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A Medium Duty Hybrid Vehicle to Meet the Needs of increasingly Sustainable Mobility

Roberto Mantia [a*], Giorgio Mantovani [a] and Marco Aimo-Boot [a]

[a] *CNH Industrial, Lungo Stura Lazio 49 - 10156 Turin, Italy*

Abstract

This paper focusses on the New IVECO Medium Duty Hybrid Vehicle being developed within Work Package 5 of the ECOCHAMPS project. The vehicle will be able to meet the needs of increasingly sustainable mobility, responsibly combining economic and productivity growth with environmental protection; resulting in a concept for possible future scenarios, meeting the needs of the evolving world of transport. The demonstrator has extremely flexible technology, capable of switching to the most appropriate source of energy and operative modes depending on the vehicle's mission. To achieve this flexibility, an IVECO patented Transfer Box and modular components, like a HV battery, a HV high efficiency E-Drive, a HV/12V smart DC/DC converter and a 3-phase AC charger, have been integrated in the demonstrator. An innovative charging system with a specific IVECO patent has been implemented to satisfy all customers' requirements, retaining the flexibility of private, public and domestic-charging.

Keywords: Commercial vehicles; hybridization

Nomenclature

EURs	End User Requirements
HV	High Voltage
KPI	Key Performance Indicator
LCV, MCV or HCV	Light, Medium or Heavy Commercial Vehicle, respectively
RESS	Rechargeable Energy Storage System
VMU	Vehicle Management Unit
EURs	End User Requirements
KPI	Key Performance Indicator

1 Introduction

The ECOCHAMPS project addresses the topic GV-04-2014 Hybrid Light and Heavy Duty Vehicles under Horizon2020. This project is realized through the activities of a 26-member consortium. The overall objectives are to achieve efficient, compact, low weight, robust and cost effective hybrid powertrains for both passenger cars and commercial vehicles, with increased functionality, improved performance, comfort, safety and emissions levels below Euro 6 or VI.

At the time of the TRA in Vienna, the ECOCHAMPS project will just have been completed after three years of

* Corresponding author. Tel.: +39 011 0078352 ; fax: +39 011 00 78104.
E-mail address: Roberto.mantia@cnhind.com

activity. In this technical paper, the progress of the work to develop the IVECO vehicle demonstrator, up to September 2017, is reported. The vehicle is on track to achieve the proposed objectives. Between September and the TRA the demonstrator will undergo a series of extensive vehicle testing and final evaluation against the overall ECOCHAMPS project targets. Therefore, the results of this testing and evaluation can not be included in this paper but will form a significant part of the presentation of the paper at the TRA.

2 Environmentally friendly mobility

IVECO customers confirm that the commercial vehicles have different missions every day; itineraries may be urban or extra-urban, with straight or more winding roads, and loads may be different depending on what vehicles carry. Based on these requirements, the IVECO demonstrator configuration will try to enable immediate traction switching, depending on the type of itinerary and its conditions, and, in this way, will achieve an important innovation towards an increasingly environmentally friendly mobility. Flexibility will be its main characteristic. The new technology should operate in a few steps: fuel chemical energy should be converted into mechanic energy for motion, whereas kinetic energy, which would be dispersed during braking or vehicle deceleration, should be recovered and converted into electric energy to be stored in the battery. If necessary, this energy will become available for electric traction. Of course, the hybrid mode will be the most appropriate working-mode for energy efficiency in extra-urban roads. Compared to a Pure Diesel Vehicle, this system could ensure reduction in fuel consumption and in emission of CO_2 up to 20%. The electric system will be the most indicated for urban, low speed or traffic areas, with a maximum speed of 50 km/h. Then, these two traction systems will make one vehicle suitable for “last mile” management in zero emission areas, whilst ensuring the best performances for extra-urban activities. The IVECO chassis could provide a natural coupling to answer the needs of urban mobility evolution.

3 Vehicle and targets definition

For the definition of the technical targets the following definitions of vehicles will be used:

- **Reference or State of the Art (SoA) Vehicle**: It is the best in the market in production in 2013. This vehicle defines the baseline for the call expected impacts and hence the derivation of the targets.
- **Base or Donor Vehicle**: This is the vehicle on which the demonstrator vehicle is based.
- **Demonstrator Vehicle**: This is the vehicle developed within the project that is the donor vehicle with the ECOCHAMPS developed powertrain systems.

Especially within the MCV and HCV, identifying applicable SoA vehicles was not easy.

The donor vehicle for the IVECO demonstrator is an IVECO Daily 7 tonne, 170CV/125kW, 70C17H 4350, MY2014. Based on this vehicle, a plug-in hybrid is going to be developed with a substantially increased performance compared to the donor vehicle. No suitable hybrid reference vehicle available in the market in 2013 could be identified for this approach. Thus, two reference vehicles have been chosen to show the improvements achieved by the development within the ECOCHAMPS project. Reference vehicle 1 is the donor vehicle itself, showing the increase in powertrain efficiency.

Comparing the powertrain weight and volume to a conventional powertrain is not useful. Therefore, in addition, the pure electric IVECO Daily, 5 tonne, 80kW, 50CE 4100, MY2014 has been chosen as reference vehicle 2. This allows for a better comparison of powertrain weight and volume. Due to the nature of the pure electric vehicle, only the electric parts of the powertrain will be compared. Building a plug-in hybrid vehicle in this class is likely to require a large battery. Therefore, the battery and the electrical drivetrain components are expected to cause weight and volume increase as well as high costs compared to the ICE donor vehicle. Hence, in the comparison to reference vehicle 2, a reduction of weight and volume is shown.

The choice of those two reference vehicles reflects the nature of the developed plug-in hybrid demonstrator vehicle, which will combine the best of the conventional donor vehicle (long range, high capacity) and the pure electric vehicle (high powertrain efficiency, low running costs).

4 EURs – KPI – Targets

In order to meet the expectations of the stakeholders (e.g. fleet owners or other end users) with the forthcoming development and to generate a good starting point for the development within the ECOCHAMPS project, end user requirements (EUR) and key performance indicators (KPI) are defined. Beside the overall project ambitions of powertrain efficiency improvement, weight, volume and cost reduction based upon the call expected impacts, these requirements shall ensure the practicability of the developed vehicles. This is important to achieve vehicles of technology readiness level 7 (TRL 7) at the end of the project.

Within the scope of the project the notation used was that:

- End User Requirements (EURs) *are taken to represent the consumers' desires at a mostly qualitative level,* and, for commercial vehicles, the end users are taken to be the customers who buy the vehicles for commercial use;
- Key Performance Indicators (KPIs) are a technical interpretation, mostly on quantitative level, for those EURs that require them;
- Technical Targets *are related to the call expected impacts set by the European Commission and the project ambitions,* and are presented both at vehicle and subsystem level where appropriate.

Therefore, the EURs include more general descriptive requirements because the end users are not considered to be technical experts. In some cases, KPIs are defined to further illuminate those EURs that require them.

Table 1. End User Requirements (left) and Key Performance Indicators (right)

EUR	Details
Costs	Cost of ownership lower than base vehicle
Fuel Consumption & CO_2	Lower than base vehicle
Emissions	Below Euro VI
Safety Standards	Pass isolation resistance and fault ground according to r100
Performance	Equal or better than Base Vehicle
Ride & Handling	Acceptable
Comfort	Equal or better than base vehicle
Noise, Vibration & Harshness	Equal or better than base vehicle
Available Capacity	Sufficient
Reliability	Equal or better than industry practice
EV Battery Life	Equal or better than industry practice
Ease of Charge	Pass[1]
HMI	Pass

KPI	Details
Cost (% over baseline)	Max 40%
Fuel Consumption & CO_2 (% under baseline)	20%
Maximum Speed (km/h)	90 km/h
Maximum EV Speed (km/h)	50 km/h
Acceleration Time (s)	0→90 km/h-30sec 30→50 km/h-5sec 60→90 km/h-16sec
System Initialization (s)	<1 minute
Charging Time to 80% SoC (hrs/kWh)	<8 hrs (overnight charge)
Charging Time to 100% SoC (hrs/kWh)	<8 hrs (overnight charge)
Braking	100m from 80 km/h to 0 km/h
Gradeability	10% at 30km/h and Go up to 10 km/h up a 18% grade - starting from 0km/h
EV Range (km)	20.0-40.0
NVH Vehicle	IVECO specific measurement inside and outside of the vehicle < Base Vehicle
Available Capacity	reduction of payload <20%

Table 2. Project Targets

Target	Details
Powertrain Efficiency	+20% versus Daily Diesel
Powertrain Mass and Volume	-20% versus electrical powertrain components of the Daily Electric
Hybrid Cost Premium	+40% Compared to conventional IVECO Daily Diesel
Emission Level	Euro VI

Where the powertrain efficiency is defined as follows:

$$Powertrain\ Efficiency = \frac{Energy\ Required\ to\ Complete\ Cycle}{Vehicle\ Energy\ Content_{Start} - \ Vehicle\ Energy\ Content_{End}}$$

'Energy Required to Complete Cycle' = $\int T.\omega.\delta t$ (at the Driveshaft(s) for positive values of T only).
'Vehicle Energy Content Start - Vehicle Energy Content End' is the sum of Fuel Energy consumed plus Battery Energy consumed (note that Battery Energy consumed may be positive or negative depending upon whether net energy in the battery decreases or increases).

1 a simple 'pass or fail', will be decided using the engineering judgement of the Golden Engineer.

5 Use Cases and Vehicle Functions

5.1 *Mission and Use Cases*

Thanks to the feedback coming from various European IVECO's customers, a specific mission profile was derived with a mix of urban, extra-urban and motorway mission; some average percentages of usage of a Daily 7t were derived from the customer's feedbacks and a summary of these are listed in the tables below :

Table 3. Data Mission Profile

	Motorway	**Extra-urban**	**Urban/DTD**	**Total**
Average daily usage [km/day]	14	40	75	**129**
Average daily usage [% of usage]	11%	31%	58%	**100%**
Average speed [km/h]	65	34	11	**37**

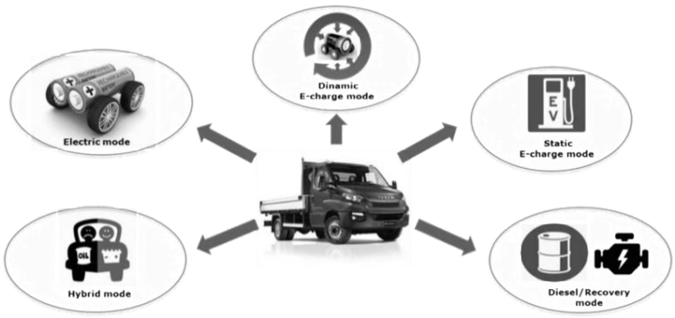

Figure 1 Vehicle Functions Use Cases

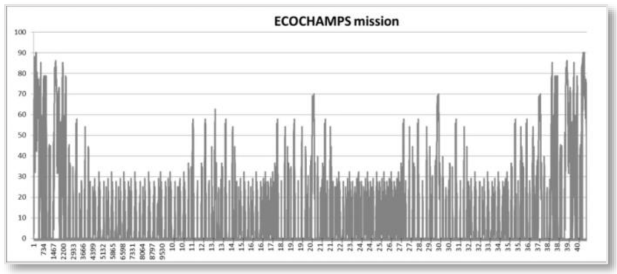

Figure 2 ECOCHAMPS Mission Profile

Considering the ECOCHAMPS mission profiles, specific energy management logics and specific way of switching between each mode has been be implemented.

5.2 *Electric Mode*

The main target of the Electric Modality is to achieve the Zero Level of Emission so as to be able to drive in closed/restricted traffic area and to cover the typical urban area missions like:

- Door to door goods/food delivery
- Home delivery
- Express courier
- Garbage collection.

The vehicle will have only the E-drive connected and the HV Battery should allow to drive up to 20-40 km without noticeable performance reductions and achieving a maximum speed of 50 km/h. The full grade-ability will be guaranteed by the well dimensioned Electric motor that, working together with the transfer box, should also allow the Electric Brake Regeneration.

5.3 *Hybrid Mode*

Minimum fuel consumption is, of course, the most important target to achieve with the implementation of the Hybrid Functionality. During this way of working, the vehicle will have the E-drive and the thermal engine connected at the same time. The user will be able to cover unlimited kilometres in any area (urban, suburban etc.) without performances limits but maintaining the desired level of fuel saving. In parallel, the logics of the system will allow the Electric brake regeneration and the consequential charging of the HV battery before the possible entrance in the Urban Limited Area. Always thinking to improve the fuel consumption, "Stop & Start" and "Stop & Go" will be integrated with the other functions of the Demonstrator.

5.4 *Diesel Mode*

Disconnecting completely the E-Drive and keeping connected only the thermal Engine, the vehicle will work in Diesel mode exploit the Engine with all its available power. This mode could be selected at speeds over 80 km/h in order to drive the vehicle like a conventional diesel, up to vehicle max. speed but, as said before, without Electric Brake regeneration. Of course, this mode could be used to cover any mission (excepted ZERO EMISSION area), but usually in highway and when traction battery SOC is full and does not need of recharging.

5.5 *Dynamic E-charge mode*

When the user will need to charge the battery during normal driving he/she could switch in this mode and the transfer box will connect both the E-drive and the thermal engine. It will be possible to cover unlimited kilometres in any no-urban area (suburban, highway, etc.) without performances limits and charging traction battery before crossing ZE area if it is not charged enough.

5.6 *Static E-charge mode*

To fully charge the battery during the parking time in the depot the customer will choose this mode. A specific IVECO patented system has been implemented in order to satisfy the requirements and to keep the flexibility of Mode 1 with CEE type connection, Mode 3 public charging capability with type 2 connectors and the home-charging (for restricted condition/recovery, one phase low power).

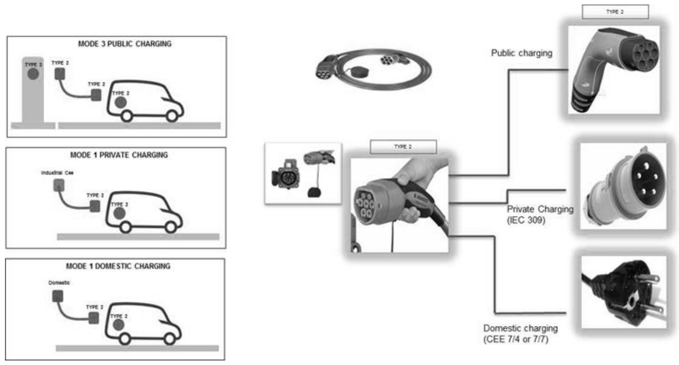

Figure 1 Flexible Charging System

6 Vehicle Architecture

The definition of the architecture has been driven by the use cases described in the previous chapters and by the Chassis Layout available on the Base Vehicle and on all the possible product line. On the demonstrator, the thermal engine will be kept (with its conventional starter) in the same front position than the base vehicle and the gear box will remain in the same position. No changes have been made to the thermal engine, but the gear box and the hand lever has been modified to incorporate a new lever to manage the hybrid features. A specific modification has been done on the transmission axle to divide it into two parts and put it in between the Transfer Unit, that has been mechanically coupled with the Electric motor. The HV Battery has been installed on the chassis, below the load compartment, in the rear overhang. The on-board charger and the socket inlet has been installed on the opposite side of the tap for the fuel filling. On the DC Link, the HV Battery, the Charger, the Inverter, the DC/DC and the EHPS have been connected through an “ad hoc” HVPD. The vacuum for the brake system will be guaranteed by a vacuum pump that will be connected to the 12V net. The VMU “brain” of the system will manage all the other ECU to guarantee the complete functionality of the vehicle.

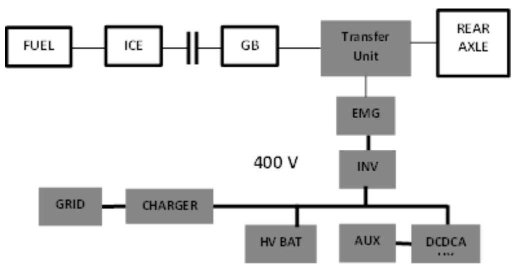

Figure 2 Vehicle Architecture

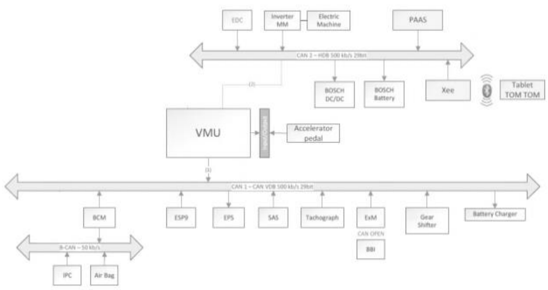

Figure 3 Vehicle CAN Network

7 Main Components

Of course, one of the main innovations and targeted key results of ECOCHAMPS was to devise a modular pre-standard framework that, for the first time, recommends standards for electric hybrid drivetrain components and auxiliaries for commercial vehicles including mechanical, electrical, and communication interfaces. This so called Modular system and Standardization Framework (MSF) for hybrid commercial vehicle components should provide planning certainty for suppliers, support commercial competition and scalability, resulting in a significant cost reduction for hybrid drivetrain components and vehicles in the mid-term.

Thanks to the activity on MSF, Bosch, as partner of the project, has been able to develop the High Voltage Battery and the DCDC converter; on the other hand, FTP as the second partner inside the IVECO work package, has developed the Modular power transfer unit that represents the core component of IVECO PHEV, to couple the mechanical energy coming from the thermal engine and from the electric motor-generator to the traction wheels. Finally, IVECO took charge, with his selected suppliers, the realization of the other components like the electric motor, the inverter, the on-board charger, the gear shifter, the VMU and the HMI system that are all fundamentals in order to make achievable all the targets of IVECO's demonstrator.

7.1 *RESS*

The RESS is one of the most important components. IVECO required for it a highly efficient solution to store electric energy in a compact design with high power/energy density to allow good ZE Range and no high impact on the payload of the vehicle. It has to fit the IVECO Vehicle Architecture perfectly and has to ensure the best energy efficiency performance whilst allowing the highest reliability with the compliance of the fast charge capability.

Considering the typical usage of this type of vehicle and its weight, IVECO shared with Bosch a set of requirements; the table below shows the IVECO requirements and the values that the Demonstrator should have a system compliant with the following requirements:

Table 4. Rechargeable Energy Storage System Requirements

Requirement	IVECO Needs
Usable Energy EOL [kWh]	15-30
Continuous Power EOL [kW]	> 60
Voltage Range [V]	240-390
Charging Power [kW]	Up to 50
Technology	Li-Ion
Cooling type	Integrated cooling preferred Air cooled
Max. weight [kg]	≤ 320
Control interface	Single Master BMS
Temperature Range [°C]	-25 to +50
Dimensions [mm]	770x720x310

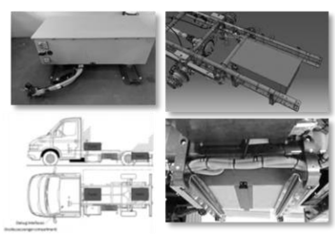

Figure 4 REES Installation

The Rechargeable Energy Storage System developed by Bosch consists of two lithium-ion battery packs and a multi-pack-coordinator (MPC) which is installed physically in one of the pack one housing. The ESS has a liquid cooling system in each battery pack that has been integrated in the vehicle low temperature cooling cycle. The total usable energy is around 22 kWh. The correct use of the battery system within the predetermined operating range and its cooling is provided by vehicle control unit (VMU). The continuous communication between the two battery packs and the vehicle via CAN is controlled by the MPC.

Basically, the main deviation of the Bosch battery respect the IVECO requirements are related to the energy density; in fact the ESS has a nominal density around 58 Wh/kg quite less than 90 Wh/kg required from IVECO. Also the dimensions of the ESS developed by Bosch were not in line with IVECO needs and the consequence was that it was necessary to install two packs instead of only one. The pack 1 with MPC is installed under the load floor between the chassis frame and the pack 2 is installed on the load compartment. Despite the deviations described before, the ESS should guaranty the performances in term of power, both for discharging and charging phases, and the should allow to cover the EV target range.

7.2 *DCDC Converter*

As for the RESS, the design of the DC/DC converter, not only followed the requirements coming from IVECO but has also respected the guide lines of the Modular system and Standardization Framework (MSF). Of course, one of the main strengths of the DCDC design is the Scalability/Flexibility in output power, output voltage, and input voltage, that will allow to use the same technology with different voltage ranges (Light, Medium and Heavy Commercial Vehicles)

Table 5. DCDC Converter Requirements

Requirement	**IVECO Needs**
Input voltage Range [VDC]	240÷420
Output voltage [V]	11÷16

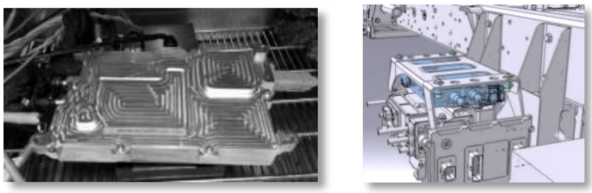

Figure 5 DCDC Installation

7.3 *Transfer Box*

The multimodal transfer box, around which all the design is conceived, is the core of the system; this unit, matched to a high speed electric motor and connected to the propeller shaft, is located almost in the centre of the vehicle, well protected in minor impacts and in a location usually not very needed by bodybuilder. This layout allows to have both the electronics and the energy storage very close to the E-drive, with good impact in term of packaging and with a very compact and efficient design.
In the parallel hybrid system lay out developed a mechanical power transfer unit is needed to connect the ICE with its gear, the EMG and the final driveline in a configuration decided either by the driver or by the vehicle control system. The selected hybrid architecture provides a high flexibility of the system, with the big advantage of requiring no change to the component which compose the driveline (except from the transmission shaft). At the same time, it helps to keep the efficiency high, thanks to the ability to disconnect all the mechanical parts.

The transfer box was born from a FPT/IVECO co-design with a modular approach, to control separately the ICE and the EMG lines. It switches into five different basic configurations:

- Traction provided only by ICE
- Traction provided only by EM
- Traction provided by the combination of ICE and EM (Hybrid mode)
- Energy recuperation
- Electric power take of (PTO) (as optional not implemented in ECOCHAMPS demonstrator)

The concept design has been developed looking at the maximum simplicity for cost/weight optimization: one stage of reduction, dog clutch connection and wet sump lubrication. The system has to meet the following mechanical requirement:

Table 6. Transfer Box Requirements

Requirement	**IVECO Needs**
Gear-train	Single stage reduction (1 gear pair)
Coupling	dog clutch
Actuator type	Electro mechanic actuator
Cooling	Air
Max. revolutions - EMG Input [rpm]	16.000

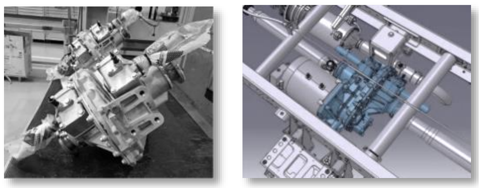

Figure 6 Transfer Box installation

7.4 *E-Motor and Inverter*

The components have been designed to optimize the level of performances and to allow the regeneration in most of the situations in compliance with the vehicle mission.

Table 7. E-Motor Requirements

Requirement	**IVECO Needs**
Mounting	Front Flange on the transferbox
Max. Power [kW]	110 @ 270VDC link (60s)
Cont. Power [kW]	≥ 70kW
Max. Torque [Nm]	400 (60s)
Cont. Torque [Nm]	270 @ 2000 rpm
Max. speed [rpm]	16000
Technology	Permanent Magnet (PM)

Figure 7 E-Motor Installation

Table 8. EMotor Inverter Requirements

Requirement	IVECO Needs
Input range voltage [V]	240÷420
Output current [Arms]	380-790

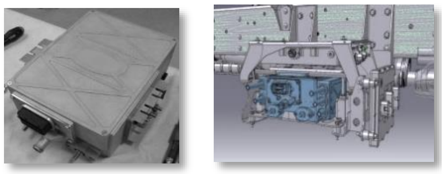

Figure 8 Inverter Installation

7.5 *Charging System*

The supplier chosen after the analysis of IVECO requirements below was able to propose the best product for our demonstrator respecting the IVECO requirements.

Table 9. On Board Charger Requirements

Requirement	IVECO Needs
Power output [kVA]	≥20 - (effic. > 93 %)
Mode Type	AC mode 1 or Mode 3

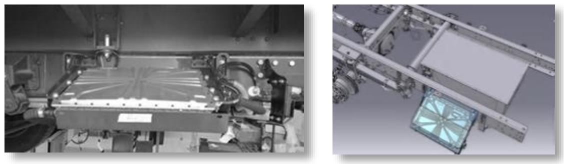

Figure 9 Charger installation

In order to implement the charging system as described in chapter 5.6 a High Voltage Power Distribution (HVPD) Box was developed by IVECO and in the same box was integrated the socket inlet for the charging cable.

Figure 10 Charging socket inlet - HVPD

7.6 *Hand Lever*

In order to provide the easiest way to manage the "Mode Switching", it has been developed a customized hand lever that integrates specific HW and SW features. Considering also a specific modification implemented on the Gear Box shifting command, the hand lever provides an additional position that allows the driver to select the Electric mode.

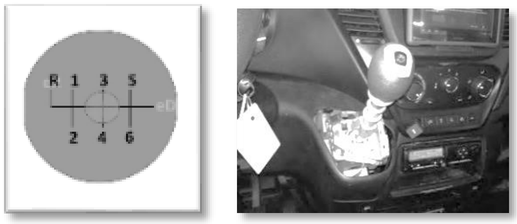

Figure 11 Hand lever

IVECO target was to not integrate any additional buttons, on the dashboard, for the Hybrid Traction Management, because all the functionalities related to the traction should be controlled by the hand lever.

7.7 *VMU*

The VMU is the "brain" of the vehicle controlling and managing all the Mode Switching, the Energy management of the vehicle and the charging procedures. The VMU is a modular electronic unit and it is designed to be used in rough operating environments and particularly suitable for the automotive applications. Enclosure in aluminium (RoHS compliant) with high strength and lightness.

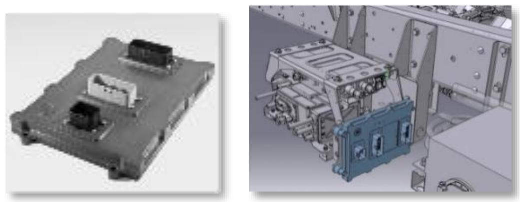

Figure 12 VMU installation

7.8 *HMI – Tablet and Gateway*

A specific HMI has been developed to have a solution with the most "Natural & Intuitive" approach. The peculiarities are:

- The modularity of solution applicable to all ranges and all missions/markets
- Easy interface with reconfiguration possible at driver level (cognitive load reduction) and engineering level (easier development)
- Lean productivity through back-office connection and automated parcel and delivery management
- Remote connectivity
- Smart & consumer-based technologies (Android tablet/smartphone)

To realize this new HMI the following component have been integrated in the demonstrator:

- The Tablet (TOMTOM) and its Cradle
- The Bluetooth Gateway

Figure 13 Cradle -Tablet – Gateway

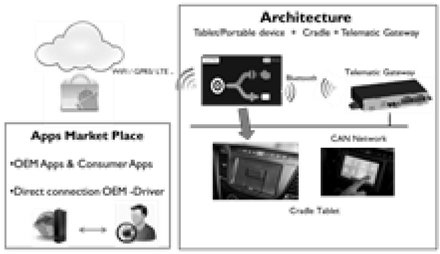

Figure 14 HMI and Remote Connectivity

8 Demonstrator

In order to give a complete overview of the vehicle, the following pictures show the demonstrators and the layout of all the components integrated

Figure 15 Demonstrator

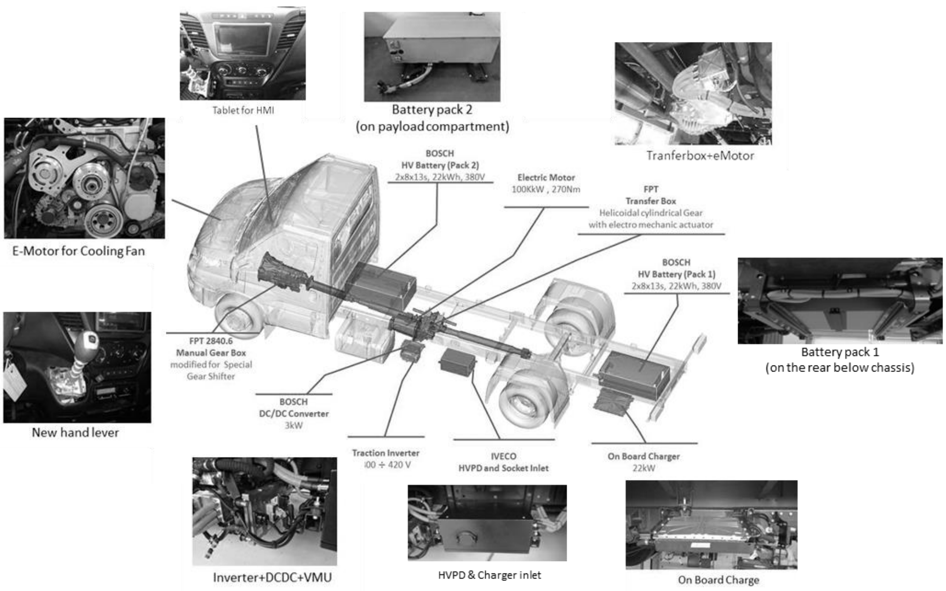

Figure 16 ECOCHAMPS demonstrator components layout

9 Conclusion

As said in the introduction, while this paper is being written, the project is still in the testing and fine tuning phase: the final assessment should be completed in November. Between September and the TRA the demonstrator IVECO will complete the final evaluation against the overall ECOCHAMPS project targets. In this chapter, some preliminary results can be shown.

9.1 *Mechanical and Electrical integration and Prototype Start-up*

According what described in detail in chapter 7 and 8, all the components for the hybridization are integrated on the IVECO demonstrator and this allowed to run the vehicle for the testing and tuning phase (on bench and on track). The preliminary electrical and functional test sessions have been performed during the start up together with the partners of the work package and the other components suppliers (Bosch and FPT).

9.2 *Vehicle Weight and Powertrain Mass and Volume*

As described in chapter 3, we have to consider as reference vehicle the IVECO Daily7 70C17H that was weighed before starting prototype setup and at the end of the building setup the demonstrator was weighed again and the results are shown in figure 19. The Demonstrator Vehicle has an increment of 15% of its curb weight with respect to the base vehicle; this means that, at the end, one of the KPI described in chapter 4, has been respected and it is possible to confirm that we will have only a reduction of the payload not greater than 20%.

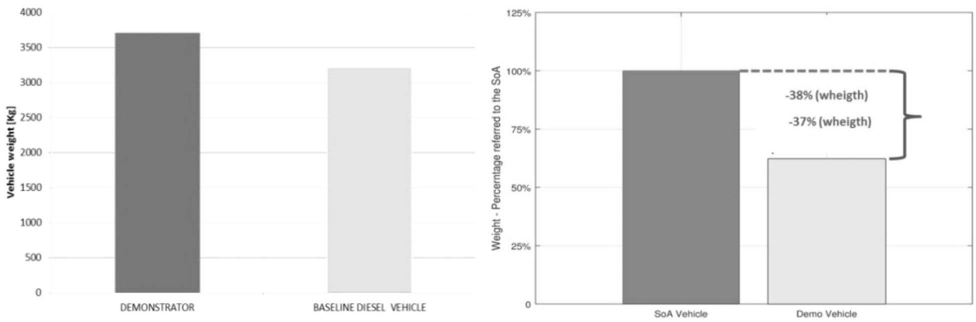

Figure 17 Vehicle weight - powertrain mass and volume

Due to the fact that no suitable SoA could be identified in the market in 2013, the Daily Electric was chosen as a reference for the powertrain components. Considering that the component of the powertrain are already available and integrated in the vehicle it was possible to measure a significant reduction in weight and volume although the electric power increased from 80 kW to 110 kW. Therefore, the power density in the ECOCHAMPS demonstrator is much higher than in the Daily Electric.

9.3 *Vehicle Performances*

Despite the tuning phase is still on going, some positive feedbacks are already available and it was possible to run the vehicle in pure electric mode verifying that it is able to cover a range of around 25 km using the 90% of the complete energy contents of the two battery packs. It was also possible to perform some test of the modes switching and to verify that the first data of fuel consumption in Hybrid mode are really promising and not so far in confirming the target values.

10 Acknowledgements

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