operating point for any given set point required by the driver.

Compared to the original forecast, the fully mechanically integrated electric traction system realized was to be implemented on a Fiat Ducato 2.3 M-JET minibus (14 seats), with a GVW up to 3.5 t, this activity has not yet been completed but will be finished by Mecaprom after the end of the project, as indicated in the recovery plan.

The following figures shows the final layout of the innovative transmission:

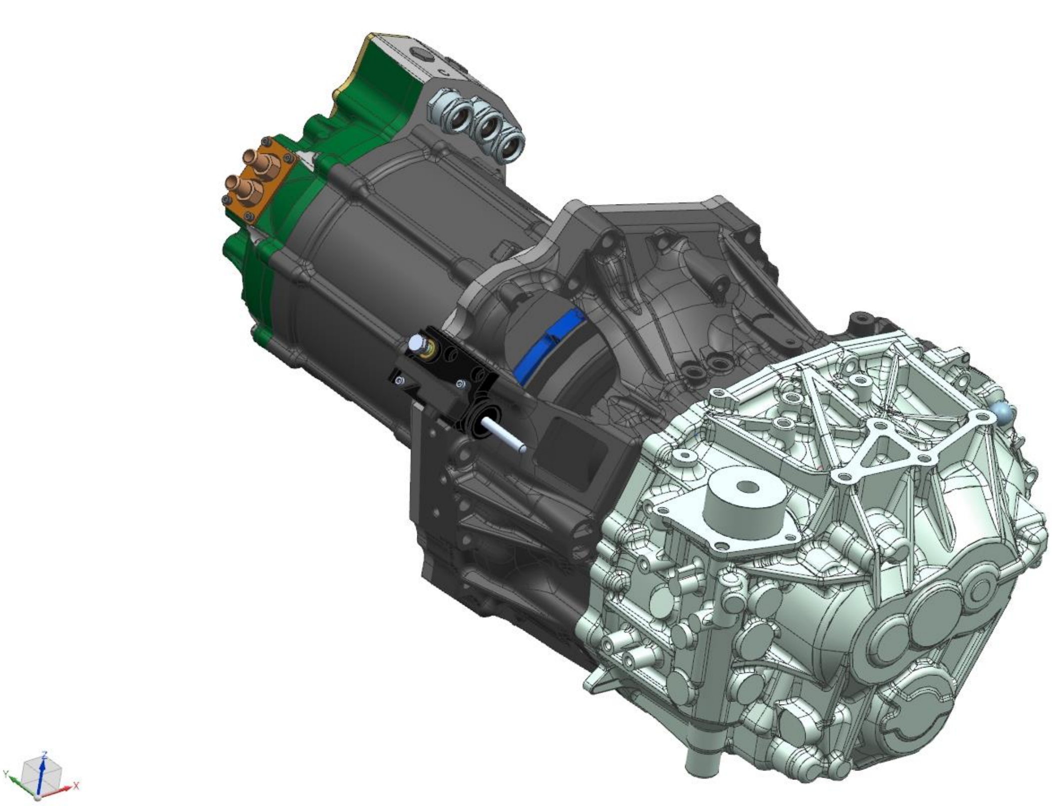


Figure 3 – Layout (front view)

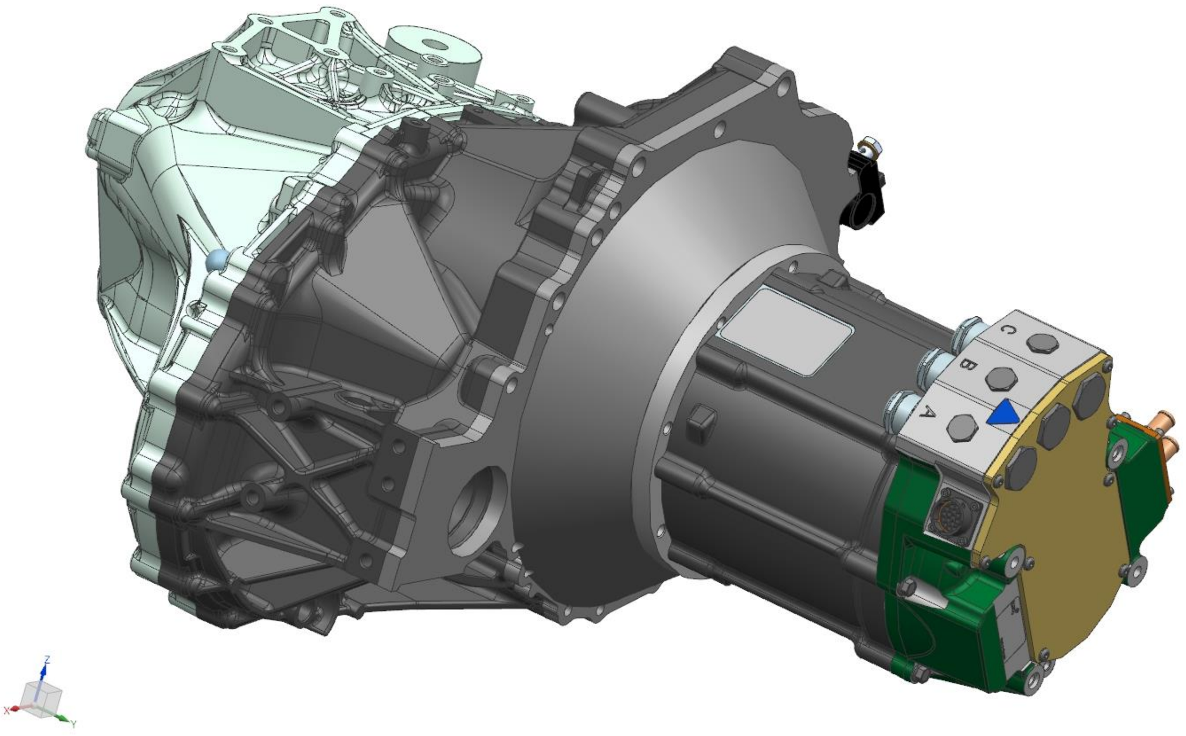


Figure 4 – Layout (rear view)

The following figures shows instead the realization of the integrated electric traction system:

Figure 4 – Integrated electric traction system

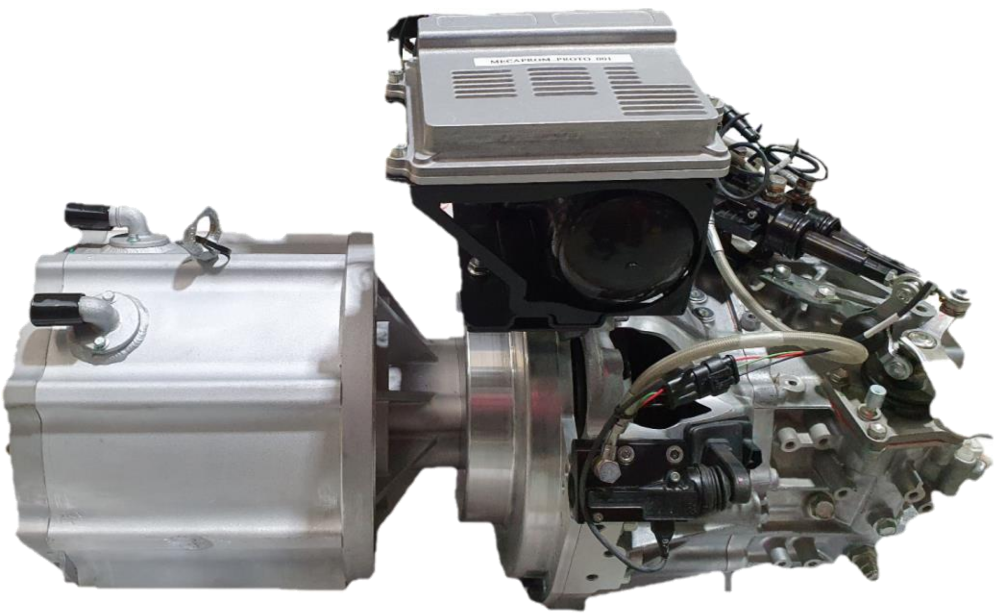
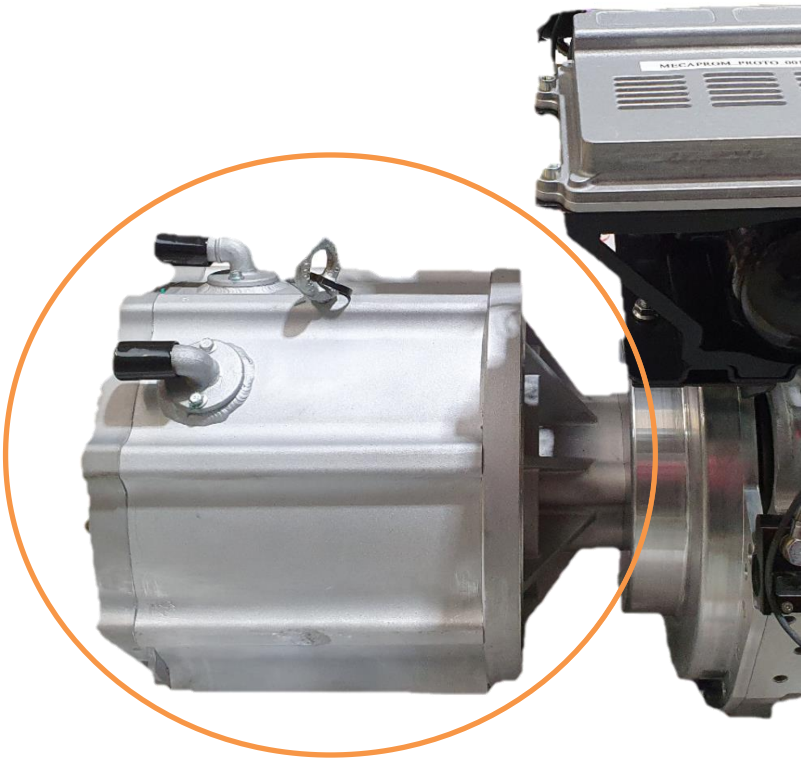
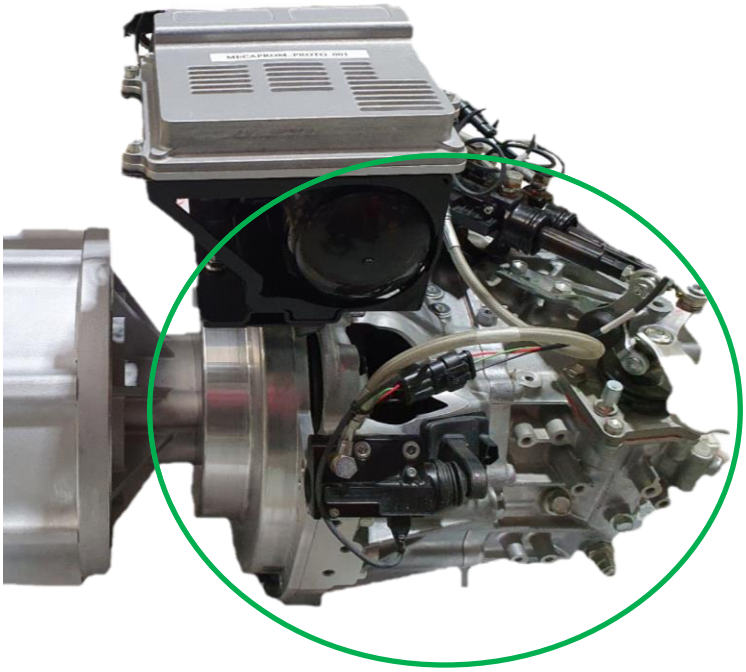


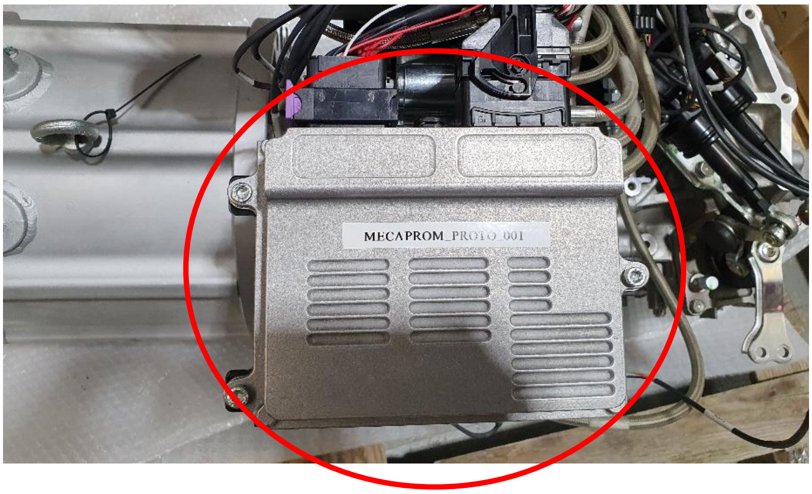
Figure 4 – Integrated electric traction system – Lateral view



Electric drive system



Transmission system



ECU

In the figures above it is possible see the other main components of the integrated electric traction system:

- **Electric drive system**
- **ECU** (Electronic Control Unit)

Electric drive system

Electric drive system converts incoming electrical energy into outgoing mechanical energy. Each drive consists of an electric motor and a controller. In this way it is possible to make the motor follow a desired behavior for a predetermined purpose.

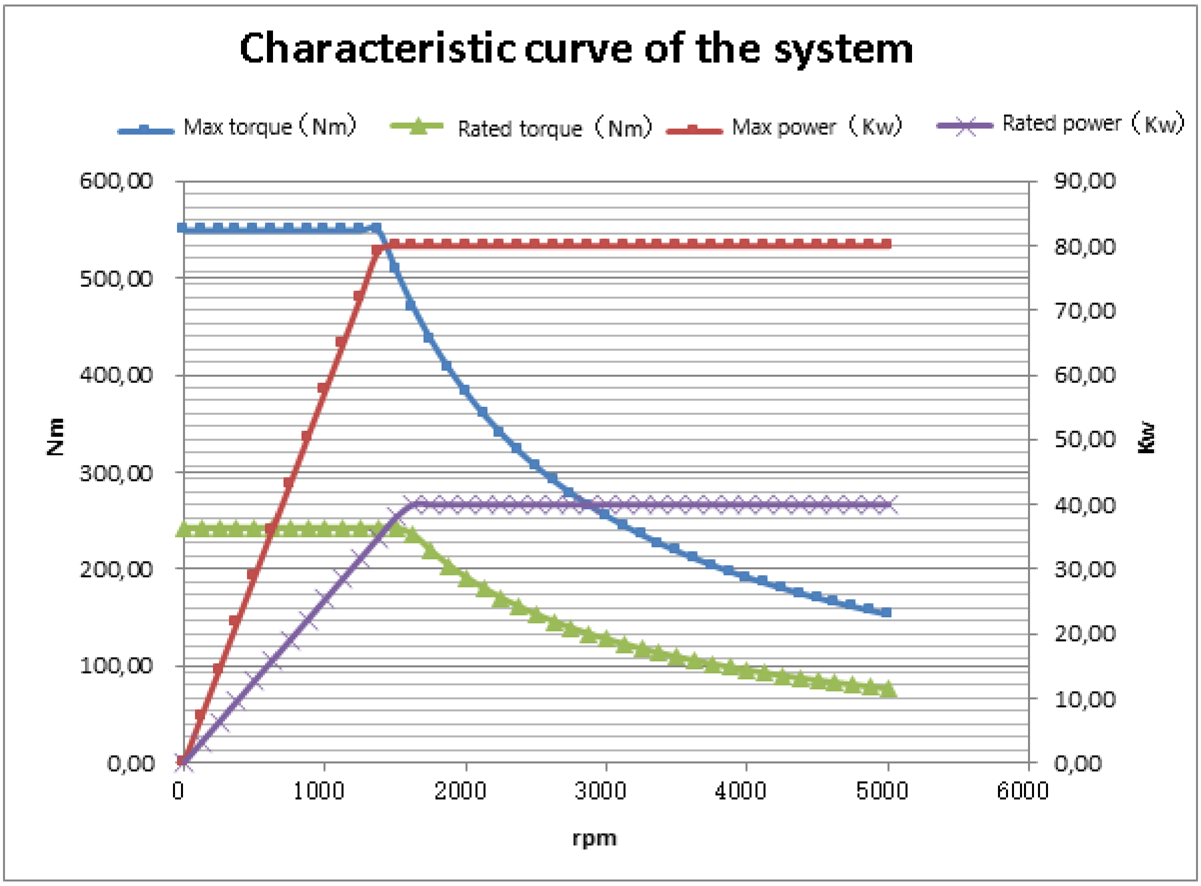
At the start of the project, an Italian supplier (Magneti Marelli) was selected, unfortunately, months later, the supplier of the selected motor was not able to guarantee improved performances and parts supply, because of company merge in a bigger worldwide industrial group. In the meantime, the improvement of the requirements due to the updated simulations performed by Mecaprom, has established the need for a higher peak output torque of the engine (going from 320 Nm from the first evaluations to the current 550Nm), however reducing the maximum engine speed up to 5000rpm.

As a consequence, a new market analysis and search was necessary, and the search of alternative suppliers was done.

The electric motor chosen has these characteristics:

Motor parameters	Product number	TZ260XSDE4 (BMLA55-XQL)
	Rated power (kW)	40
	Maximum power (kW)	80

	Rated torque (Nm)	242
	Peak torque (Nm)	550
	Rated speed (rpm)	1575
	Maximum speed (rpm)	5000
	Insulation class	H
	Cooling method (cooling)	Water cooling
	Protection level	IP67
	Dimensions (outer diameter / length) (mm)	Φ 326*280mm
	Outer diameter of water nozzle	Φ20
	Mass (kg)	81
	Motor rotation direction	Counterclockwise



A related and fundamental component for the usage of the electric motor is the controller, used to produce a variable output voltage range, that are used within motor speed controllers. Control and feedback circuitry is used to adjust the final output of the inverter section which will ultimately determine the speed of the motor, operating under its mechanical load.

The controller chosen has these characteristics:

Controller parameters	Product number	KTZ38X40SG3B (PC30-N)
	Rated battery input voltage (V)	380
	Battery input voltage range (V)	333 - 437
	Low-voltage power supply voltage (V)	12
	Rated output current (A)	200
	Maximum output current (A)	400
	Rated capacity (KVA)	60
	Maximum capacity (KVA)	120
	Protection level	IP67
	Outer diameter of water nozzle	Φ 16
	Body size (mm)	300 * 284 *149
	Mass (kg)	15

In the figure below it is possible to focus attention on the attachment flange between the electric motor and the transmission.
The flange has been specially made to allow the connection between the two systems and has been designed in a flexible and robust way to withstand the stresses and vibrations of the vehicle.

The thicknesses of the motor connection interfaces and those of the flange were such as to constitute an oversized coupling without further exceeding with weights and dimensions that would have been useless.

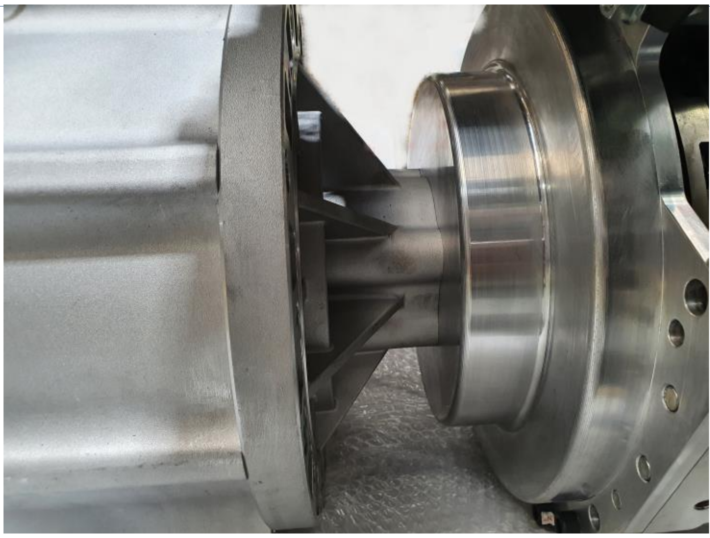


Figure 5 – Flange

ECU (Electronic Control Unit)

A suitable ECU (Electronic Control Unit) shall be implemented for managing the innovative transmission, in particular considering that some function, which is mechanically implemented in traditional AMTs and DCTs, is now implemented by control strategies. In order to be cost effective, ECU shall concentrate and substitute all auxiliary relays used to drive electric ancillaries.

ECU shall be capable of:

- managing vehicle input signal (e.g. accelerator, brake, shift lever, etc.);
- driving main electric ancillaries (e.g. back up light, brake pump enable, etc.);
- controlling and protecting power supply (e.g. A/C compressor, water pump, etc.);
- managing communication networks (e.g. CAN, LIN) to interface original equipment and electric powertrain devices;
- managing fault diagnoses and implementing recovery strategies;
- implementing wheel torque-based traction control logics.

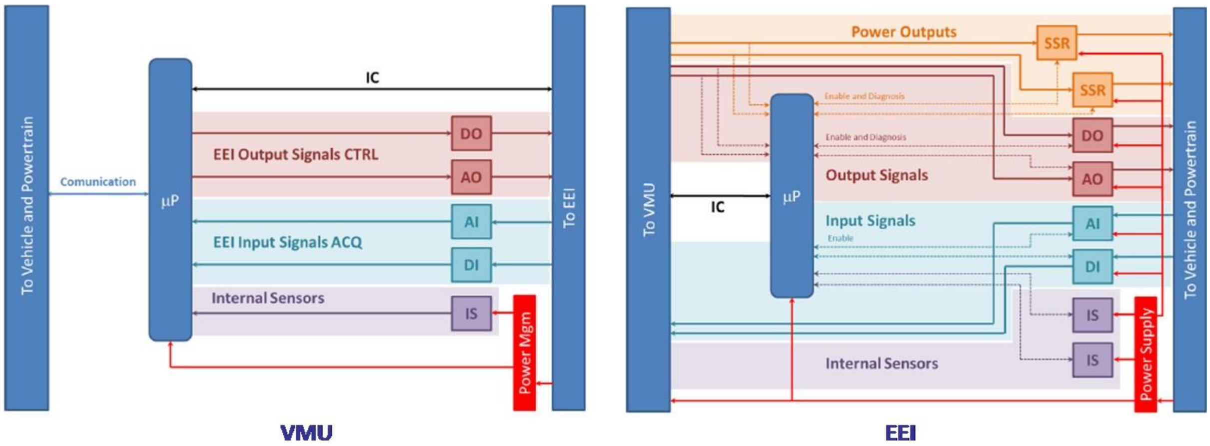


Figure 5 - HW architecture

Proposed HW architecture consists of one board, named EEI, in charge of controlling electric load power distribution and of a second board, named VMU, in charge of managing electric traction. On one hand, EEI mainly implements power driver and substitutes all the relays which are spread under the hood for activating electric ancillaries. On the other hand, VMU is focused on supervising traction and vehicular communication. EEI and VMU communicate via a dedicated digital line to allow and exchange of data enhancing safety.

2. General architecture

2.1. Considerations

Specific control algorithms shall be implemented in order to fulfil system targets. Besides usual control functionalities common to embedded traction control and vehicle supervising algorithms, the ECU requires specific logics to be implemented.

These specific functionalities can be gathered into 3 groups:

- gearbox actuation control;
- longitudinal traction control;
- pedal interpreter.

2.2. Control system overview

Generic control system architecture is depicted in the figure which shows specific high level functionalities and their relationships.

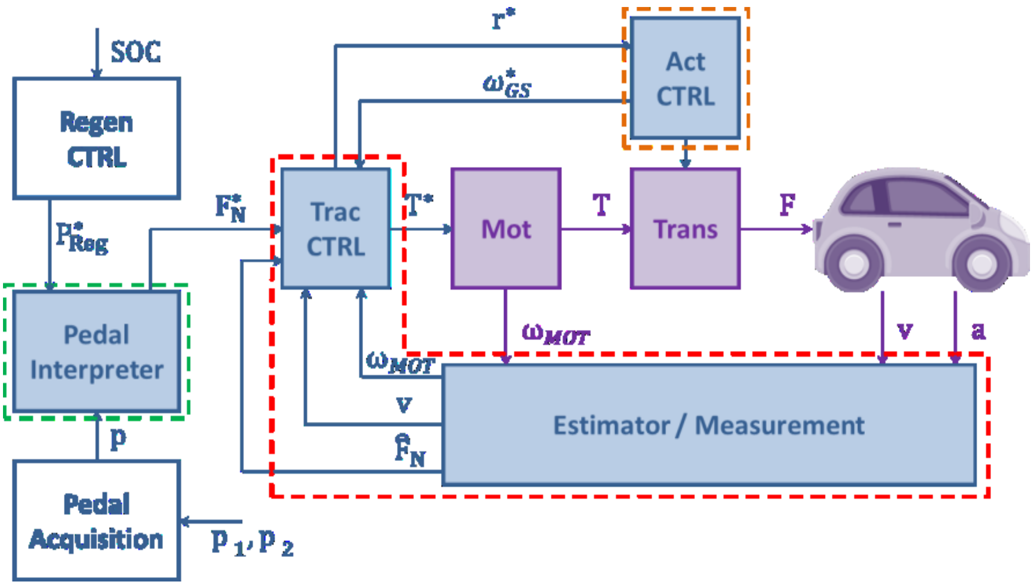


Figure 6 – Control overview.

Car together to violet blocks (**Mot** and **Trans**) represents plant physical model to be controlled.

Three more components complete the architecture:

- regeneration control
- estimation or measure algorithms
- gear shifting actuation control

Briefly, regeneration control calculates the power which can be instantaneously regenerated on the basis of actual SOC value.

Estimation or measurement algorithms shall acquire, filter o estimate variables which characterizes plant status as vehicle speed, acceleration and traction motor speed. Gear shifting actuation control is in charge of controlling auxiliary motor and synchronization of traction motor for performing a correct maneuver.

3. Gear shifting actuation control

3.1. Control purpose

Gear shifting actuation control is in charge of coordinating movements of cam governing gears engagement with traction motor delivered torque and speed in order to obtain a clutch-less shifting.

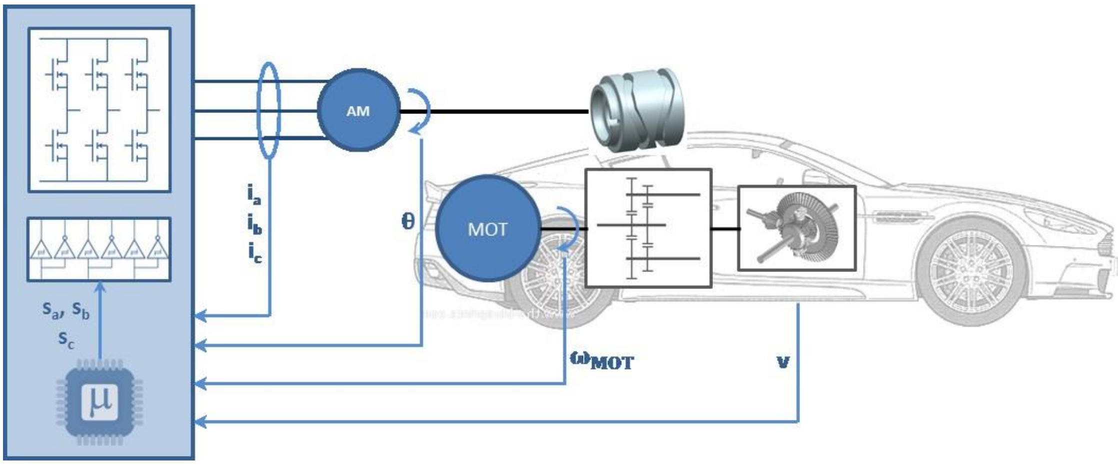


Figure 7 – Gear shifting control sensors and actuators.

Figure above shows an overview of electronic components involved in this control.

Synchronization between auxiliary motor and traction motor is performed on the basis of vehicle speed, involved gear numbers and traction motor speed.

A correct disengagement and engagement are performed taking care of unloading gearbox, that is main shaft applied torque shall be almost null. Moreover, a synchronization of main shaft and secondary shaft speeds is necessary for actuating dog-clutch mechanism. This synchronization is performed keeping main shaft speed inside a band on the respect of secondary shaft speed scaled to main shaft.

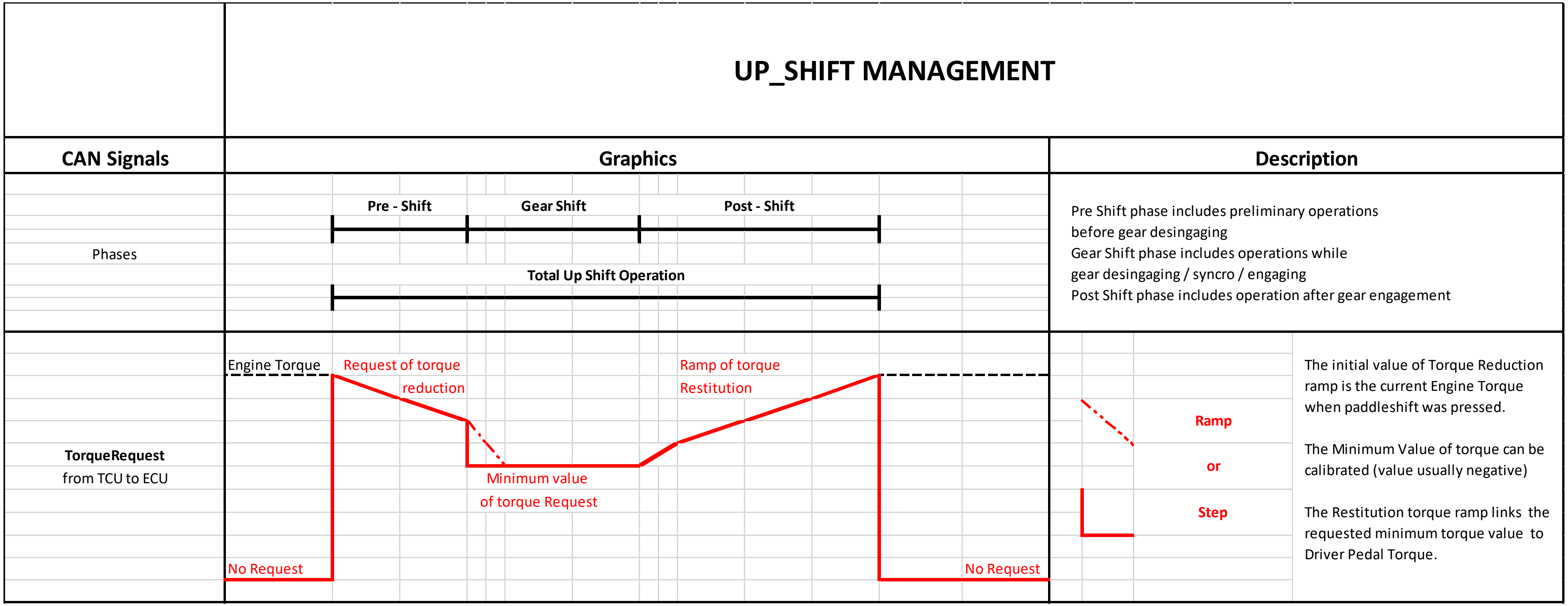
Electric drive control shall determine what gear shall be engaged and consequently it shall calculate traction motor torque reference or torque references in the case more power units are installed. Gear selection shall be performed for optimizing transmission exploitation preventing too frequent gear shifting which can be either uncomfortable for the driver or even harmful for the gearbox. Electric drive control shall trigger gear shifting operation once a different gear has been selected and it shall be subdued to gear shifting control requests. Electric drive control shall implement a speed reference tracking algorithm because this feature is necessary during gear shifting operation. Electric drive control shall switch between speed and torque reference smoothly implementing a bump-less strategy based in its internal state and on the state of gear shifting control.

4. Simulation on test bench

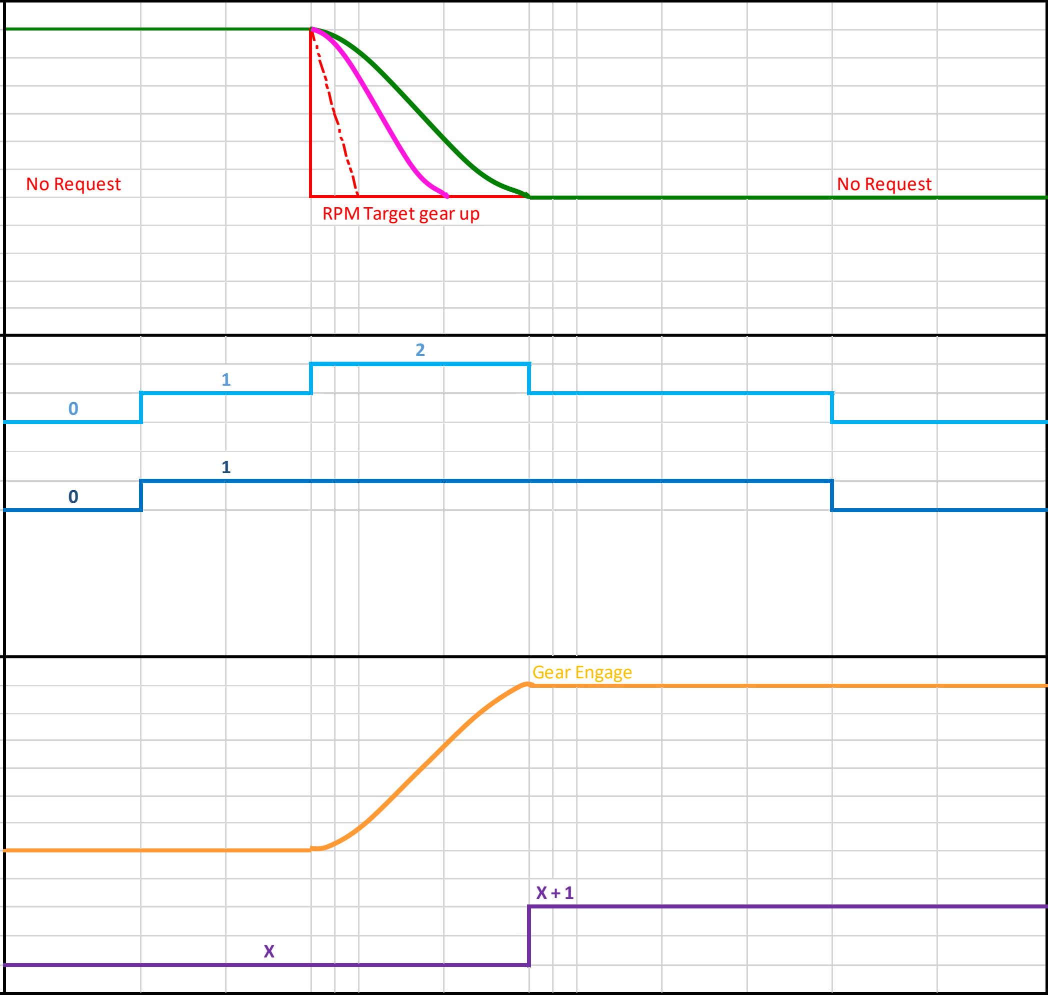
Preliminary tests on the gear shift management were carried out to validate the prototype.
The tests on the vehicle will be carried out when the system will be installed on the vehicle.

Below are shown first the simulations and then the real tests.

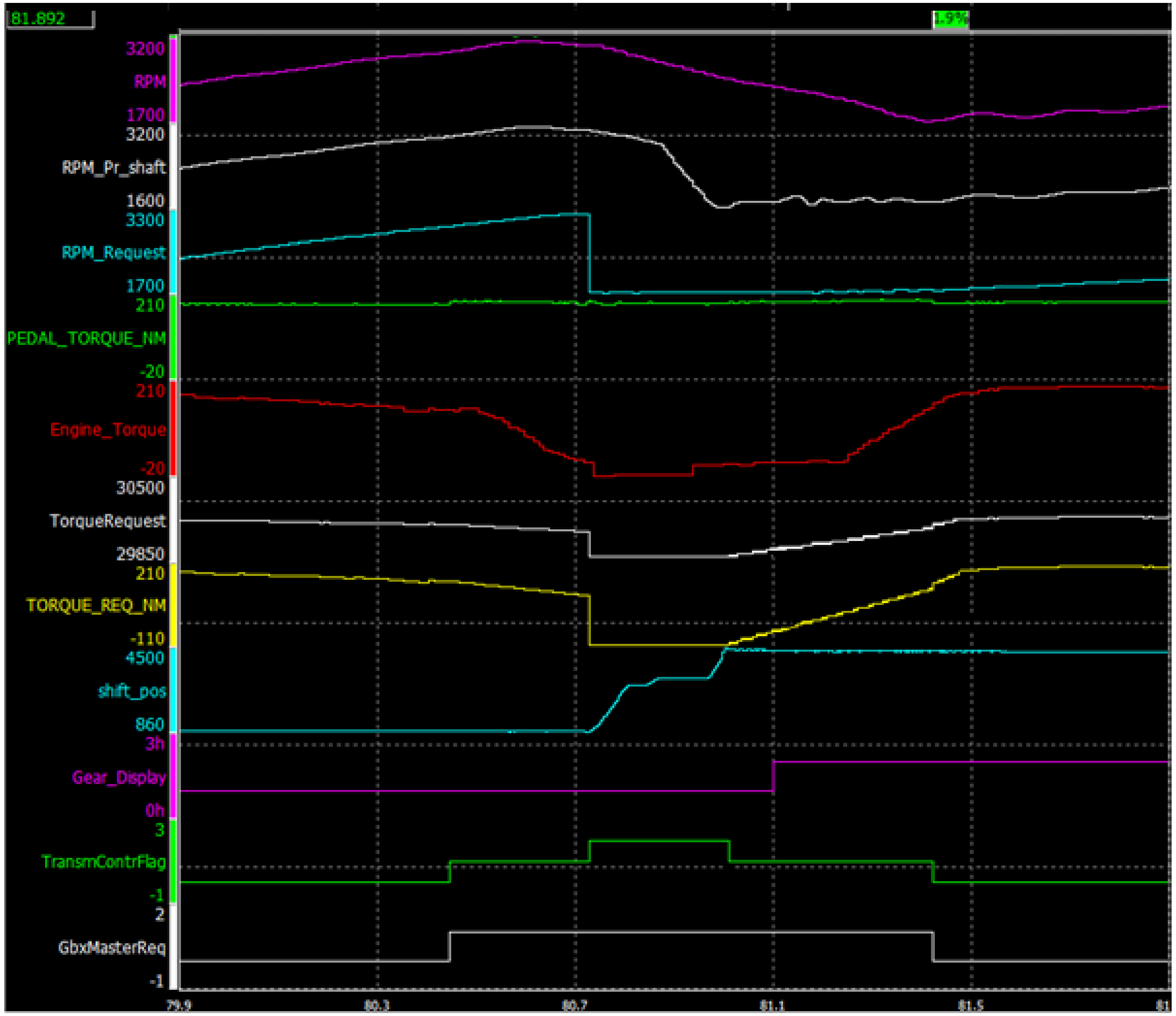
Gear shift Management: UP mode - Simulation



UP_SHIFT MANAGEMENT

CAN Signals	Graphics	Description
EngineRPM **PrimaryShaftRPM** **RPMRequest** from TCU to ECU		Ramp or Step TCU requests to the engine the necessary speed to syncronize with the Primary shaft speed.
TransmissionControlFB TCU sends this flagbyte to ECU to manifest it will use Rpm or Torque Control **GbxMasterRequest** TCU sends this flag to ECU to ask for Engine control over driver gas pedal		0 no intervention 1 Upshift TORQUE Control 2 Upshift RPM Control 0 GCU intervention OFF 1 GCU intervention ON Pre-shift phase (torque reduction): TCU asks for torque control while asking for torque reduction. Gear-shift phase (cut-off): TCU asks for Rpm Control, to syncronize Engine rpm to primary shaft rpm. Post-Shift phase (torque restitution): TCU asks for torque control.
ShiftPosition		
GearDsply message communicated by can		TCU sends the gear information for dashboard usually 0 means Neutral, 11 means Reverse.

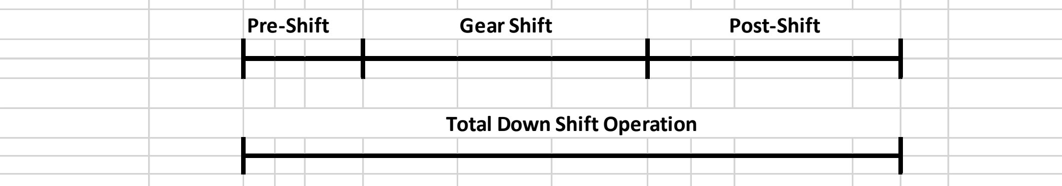
Gear shift Management: UP mode – Real test

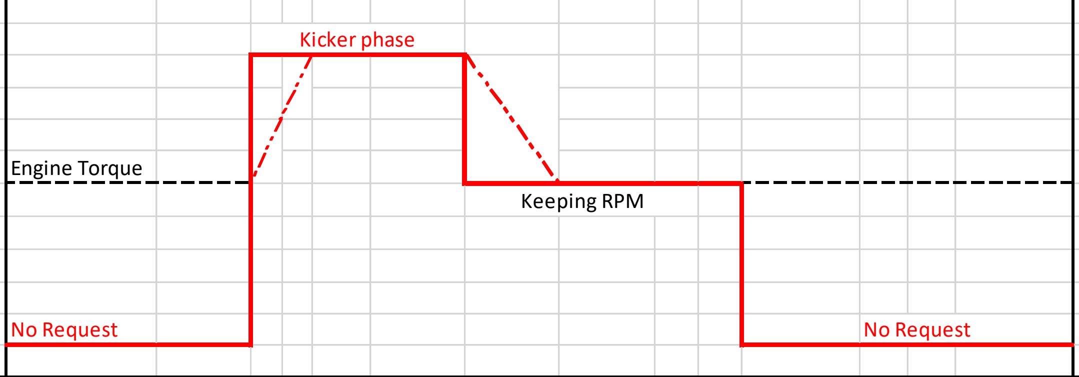


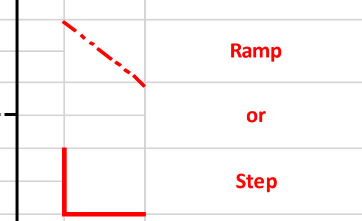
Gear shift Management: DOWN mode - Simulation

DOWN_SHIFT MANAGEMENT

CAN Signals	Graphics	Description
Phases	see figure 1 below	Pre Shift phase includes preliminary operations before gear desingaging Gear Shift phase includes operations while gear desingaging / syncro / engaging Post Shift phase includes operation after gear engagement
TorqueRequest	see figure 2 below	see figure 3 below Kicker: TCU asks for torque abrupt raise, the main control is on RPM. Then TCU links this value with the gas pedal demanded torque.







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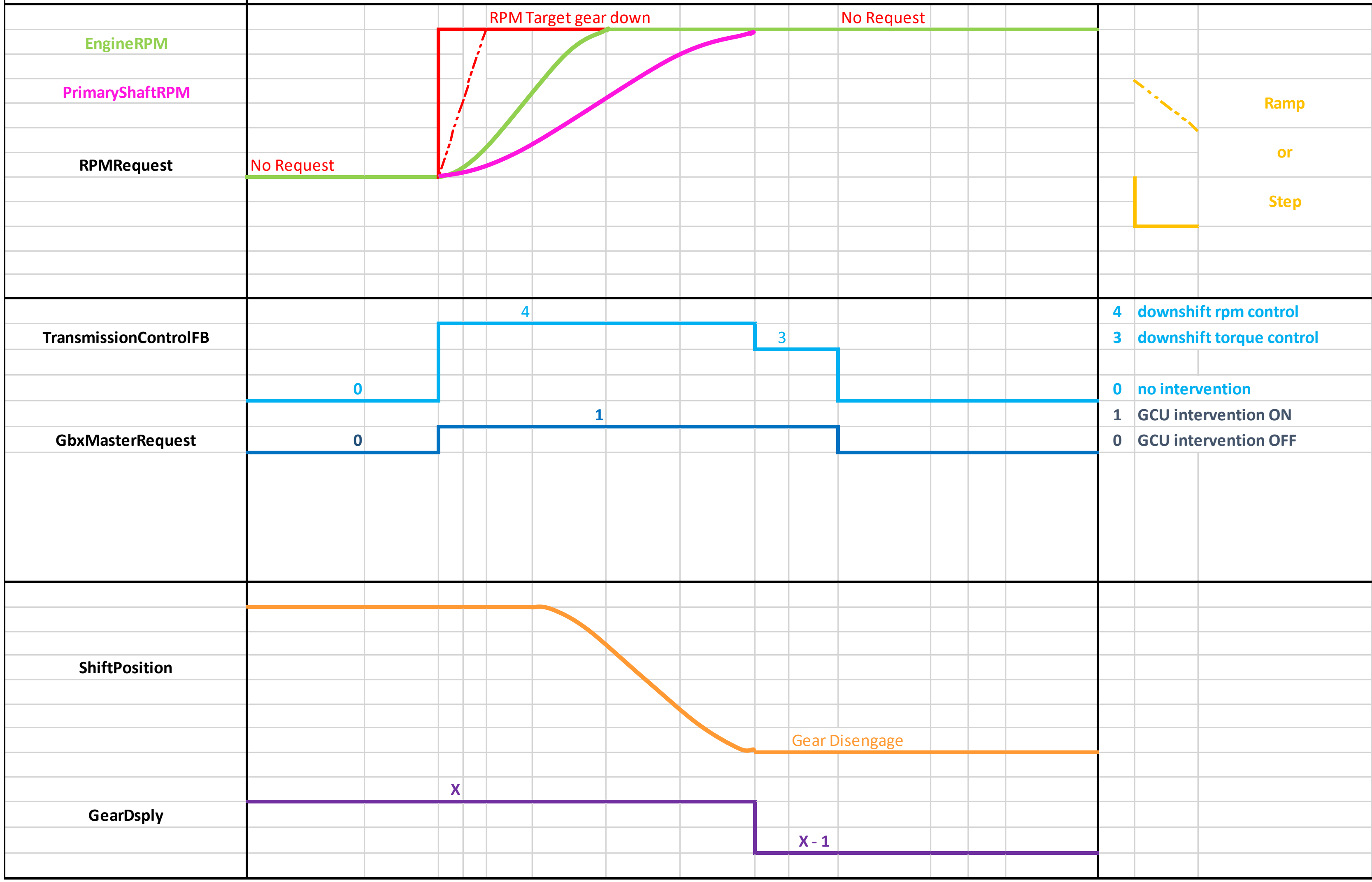
DOWN_SHIFT MANAGEMENT

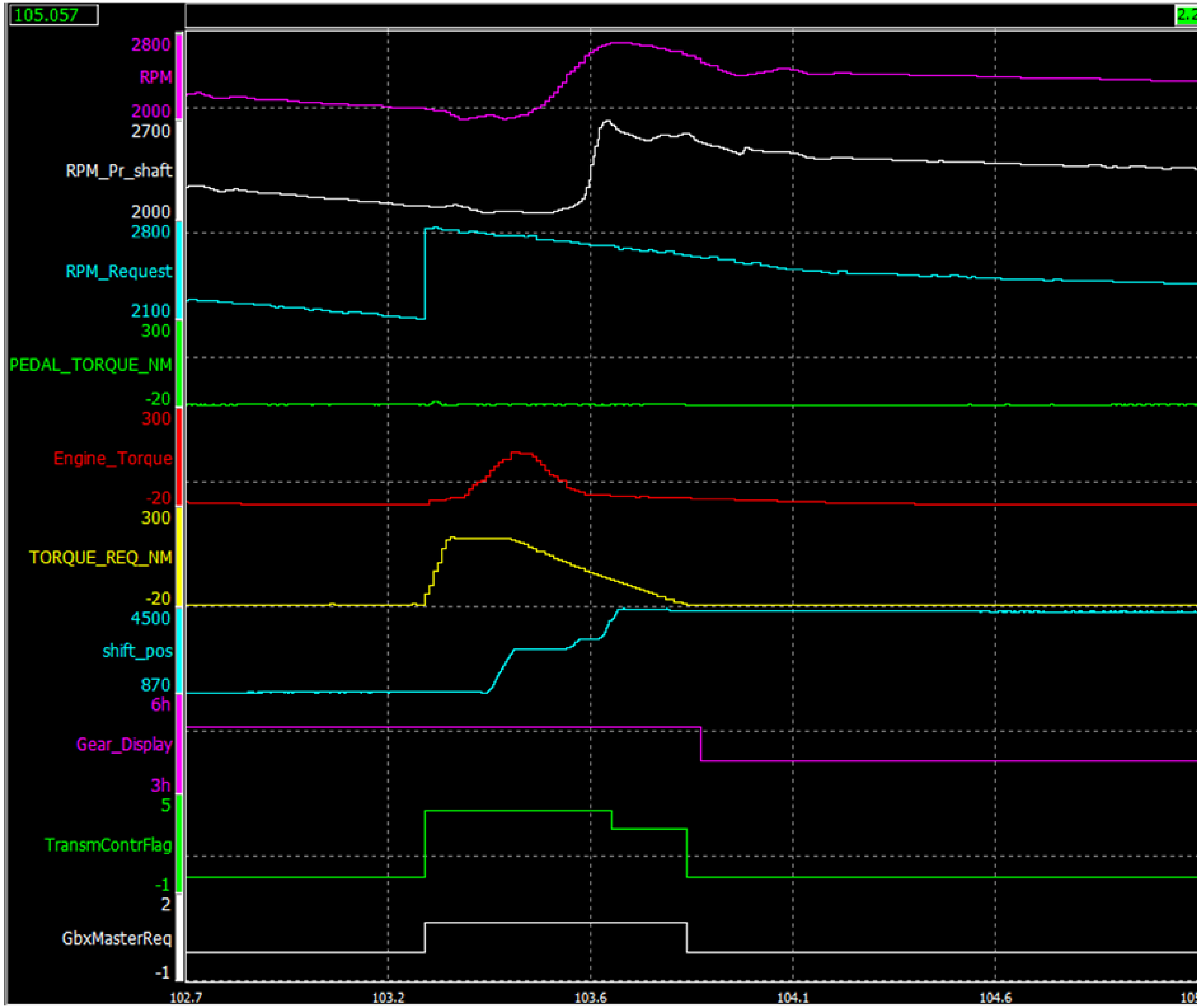


TCU asks for the necessary rpm to sincronyze the engine with the primary shaft.

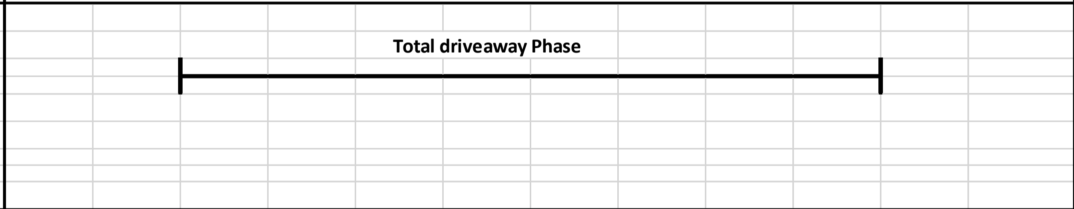
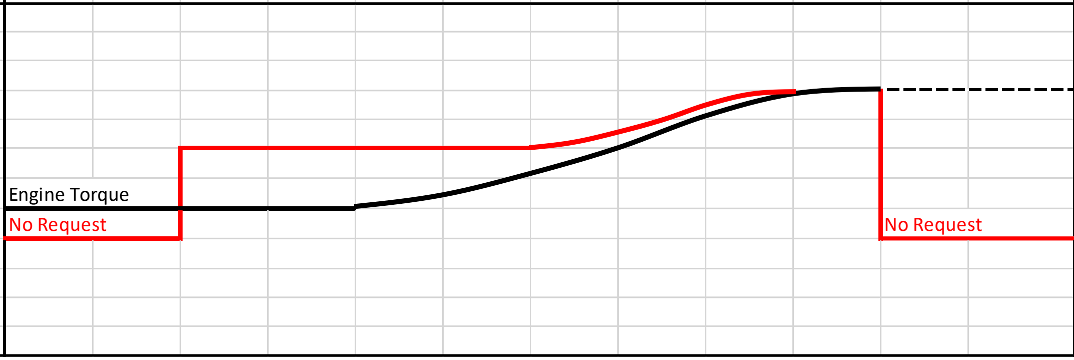
TCU asks for Rpm Control to syncronize the engine speed with primary shaft.

Then TCU asks for torque control to converge the Engine Torque to Pedal Torque.

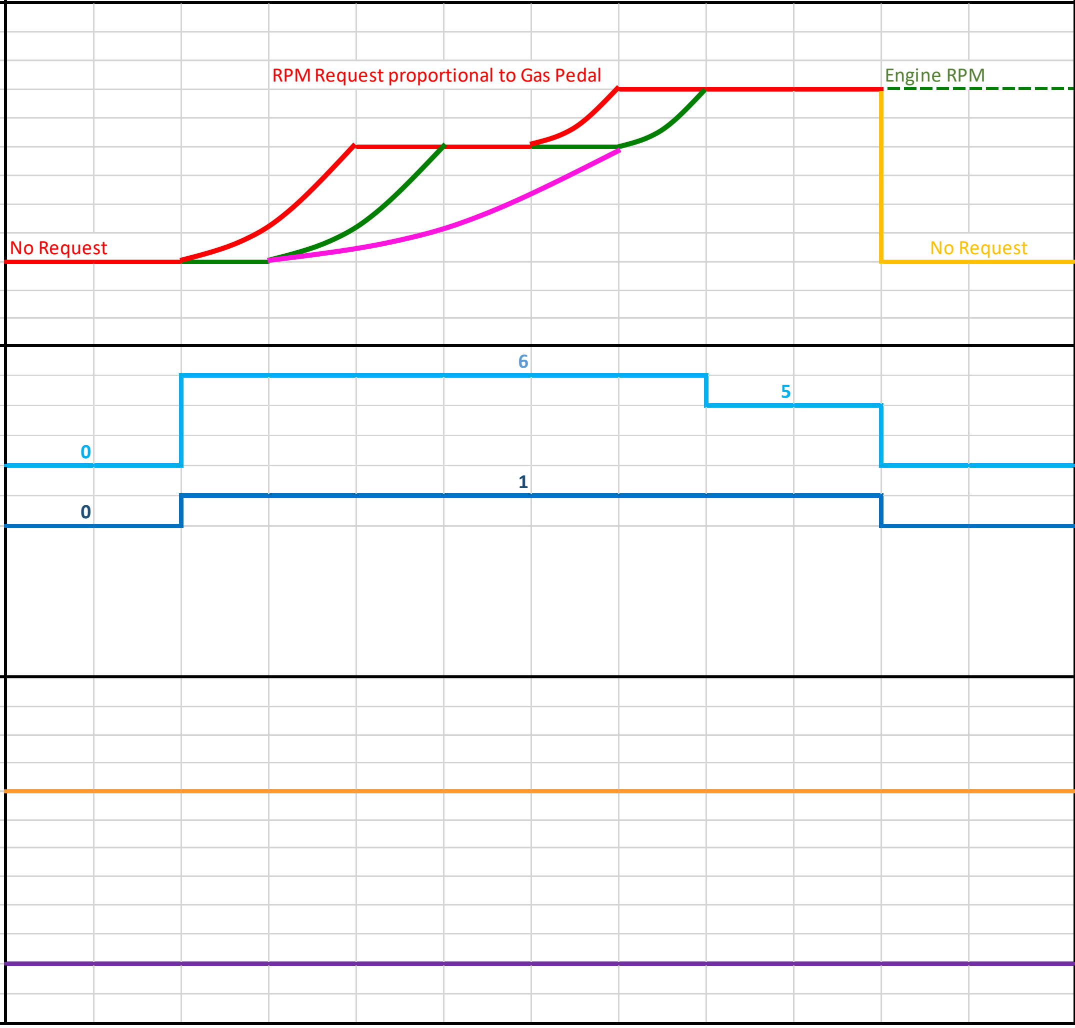
Gear shift Management: DOWN mode – Simulation



Gear shift Management: DRIVEAWAY mode – Simulation

	DRIVEAWAY PHASE	
CAN Signals	**Graphics**	**Description**
Phases		
TorqueRequest		TorqueRequest asked by TCU is proportional to the GasPedal

DRIVEAWAY PHASE



CAN Signals	Description	
EngineRPM PrimaryShaftRPM RPMRequest	The Engine RPM Request is proportional to the GasPedal	
TransmissionControlFB	6 driveaway rpm control 5 driveaway torque control 0 no intervention	The first phase of driveaway starts when the gas_pedal is pressed. TCU send a Rpm Request to ECU, and then begin closing clutch. When the Engine Rpm is syncronized to the PrimaryShaft and the clutch is almost closed, TCU asks to Torque control to align the Engine Torque to the Driver Pedal Torque. When the clutch is totally closed, TCU turn off the control.
GbxMasterRequest	1 GCU intervention 0 no intervention	
ShiftPosition		
GearDsply	FIRST Gear or REVERSE Gear	

Gear shift Management: DRIVEAWAY mode – Real test