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ECOCHAMPS – City Bus Application

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Abstract

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. In particular, to achieve 10% powertrain efficiency improvements for the Hybrid Bus Demonstrator and weight plus volume reductions with respect to the best in class vehicles on the market at the time of proposal, whilst having a maximum of a 10% cost premium. At the time of the TRA2018, the project will just be completed. The bus application, a serial hybrid vehicle with Diesel ICE, as being worked on by MAN and partners in Work Package 6, will be presented in this paper.

Keywords: ECOCHAMPS; e-mobility; Hybridisation; Efficiency; Hybrid City Bus; Modular Hybrid Bus; Basic Electric Bus; Generator Set; Electric City Bus; Fuel Cell Bus; Full Battery Bus;

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Nomenclature

AUX Auxiliaries
BAT Battery system for propulsion
DC-DC "Direct Current to Direct Current"- Transformer, Power Electronic for 24V Board net supply
ECOCHAMPS European COmpetitiveness in Commercial Hybrid and AutoMotive PowertrainS
EM Electric Machine (used as E-Motor or Generator)
EV Electric Vehicle
FCEV Fuel Cell Electric Vehicle
GB Gear Box (transform high speed of EM to low speed of shaft)
Gen-Set Combination of e.g. ICE with EM, or FC-System with battery, or enhanced battery system with charging technology
HEV Hybrid Electric Vehicle
HD Heavy Duty
HV High Voltage (120 VDC – 1500 VDC)
ICE Internal Combustion Engine
INV Inverter (power electronic to supply EM using DC Voltage)
OEM Original Equipment Manufacturer
PHEV Plug in Hybrid Electric Vehicle
SoA State of the Art
TCO Total Cost of Ownership
WPn Work Package defined in the ECOCHAMPS Project

1. Introduction

All OEMs strengthen their activities on e-mobility. An important barrier to introduction of EVs is costs, another the lifetime of the main components for traction drive and electrified auxiliaries in heavy duty applications. In particular, the market for public transport city busses is driven by costs and politics. Bus OEMs are asked for many different drive traction systems: resulting in high costs for a small number of specialized busses. From this background, the following options to achieve cost reductions are being evaluated:

1. Using components from standardization, in particular OEMs create common standard requirements for components;
2. Using components or derivatives from "high volume production", such as passenger car components;
3. Especially for busses: definition of a basic E-Bus in a model kit, which can be readily changed from Diesel Hybrid to Fuel Cell or Full Battery Vehicle.

According to the first option, auxiliaries for heavy duty application that can be easily shared between busses and trucks are, e.g., the electric steering pump system and electric air compressor for braking. Such components are being developed by the suppliers within WP2, before being fitted to the demonstrators.

To evaluate the second option, the traction drive of a small car is analyzed: typically, this has a high speed electrical machine combined with a gearbox. Therefore, such a machine with inverter will be used, where the gearbox will be adapted to the torque and speed necessary for a city bus. If successful, costs are significantly reduced. The drive will be developed and tested, to validate the efficiency and maturity of such a concept. Also, a modified battery system from small car production will be evaluated for their suitability for inner city cycle operation.

During the project the high speed machine from the small car production was not available for the demonstrator bus vehicle. Therefore, the high speed traction drive will be tested on a test bench, and the efficiency data will be used to simulate and calculate the fuel consumption. The demonstrator itself will be equipped with an electric traction drive with high performance for heavy duty application to realize a safe bus operation in the timeframe of the project.

The third option is explored by identifying the main system components and modularization of the bus-structure of several bus types. The basis for these bus types is an E-vehicle. This basic type can be complemented with an electricity source according to customer wishes using the preferred "fuel". These "fuels" can be, e.g., Diesel-

Hybrid, fuel cells or EV (i.e. fully equipped with batteries). The ECOCHAMPS demonstrator bus vehicle is a Diesel Hybrid Bus.

2. Concept

2.1. Conceptual starting point: MAN Lion's City Hybrid Bus

The starting point of all project considerations is the MAN Lion's City Hybrid Bus with an Internal Combustion Engine (ICE) for Diesel fuel. In the ECOCHAMPS project the MAN Diesel Hybrid Bus will be redesigned according to the paths described above, especially step 3. The goal is to have a new platform for several bus types for several fuels. This new concept should reduce all cost aspects of our customer, i.e. the total cost of ownership (TCO). The concept of a basic bus vehicle in a modular kit is made for several customer wishes according to different bus traction drive systems for different fuels. This concept can be transferred in general to other applications like trucks, but this must be developed by each OEM to suit his specific product portfolio.

The demonstrator vehicle, the "New MAN Diesel Hybrid City Bus Concept" should have at minimum the properties of the "MAN Lion's City Hybrid" from 2013, Fig. 1 and Table 1. The 2013 version of this city bus is considered to be the best-in-class and will, therefore, be chosen as the reference vehicle (State of the art vehicle: SoA vehicle, Fig. 1). All aspects of ambitions will be compared between SoA Vehicle and the Demonstrator Bus Vehicle.

Fig. 1 MAN Lion's City Hybrid as vehicle SoA for Reference with demonstrator.

Table 1   Main Properties MAN Lion's City Hybrid

Property	Value
Vehicle Type	Low Floor city bus
Vehicle Length	12 m
Vehicle Weight (Max)	18 t
Available Capacity	78 Persons
Acceleration Time	20 s (0-60 km/h)
Lifetime	12 Years / 720,000 km

2.2. Traction drive analysis of current state of city bus applications

New vehicle concepts developed with respect to the e-mobility are using renewable energy. These developments require new components with more efficiency, and mass production of the main traction drive parts is the most effective way to reduce the costs.

Especially the market of city busses for public transport is driven by costs on the one hand and by politics on the other. Communities try to minimize their cost for public transport while at the same time trying to use renewable energy from their own region, i.e. using local energy resources. Such local resources can be e.g. natural gas, fuel from bio-mass and bio-gas, hydrogen or direct electricity from renewable sources like wind power, photovoltaic, and water power. OEMs for bus vehicles will be asked for many different drive traction systems under those general conditions. In the absence of dedicated technical solutions, the consequence of these differentiated customer requirements will be high costs for a small number of specialized busses running on several renewable energies.

The powertrain concept proposed by MAN for a city bus is a new basic E-vehicle concept, which based on a serial hybrid concept, realized in the “MAN Lion's City Hybrid”. This new bus application allows the customer to modify the bus to his preferred fuel. The primary concept is the modularization of the main system components as well as the bus structure, i.e. the chassis. The main objective is the development of a Basic-Electric-Bus, which can be readily modified and custom made for the operation with respect to customer wishes and requirements.

The basic vehicle is a complete electric bus with the electric traction drive, all auxiliary systems and in addition equipped with one “short term electric energy storage” mainly used for recovering of brake energy. All partial systems of the Basic-Electric-Bus are enclosed by the blue lines in Fig. 2.

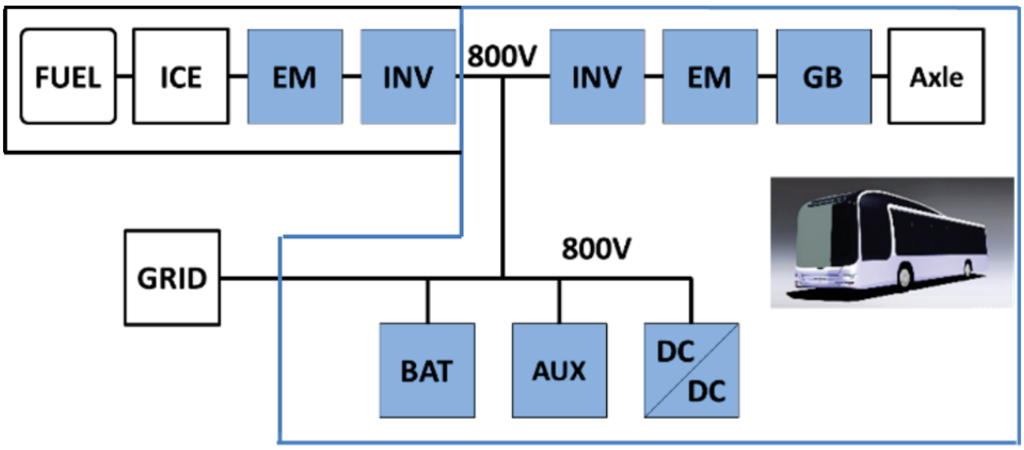

Fig. 2 Main block schematic of serial hybrid electric vehicle

The Basic-Electric-Bus can be enhanced by “Generator Systems” options, the so-called “Gen-Set”. The Gen-Set includes generators such as an ICE with an electric generator, fuel cell system or extensive battery system in addition to the “short term battery”, to have a full electric bus. This main part of the traction drive is enclosed by black lines in Fig.2.

2.3. Modularization of the bus-structure

An integration study of several vehicle types is given in Fig. 3. Coming from the modularization, the basic vehicle contains the following main partial systems:

- Main drive with power electronic and E-motors and brake resistor, storage (recovery of braking energy) and auxiliaries as it is described above.

The modularization of electric supply for drive train leads to the enhancement of the basic vehicle with the Gen-Set. With this concept, the following vehicle component package, Fig. 3, can be ordered by the customers:

- HEV with Diesel Gen Set
- HEV with CNG Gen Set
- FCEV: Fuel Cell Electric Vehicle
- BEV: Fully electric battery bus.

The most important package place is the roof area of the bus, where free space for all several storage systems, like batteries or gas vessels, is foreseen. The chassis structure must be designed according the load requirements that these roof mounts bring.

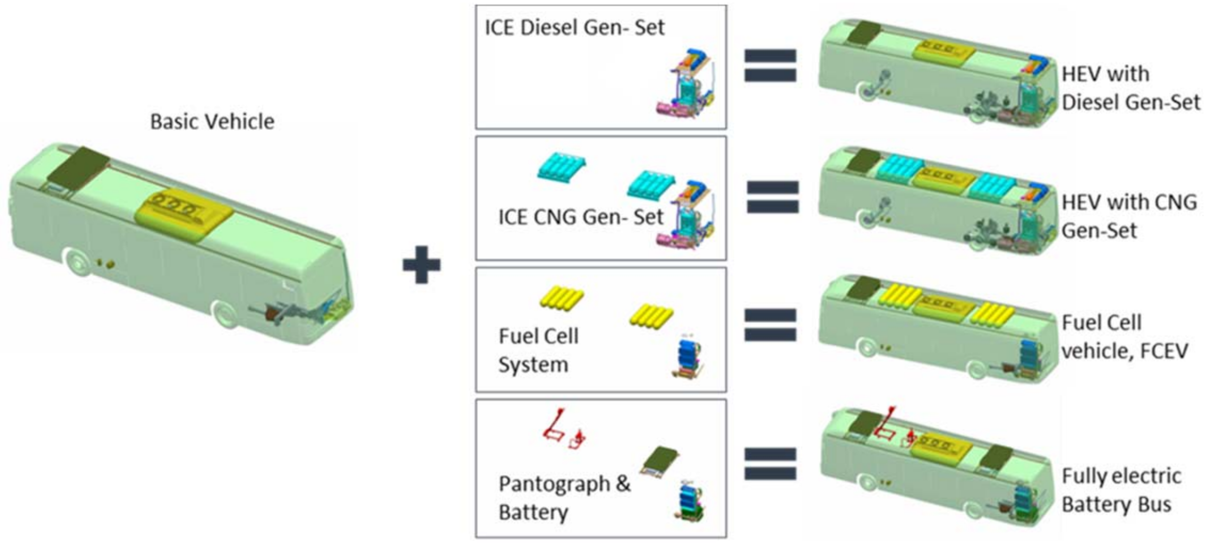

Fig. 3 Overview of enhancement of basic bus vehicle by several Gen-Sets

3. Results

The project ECOCHAMPS will end in April 2018. Therefore, in this chapter the current state of the demonstrator vehicle hardware and the estimated values of the expected results of ambitions are presented.

3.1. Auxiliaries for both heavy duty applications bus and truck

According to step 1 of the cost reduction mentioned above, the result of workshops with experts from OEMs and suppliers is a new list of standard requirements for auxiliary components. From that list, two main auxiliaries for heavy duty application were created, Fig. 4:

- Electric steering pump system with integrated 24 V power electronic, E-motor and hydraulic pump in a common housing
- Electric air compressor system with integrated power electronic, E-motor and pneumatic compressor supplied by high voltage in a wide range of several voltage levels (300 V DC - 800 V DC)

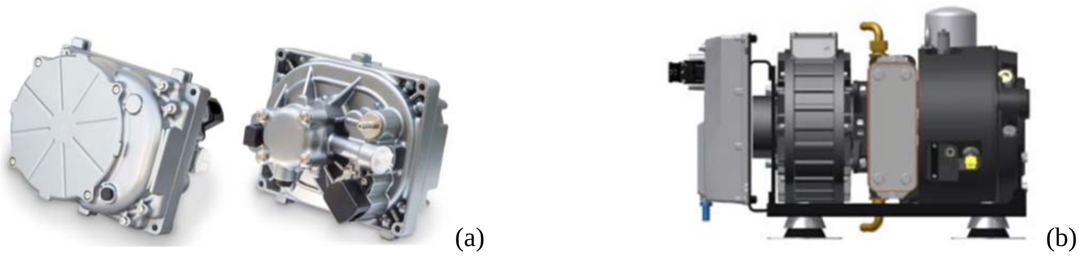

Fig. 4 (a) Steering Pump System 24 V by MAGNA ECS; (b) Air compressor system for HV by Gardner Denver

Both auxiliaries system are very compact and will be used in the bus and truck application of ECOCHAMPS demonstrator vehicles. There are more possibilities to share auxiliaries, like a DC-DC converter and other electric components between several applications. This is described in the paper of ECOCHAMPS WP2.

3.2. Derivatives of Small Car Components from High Volume Production

3.2.1. Drivetrain of a serial hybrid bus with high speed machine and gearbox

According to step 2, a new developed high speed electric machine for passenger cars with max. gross weight up to nearly 2 t will be used in order to reduce costs further costs. This electric machine will be combined with a gearbox to transform high speed at low torque to high torque at low speed, which is transferred by a shaft of a bus vehicle with a cross weight of 18 t. Fig. 5 shows that this concept can be implemented in an adapter gearbox between generator and ICE as well as for the traction drive shaft of a serial hybrid vehicle.

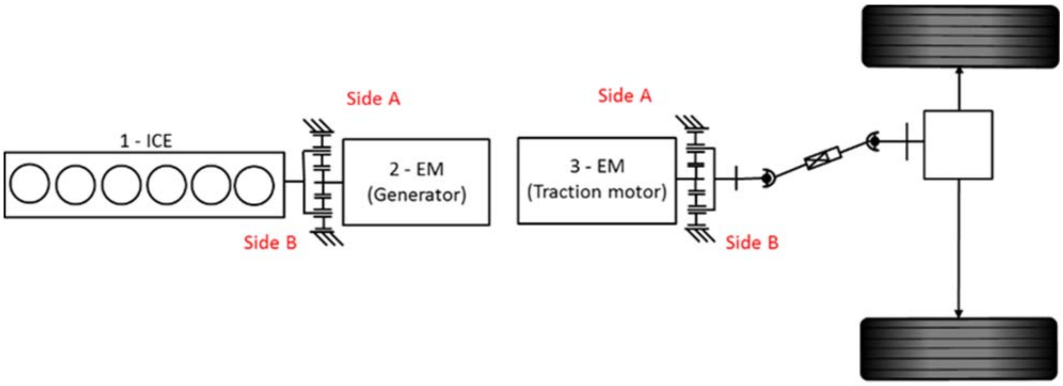

Fig. 5 Traction drive train of serial hybrid bus with high speed machine and gearbox for Gen-Set and traction drive

Fig. 6 shows both variants of the gearbox, which are different at the shaft for connection to the ICE or traction drive shaft only. To reduce costs and in order to increase volume, most of the components for the gearbox are equal and differs only in a little number of parts. The result is a high compact gearbox, which can be used in a wide range of heavy duty applications like bus and truck. In this project it will be primarily used for the bus vehicle.

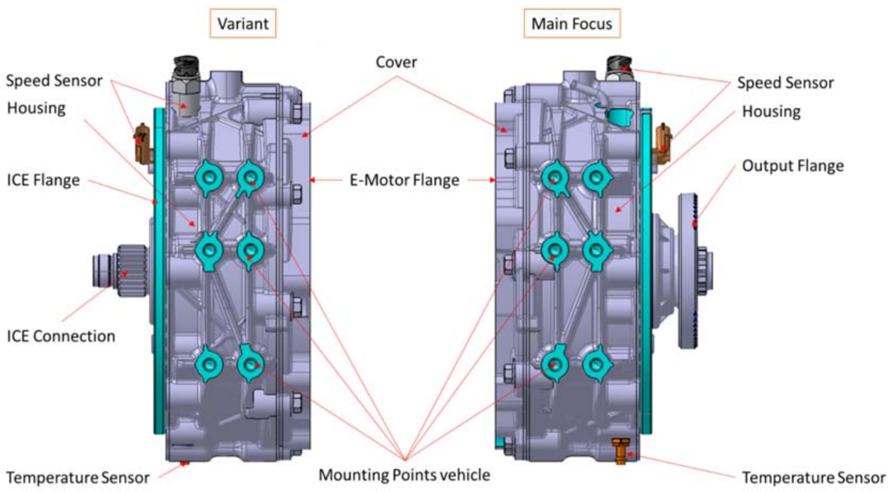

Fig. 6 Gearbox by MAGNA ECS with several shaft design: left side to ICE, right side connected to the traction drive shaft

The gearbox for the high speed machine will be developed in the time frame of the ECOCHAMPS project to show the efficiency and maturity of such a concept. Therefore, it will be tested in combination with the high speed machine on a test bench and data will be used in the simulation for validation of efficiency and fuel consumption.

3.2.2. Battery system as derivatives form passenger cars for Heavy Duty application

The second main component of all electric vehicles is the e-storage system, which is a battery system produced by the company VW and this is also a derivative from “small car production components”. It is shown in Fig. 7

that the battery is a double system with a cooling unit between them. It is also shown in Fig. 7 that a connector box for charging is foreseen next to the entrance door in the front, which allows to enhance the functionality of an HEV to a PHEV.

3.3. ECOCHAMPS bus application demonstrator vehicle

According to step 3 for cost reduction, and as it is shown in the integration studies above, the bus vehicle structure and package are overworked to have additional space on the roof to enhance the vehicle fuel storage systems. Fig. 7 shows enough space for, e.g., additional batteries or for H_2 tanks for a FCEV-Bus. The storage and the Diesel Gen-Set are changed only, if another type of a bus vehicle is wished by the customer. All components, coloured in blue, are parts of the so called “Basic Electric Bus” described in the chapter 2 “Concept” above. The components, identified by green letters, come out of the WP2: steering pump system and air compressor system.

The other auxiliaries like HVAC and DC-DC converter can be delivered by many suppliers and can be used by many OEMs in several applications, as it is worked out by WP2 in ECOCHAMPS. Also, the traction drive components of a serial hybrid drive (EM, INV, Bat-System) can be used in several applications for busses and trucks. In the case of these main traction components, the OEMs and suppliers might be in competition situation, which is well for the whole market and will also lead to cost reduction.

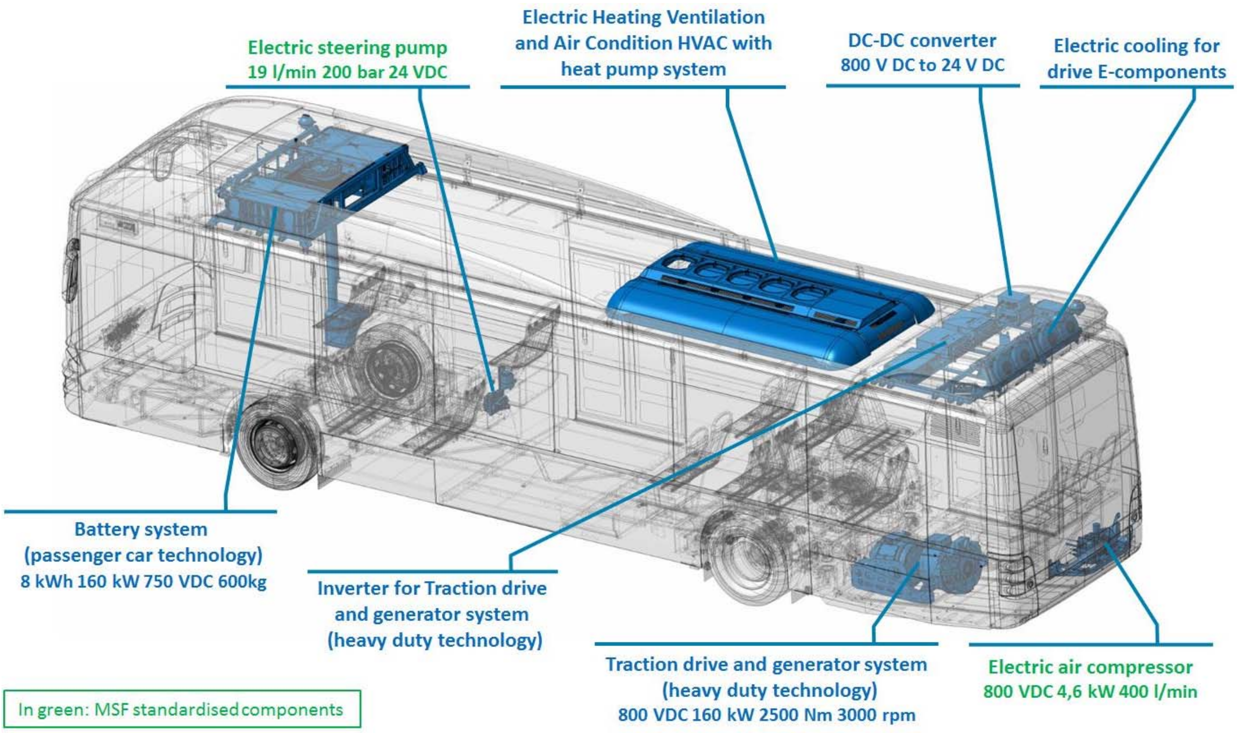

Fig. 7 Modular Hybrid Bus Demonstrator Vehicle

The traction drive with a combination of high speed electric machine and gearbox is a first attempt to show the possibility using of derivatives from high volume production of passenger cars. Given the time line of the ECOCHAMPS project, only “very fresh developed components” could be used in the bus demonstrator vehicle. This means that the maturity is not high enough for safe operation on public roads. The bus must pass a number of tests for qualification, which cannot be realized in the time frame of the ECOCHAMPS project. Therefore, the bus demonstrator will be equipped with a high efficiency electric drive for heavy duty application, Fig. 7, which is state-of-the-art in 2016. However, to have the data from the high-speed electric machine, this drive will be compared with the traction drive of the reference vehicle from 2013.

3.4. Simulation of power train efficiency

The vehicle concept will be verified with a simulation of the complete vehicle drivetrain. For the simulation a "MAN drivetrain simulation model" in Matlab/Simulink will be used, to show the energy consumption of the drivetrain and the fuel consumption of the vehicle. For the fuel consumption result from typical bus cycles will be used.

The "MAN drivetrain simulation model" is a "forward simulation" model, which means the simulation of a real driver (driver model) as a controller and the calculation of all components from the engine to the wheel (drivetrain). The main parts of the simulation model are shown in the figure "MAN simulation model".

The planned simulations and measurements of the reference and the demonstrator vehicle are shown in the Fig. 8 "Overview simulation & measurement". MAN has a validated simulation model of the Reference vehicle (1). For the validation the measurement results of the MAN roller test bench were used (2). For the ECOCHAMPS project a simulation model of the demonstrator vehicle will built up (3). The results of the simulation of the demonstrator vehicle can be used for a comparison with the values of the reference vehicle. The results can be used for the tracking and the evaluation during the development process. For the final validation of the demonstrator vehicle, measurements on the roller test bench are planned (4).

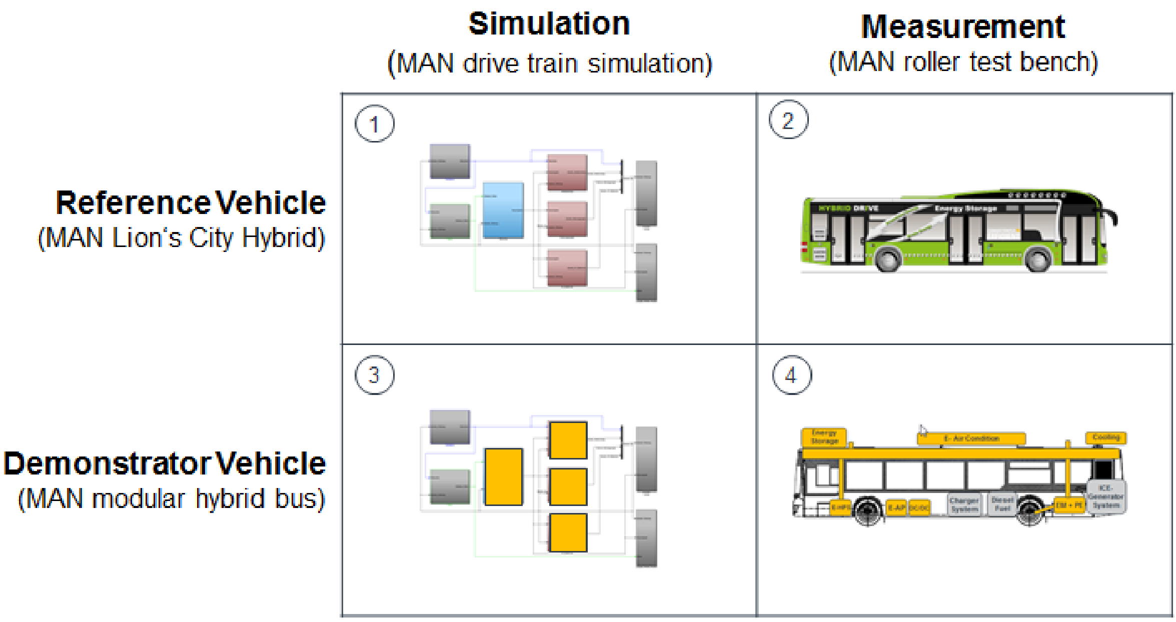

Fig. 8 Overview Simulation & Measurement

Fig. 9 shows the estimated efficiency of the new traction drivetrain in several simulated ranges. The efficiency is depending on the used driving cycle: between 11%-points (heavy urban) and 7%-points (suburban), planned ambition: 10%. The energy consumption of the auxiliaries is set to the same value for reference vehicle and demonstrator.

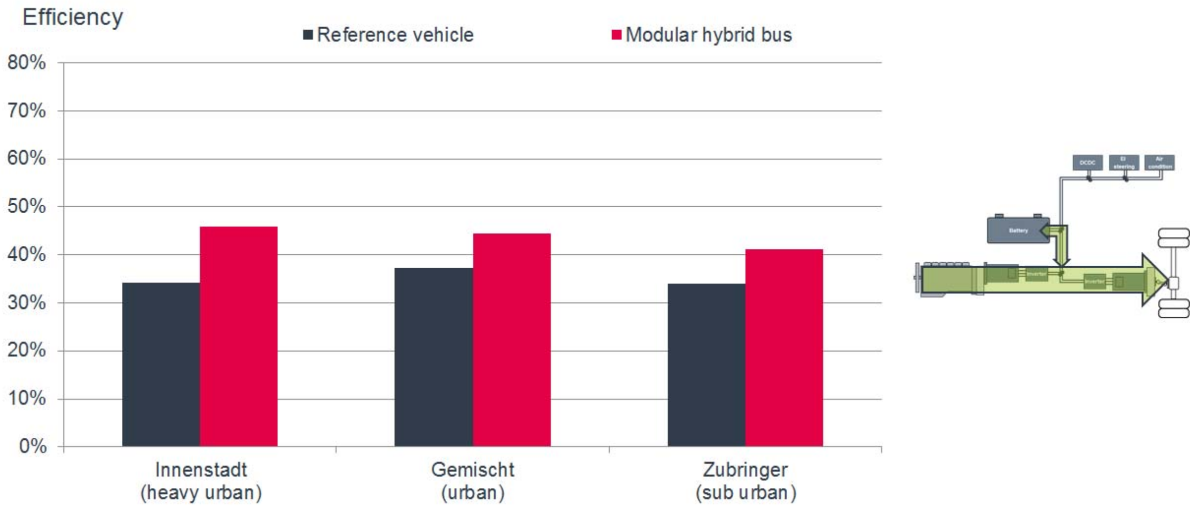

Fig. 9 Traction Drive Efficiency in several cycles as use cases

3.5. Comparison of the "High Speed Drive" with "Current state of traction drive" for HD

A first comparison of the of the "High Speed Drive" with the "Current state of traction drive" for HD-Applications is given in Table 2. The values are preliminary and give a first impression of reduced weight and reduced mass of the traction drive components. The exact values will be stated in the final report of ECOCHAMPS project.

Table 2 Comparison between High Speed Drive and conventional Drive for HD applications

Properties of Traction Drives	High speed Drive with gearbox	e-Drive conv. heavy duty application
Maximum Speed	16000 rpm	3500 rpm
Rated Power	150 kW	160kW
Motor Dimension (D x L)	380 mm x 320 mm	520 mm x 465 mm
Gearbox Length	240 mm	-
Total Length	560 mm	465 mm
Total Volume	668 dm³	760 dm³
Weight of Gearbox / EM	37 kg / 180 kg	- / 300 kg
Total Weight	217 kg	300 kg (not SoA)
Reduction of Volume	- 12%	100%
Reduction of Weight	- 28%	100%

One result of Table 2 is that the volume of the high speed drive is 12% below the current conventional Drive for HD applications and will have also a reduction of 28% in the total weight.

4. Summary

With respect to the current state of the project, the main ambitions seem to be reachable: 10% more efficiency of traction drivetrain, volume and weight reduction of 10%.

Traction drive efficiency is preliminary calculated by simulation, Fig. 9 and volume and weight reduction is foreseen as it is given in Table 2. Fuel consumption and from that the CO_2 output will be stated in the coming validation phase driving the demonstrator vehicle on the dynamometer test bench at several cycles. An estimation of fuel reduction will be simulated with the efficiency values of the high speed drive with gearbox by using characteristic data from the test bench. Costs comparison is still under work. A minimum driving range at zero emission is 5 km by using the battery system only, i.e. the ICE is stopped. This will be tested in the coming validation phase of the project.

The main aspects of the ECOCHAMPS project to see, what is realized of the foreseen “ambitions”, will be available at the end of year 2017.

References

- H2020-GV-2014_653468_SIGNED_PROPOSAL[1].pdf

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