Range Extender for Two-Wheeler Applications

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Abstract

The scooter market class L1e (<50cm³, speed limited to 45km/h) is facing a significant change due to the implementation of the new EURO 3 regulation, obligatory for new type approval by 2014 and for all newly licenced types by 2015, the market will suffer the loss of low cost vehicles due to the requested durability of exhaust gas after treatment systems. More complex drive units will have to follow. Pure electric scooters pose a further possibility to respond to the new requirements. A significant cost increase is common to all of these approaches. The goal is to find an alternative to be able to comply with the requirements of emission legislation and to keep the product price as low as possible at the same time.

A technological comparison of different approaches revealed the series hybrid variant as most promising. The evaluated system and the derived concept consist of a combination of an electric scooter with a halved battery size (cost reduction) and a Range Extender with the possibility to extend, if necessary, the range to the standard of conventional ICE variants. This alternative is able to offer electro-mobility and therewith local zero emissions without the immanent “range anxiety” usually caused by pure electric vehicles [8].

Having defined the system layout as plug-in hybrid-electric vehicle (PHEV) and checked the characteristics of single components in numerous preliminary investigations, a longitudinal backward simulation was carried out. It permits the testing of different operational strategies in combination with a subsequent evaluation of the fuel consumption reduction potential [16].

A packaging analysis could verify the constructive feasibility.

Finally, the draft design of a Range Extender vehicle will be presented showing the potential of CO_2 reduction.

1. Introduction

Nowadays, politicians are forced by air pollution prevention to demand zero emission vehicles (ZEV) in the form of pure electric vehicles. The poor capacity to weight factor of actual batteries compared to any kind of liquid or gaseous hydrocarbon fuel is the main reason for the retarded implementation of local ZEV.

Solutions offered by automobile manufacturers are mild to full hybrid powertrains based on the well-established ICE platform. The difficulty of those approaches of electrification is to compete with the performance and benefit customers expect from standard automobiles. Pure electric vehicles are rare and often disappointing regarding range and/or performance. Additionally the costs for such vehicles, which are mainly driven by the battery prices, are comparatively high, impeding their market entrance and acceptance.

Low price electric city scooters are actually offered as pure electric vehicles in a wide variety of different models. The category of city scooters (L1e [1]) is regulated regarding limited speed and engine capacity. The driving distance is generally short (<10km) and additional comfort features (such as heaters or air condition) are not expected nor demanded by the customers.

The selling numbers of electric city scooters are strongly depending on the local legislation. In case of the establishment of restricted areas with exclusive access for zero emission vehicles, their share will be positively affected due to the capability of pure electric driving (China). The only disadvantage is range distance uncertainty due to the small battery size of such economic vehicles together with time consuming charging.

This can either be improved by increasing the battery capacity (negative influence on costs) or by implementing a Range Extender technology (greening influence) with a simultaneous decrease of the battery size. A small combustion engine with a generator, loading the batteries in case of long distance driving, is required.

Nowadays the European 50cm^3 scooter market is dominated by a large variety of low cost vehicles respecting the consumer's behaviour to look for cheap short range mobility solutions for inner city or for the younger traffic participants (between 16-18 years old) without driving licence.

As a maximum power (~below 4kW) is desirable the low cost sector is mainly represented by vehicles with two stroke engine equipped with carburettor and a simple after-treatment system in form of oxidation catalytic converters in combination with secondary air systems. These vehicles are homologated according to EURO 2. With the implementation of the new EURO 3 regulation [1], obligatory for new type approval by 2014 and for all newly licenced types by 2015, the market will suffer the loss of these low cost vehicles and will be forced to offer more complex and thus expensive alternatives (Fig. 1). Reason therefore is the requested durability of exhaust gas after treatment systems.

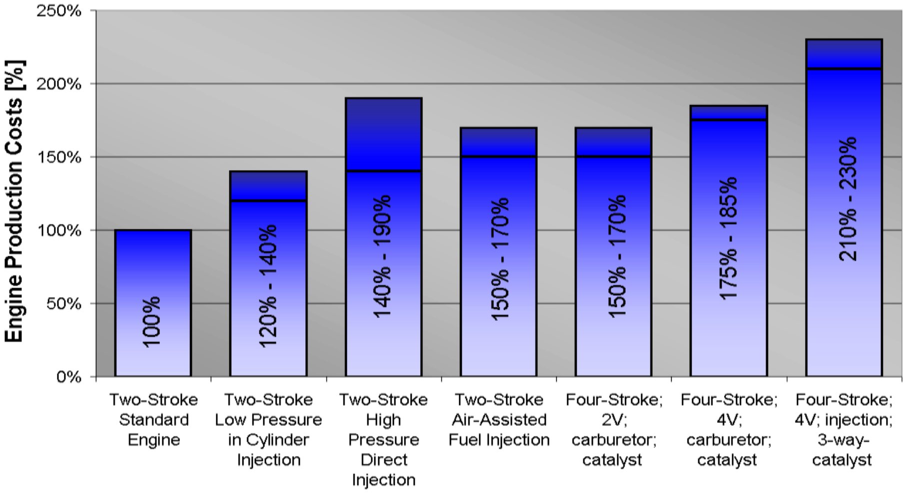
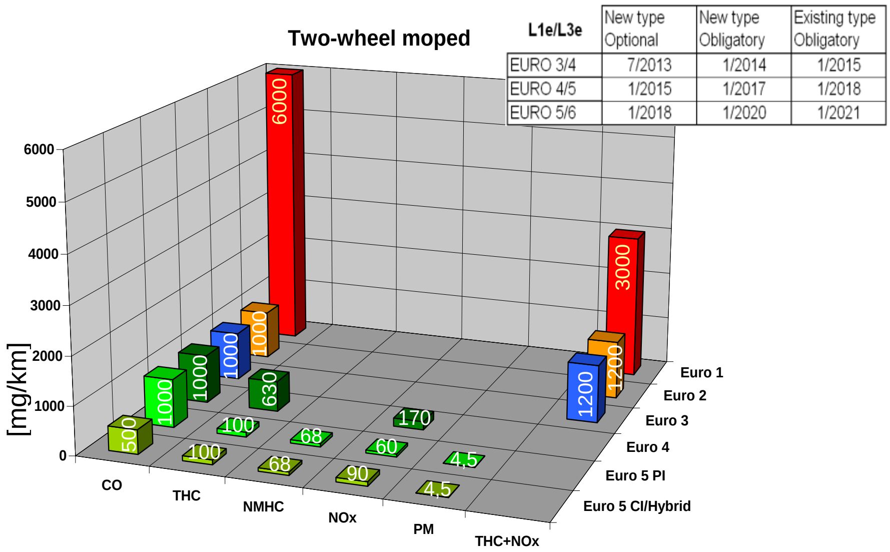


Fig. 1 *Estimated engine costs relative to the two-stroke standard engine [3]*

The next steps of emission regulation will further drive this trend towards higher costs for Internal Combustion Engine Vehicles (ICEV) and, as a side effect, raise the competitiveness of Electric Vehicles (EV) (Fig. 2).



L1e/L3e	New type Optional	New type Obligatory	Existing type Obligatory
EURO 3/4	7/2013	1/2014	1/2015
EURO 4/5	1/2015	1/2017	1/2018
EURO 5/6	1/2018	1/2020	1/2021

Fig. 2 *European emission limits [1]*

Apart from the efforts made by legislature, also local measures are taken to reduce emissions in inner city areas. Road pricing, low emission zones and limited (emission depending) access to the city centre are being installed in major cities in Europe and Asia. The political will to promote zero emission vehicles is present, but is actually confronted with a relatively small or not price-competitive offer of such vehicles.

Zero emission vehicles are Electric Vehicles (EV) driven by electric motors and storing the drive energy in batteries. Their main problem is the low energy density of these batteries compared to regular fuel, even though improvements were made by the lithium technology. Actual battery costs, especially for lithium, are high and therewith negatively affect the system cost of EVs. EV prices strongly depend on the battery costs and are at present up to three times more expensive compared to the EURO 2 low cost ICEV equivalent.

To overcome this circumstance, the project HyScooter, embedded in the research framework ECO-PowerDrive [4], is researching the possibility of decreasing the dependency of EV prices on battery prices by hybridisation, keeping up or even improving the performance with regard to range and drivability. Prior studies [5] indicated that fuel economy and emission should be better than in ICE driven scooters due to the avoidance of transient engine operation.

The research and development activities are strongly driven by simulation measures in order to optimize the layout, reduce research prototype and test costs and to shorten the development time.

2. Hybrid concept

The starting action is to virtually reduce the range of pure electric driving by downsizing the battery. Simultaneously; vehicle weight and price are also improved.

As the studied vehicle class L1e (<50cm³, speed limited to 45km/h) is mainly used for short range travel, this measure should not have any negative effects on the performance. “Range anxiety” - driving with the reserve lamp lighting is common to EVs - and strongly depends on the way the vehicle is used, e.g. uphill driving, strong acceleration and even operation at low ambient temperature can dramatically shorten the range.

In order to determine the characteristics of the virtual vehicle and its components, some preliminary research studies have to be made. In a first step a market research is carried out for Electric Scooters (ES) to find specifications for power, weight, range, battery type and capacity, voltage and climbing ability (Fig. 3 Table). Various studies with focus on costumers needs have been performed [e.g. 6], nevertheless the specific use and environment of this vehicle class requires a new survey.

In contrast to automobile applications [7], EVs of this class are commonly equipped with 48V lead acid batteries with Absorbent Glass Mat (AGM), also known as deep cycle batteries widely used in mobility applications. Higher priced models are using lithium batteries, but they are still rare on the market. The low

voltage of 48V is selected for safety reasons in order to prevent fatal electrical accidents during service, maintenance and manipulation.
The minimum range is specified to be about 40km (30km/h running on flat surface) when battery capacity is around 40Ah. The stored energy is therefore about 2kWh. Reducing this value to ~1kWh will help to nearly half the volume, weight and cost of the battery. An AGM battery with 48V and a capacity of 20Ah was selected and implemented in the longitudinal dynamic simulation model for the further studies. The resulting range will be less than the half, because battery energy output is depending on the load to capacity factor (in A/Ah) of the battery type.

CLASS	STATUS	CONCEPT
	Pure Electric Scooter	Hybrid Scooter
Power	1.1 – 2.75 kW	2 kW with boost function +50%
Range	30 – 90 km	more than 100 km
Weight	98 -190 kg	less than 120 kg
Battery type	Lead acid / AGM	AGM / Lithium
Voltage / Capacity	48 V / 17-60 Ah	48 V / 20 Ah
Climbing ability	9 – 15%	15 % @ more than 15 km/h
Charging	Plug in 4-8 h	Plug in 2 h

CLASS	ICE Scooter	Hybrid concept Scooter
Fuel consumption	depending on test cycle and mixture preparation	less
Emissions	depending on test cycle and mixture preparation	less

Fig. 3 *Table: Concept specifications deduced from market research*

As there are different possibilities to realise a hybrid scooter, a technology comparison is carried out for the different drive train variants.

- Hybrid Parallel
- Hybrid Series (with Range Extender)

The following vehicle architectures and setups are used as basis for the evaluation

- Conventional CVT scooter 2-stroke ICE
- Pure electric scooter (pure EV)

Description of assessment criteria (see Fig.4 Table):

- **Range** is evaluated as [+ +], if it is practically not limited. Refuelling can be done in a relatively short time compared to recharging, which takes several hours. A parallel hybrid drive train can continue driving with the ICE even when battery is completely discharged. A series hybrid drive train will not run out of battery as long as it is recharged by the ICE through the generator. In both applications the range is unlimited.

- As for all vehicles with ICE support, the SOC (state of charge) at cycle end is assumed to be equal than at cycle start, the **fuel consumption** is therefore an indicator for system efficiency. The fuel consumption assessment is positive [+ +], when no fuel is needed and negative when a huge amount is needed for relative poor mechanical output.

- **Emission** assessment is based on regulated local emissions and defined to be positive, if they can completely be avoided. The ranking results from the complexity of necessary technological measures that guarantee values under the defined limits of emission regulation, also considering a partly local zero emission operation.

- The mark for **noise** is better the quieter the drive train performs. Combustion and mechanical noise emissions are evaluated.

- **Drivability** aspect is marked positive when no gear change effect is noticed by the driver and the higher starting torque is experienced.

- The **maintenance** aspect includes all components in a vehicle requiring some kind of care, as engine, CVT, secondary gear. The necessity of regular control of liquids of wear by the vehicle owner is also negative for this criterion.

- The less the vehicle functions depend on the **battery** the higher the mark is.

- **Weight** and **price** are marked according to the lower the better.

	ICE	**EV**	**HYBRID**	
			PARALLEL	**SERIES**
range	+ +	- -	+ +	+ +
fuel consumption	- / - -	+ +	-	+
emission	- -	+ +	-	+
noise	- -	+ +	- -	+
drivability	-	+ +	+	+ +
maintenance	-	+ +	-	+
battery	+ +	- -	+	+
weight	+ +	- / - -	-	+
price	+ +	- -	-	-

Fig. 4 *Table: Technology comparison*

As the ICE of a series hybrid runs at constant speed and in regions of best efficiency, fuel consumption should be lower than in the parallel hybrid due to the avoidance of transient engine operation. Engine warm-up and exhaust emissions could hereby also affected positively [15].

For the series hybrid mechanical noise emission can be reduced significantly by decoupling the ICE from the rest of the vehicle and exhaust system muffler can be designed and tuned for the constant engine speed to further reduce combustion noise.

The additional weight of the generator needed in the series drive train is overcompensated by the missing CVT and secondary gearbox used in the parallel hybrid and ICE drive train.

As a result of the technology assessment (Fig.4 Table) a series hybrid system was chosen as most promising concept.

2.1. Series hybrid system

A series hybrid system is composed of an e-motor as propulsion unit, which is fed by the energy stored in the drive-battery. In case the battery is discharged, it will be charged by a generator, driven by an internal combustion engine. In this configuration, the internal combustion engine acts as range extender (REX). Different concepts can be distinguished, depending on the battery size/capacity.

A configuration without battery is called “electric gearbox” and is not considered a hybrid system by Directive 2009/108/EC [9] due to the missing second type of energy source.

Utilizing the advantages of the above mentioned legal regulations for hybrid concepts, the size of the necessary battery has to be chosen. Hybrid concepts with full size batteries (compared to a pure EV) suffer basically equal to the pure EVs from the high cost and weight.

A system with a small to medium size battery (compared to a pure EV) which operates the ICE only when battery charge is low offers the advantage of lower cost and weight but affords higher operation frequencies of the REX. Considering the target of low cost, this hybrid concept with smaller battery was chosen for the first layout studies. Line charging has to be maintained analogous to the pure electric variant, as significant CO_2 advantages can be achieved due to the valid emission calculation.

In order to evaluate the potential of this plug-in hybrid concept, a simulation assessment was carried out. Prior to this, a basic layout of the hybrid system and its components must be defined. A schematic layout of is displayed in Fig. 5.

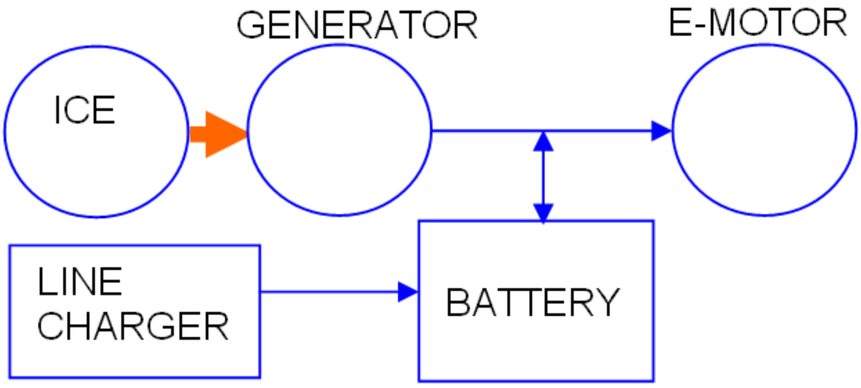


Fig. 5 *Main components of a PHEV with REX*

2.2 Basic hybrid system layout

The minimum of mechanical rear wheel power, in case of an empty or zero battery, is defined to 1kW, which is the power demand for a 45-50km/h flat surface drive (Fig. 6). The climbing ability calculation for this worst case results in a speed of 17km/h at 10% incline.

For the standard case of the pure electric drive, the rear wheel power is defined to 2kW.

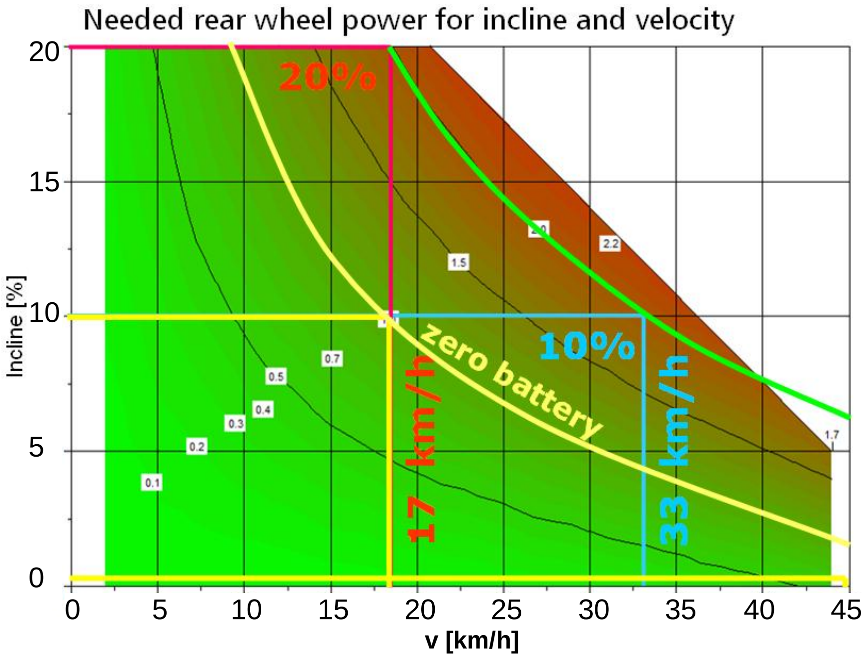


Fig. 6 *Basic system layout*

As the ICE acts on the generator, which delivers the electrical power to the controller and the e-motor, efficiencies of all involved components have to be determined.

2.3. E-drive efficiency

E-drive denominates the combination of controller and e-motor. As a first approach, the e-drive efficiency map of a selected reference EV (iDep [10]) was experimentally determined on the roller test bench. The resulting efficiency maps for motor and break operation are shown in the figure below (Fig. 7).

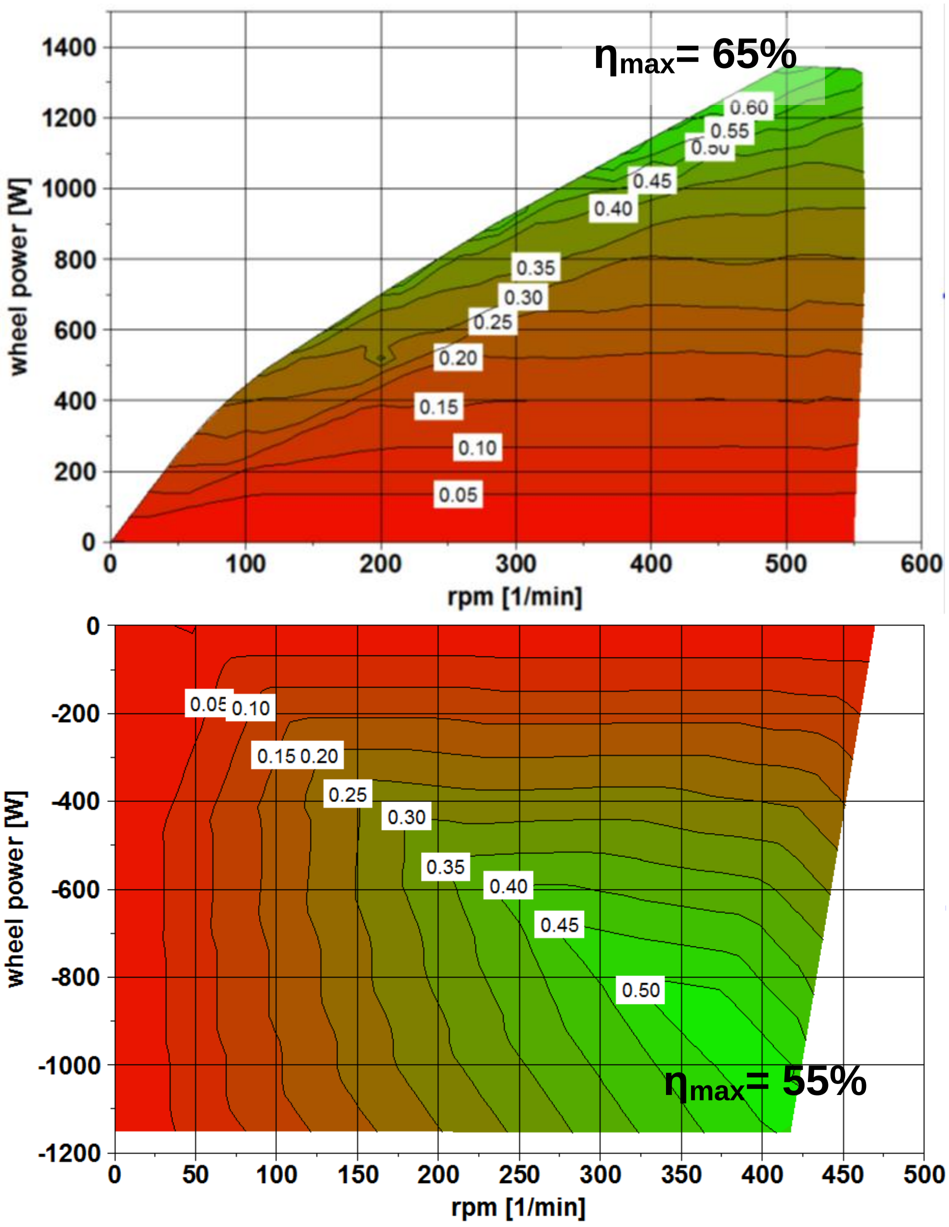


Fig. 7 *Results for motor and braking/recuperation efficiency of the reference EV*

The maximum E-drive efficiency is quite low with 65%, as it depends on the size of the E-motor and the resulting higher gap losses.

2.4. Generator subsystem efficiency

The efficiency of the subsystem, which is composed of generator and rectifier, was estimated as 80% for the further calculation. Actual experimental investigations on the generator subsystem efficiency approve this first estimated value.

2.5. Hybrid drive train efficiency

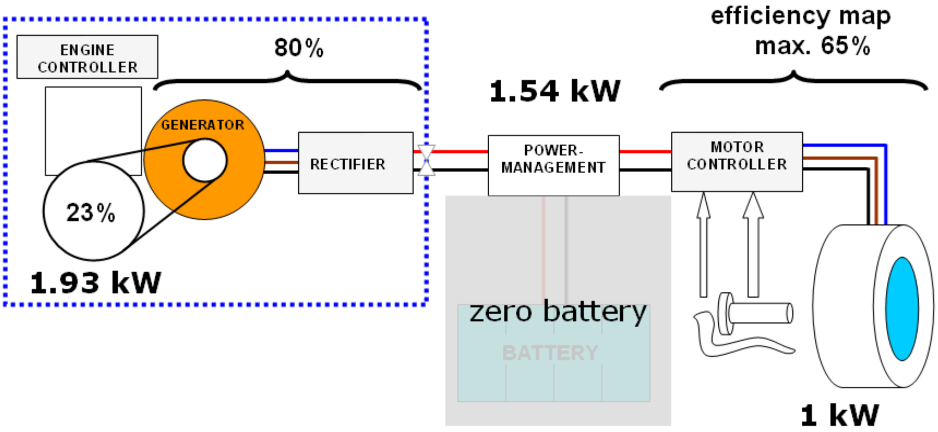


Fig. 8 Hybrid drive train efficiency

With the single drive train component efficiencies the overall drive train efficiency results to 52% (Fig. 8), assuming no battery activity (min SOC) and therefore no additional battery loss. This is lower than the efficiency of 65% of a common CVT drive train.

The neglected battery losses in this first system lay out will be treated in the longitudinal dynamic simulations. The battery subsystem is represented by a equivalent circuit composed by a capacity, an inductance and an inner resistance. Battery losses are thereby driven by the current drawn from or charged into the battery, so that the resulting battery efficiency is strongly depending on the test cycle and the operation strategy of the REX.

As 1 kW was defined as rear wheel power considering the efficiency of 65% of the electric drive train, the electric power demand from the generator is calculated to 1.54 kW. Due to the efficiency of 80% of the generator subsystem, the mechanical power output of the engine is determined to 1.93 Kw (Fig.8).

2.6. ICE concept

The ICE capacity is defined by regulation to 50cm^3 for the vehicle class L1e. For low Noise, Vibration and Harshness (NVH) an operation of the ICE at low rotational speed is fundamental. Under this aspect different engine concepts have been evaluated. The advantages of high torque as delivered by a 2-stroke engine in combination with its simple and low weight construction were decisive for its selection. The disadvantage of high emissions caused by the scavenging losses of standard carburetted loop scavenged engines can be reduced by a low cost direct injection system. Published concepts point to a significant HC-emission reduction [11, 12]. Water cooling of the engine contributes to optimized NVH and best fuel efficiency.

2.7. Packaging analysis

After the definition of the battery dimension and the REX components, a packaging analysis was made for this configuration.
Requirements were the conservation of the helmet case (storage space) and the design of an ICE scooter. The packaging of the REX and its vehicle integration seems to be feasible according to the results of this study (Fig. 9).

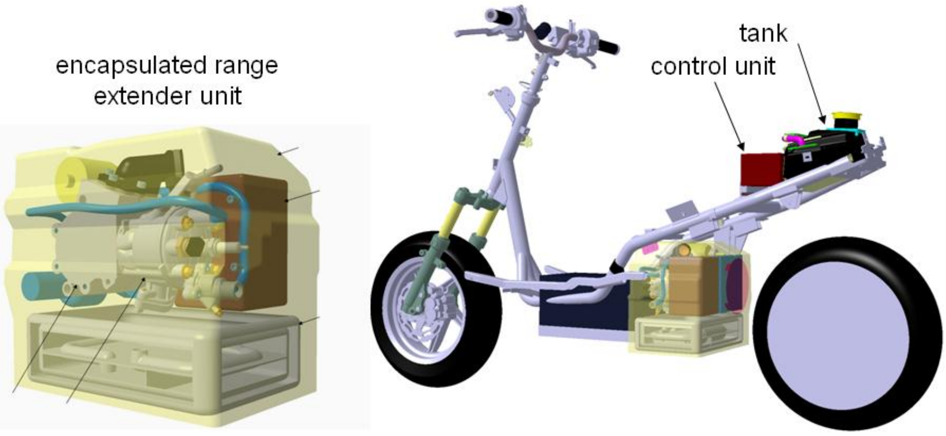


Fig. 9 *Packaging study of the concept for a Hybrid Scooter with REX*

2.8. E-motor definition

As a result of the packaging analysis regarding vehicle integration, the motor type was defined as hub motor. A hub motor is placed in the driving wheel and does therefore not require any space in the vehicle frame. Unsuspended mass is increased but not critical in comparison to ICE Scooters, as the complete drive train is also partly unsuspended.

The e-motor was defined, once by the result of the market research and also approved by the simulation results, to have 2kW of mechanical power output. Resulting from a market research on hub wheel motors, this is the highest constant power offered for 10” wheels. For a short time a “boost function” up to 3kW is possible and would increase the fun to drive.

2.9. CO_2 reduction potential

In order to evaluate the REX drive train regarding its potential for CO_2 reduction, several simulation studies had been performed. These studies were based on the above described concept definitions and reference vehicle date. The results are compared to those of the chosen reference vehicles.
The longitudinal dynamic simulations were carried out for several official emission test cycles (ECE R47, WMTC, CADC and NEDC) with the in-house code PHEM. PHEM serves as software tool to study the fundamental dependencies and is mainly used to calculate a large number of ICE vehicles in transient operation and delivers results for fuel consumption and exhaust emissions. PHEM is also capable to calculate the energy demand at each time step for different hybrid vehicle systems in given test cycles. Thereby the hybrid concept itself and the influence of the hybrid operation strategy on fuel consumption can be evaluated and compared to an ICE-Scooter.

2.10. Potential of recuperative braking

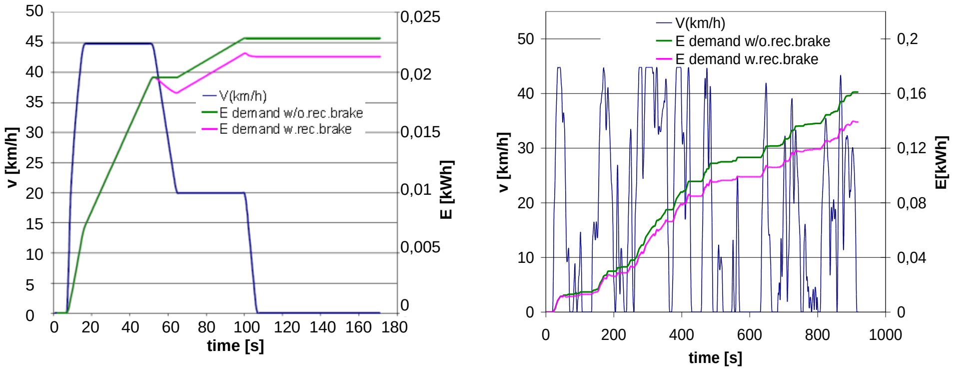


Fig. 10 *Results of recuperative braking analysis for ECE R47 and CADC test cycle*

In order to assess the advantage of use of recuperative braking in electric drive trains, several test cycles were simulated. Depending on test cycle, (Fig. 10) recuperative braking has the potential to reduce energy demand by 5 to 15 %. This advantage has to be faced against the considerably higher costs for an electric drive train, capable of regenerating electric energy from braking (4 quadrant operation mode).

2.11. Operation strategy of the rex

As the operation strategy of the Range Extender concept is decisive for the CO2 reduction potential (fuel consumption) of the virtual hybrid vehicle [14], in a third simulation task this operation strategy of the range extender concept was investigated by means of a simulation. This task required the programming of a MatLab module to implement the hybrid control parameters to the PHEM simulation code.

The following parameters were used:

- The minimum State Of Charge (SOC) for starting the range extender, which is decisive for battery life
- The maximum SOC for stopping the range extender which has great influence on the hybrid system efficiency and thereby on the fuel consumption.
- The minimal operation time and the start interval which should avoid cold start emissions [15].
- Operation mode of the ICE as a function of vehicle speed and maximum charging current of the battery.

A REX operation strategy of charging start at 30% SOC and charging stop at 35% SOC while running in two different power modes is displayed in Fig. 11.

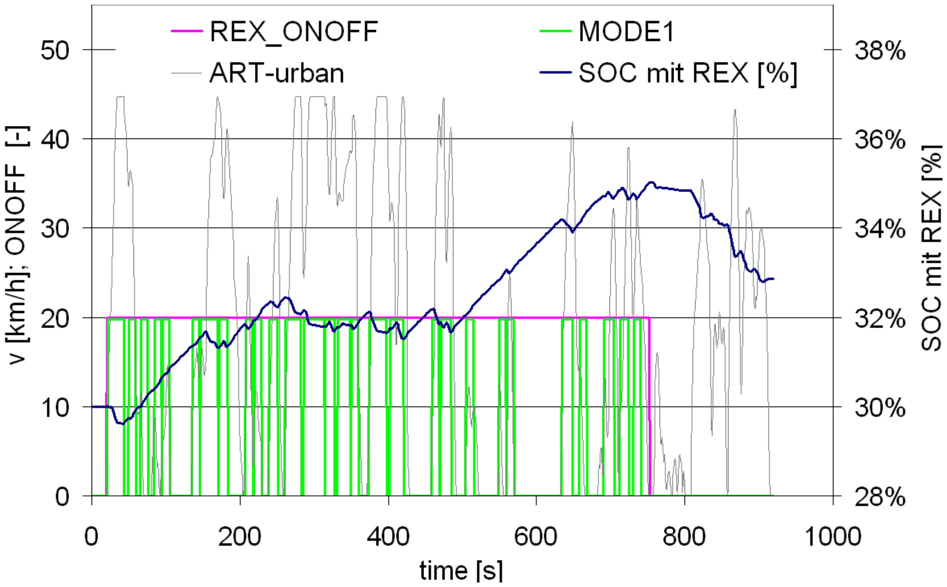


Fig. 11 *REX operation strategy analysis for CADC*

The results of this displayed parameter set revealed a fuel consumption reduction of more the 40% in the CADC in comparison to the reference ICEV (EURO 3 ICE scooter).

The fuel consumption advantage strongly depends on the dynamics of the investigated driving cycle. This allows the conclusion that a lower consumption is the result of recuperation (up to 15%) as well as of the avoidance of the highly transient operation of the ICE. The ICE of the REX is working in the range of best efficiency, whereas the ICE scooter shows worse efficiency, especially at part load. The high fuel consumption of a standard ICE scooter is also caused by a low CVT efficiency of a maximum of about 65%. In the slipping mode of the CVT transmission, efficiency is even lower.

Driving at constant speed (with the highest CVT gear and stationary mode of ICE) shows no consumption advantage, as the entire efficiency of 52% of the hybrid drive train is lower than those of the CVT drive train.

Conclusion

The basic idea to overcome the disadvantages of today’s electric scooters in regard of range and price has led to a concept for a plug-in series hybrid scooter with range extender.

For an estimation of the CO_2 reduction potential several simulation studies were carried out. The simulation model and methodology has been referenced by the use of experimental data from pure electric scooter vehicles (reference vehicles).

The first hybrid vehicle simulation results demonstrate the potential for significant fuel saving compared to an actual EURO 2 ICE scooter. With these figures the basic concept proof is successful and further effort should be made to build up a detailed simulation model [cf. 16] on a MatLab basis and in parallel build up an experimental testing platform to validate the simulation.

Outlook

For the ICE, the basic layout process will be started with 1 D CFD simulation [17] leading to a design layout of an experimental research engine. Using standard components an experimental testing platform of the electric power train will be set up. This platform will be used for referencing the Matlab Simulink model as well as to validate the simulation results.

Using and extending the general simulation platform of the ECO-POWERDRIVE project [4] ECO-SIM [18] as vehicle longitudinal dynamic simulation, further investigations will be made. The foci of these investigations are the hybrid system with respect to an energy demand consideration which is based on energy content of battery and / or fuel in various test cycles and the REX control strategy in regard of power management, battery life, fuel economy and NVH.

Definitions, Acronyms, Abbreviations

1-D CFD	1-Dimensional Computational Fluid Dynamics
AGM	lead acid batteries with Absorbent Glass Mat
CADC	Common Artemis Driving Cycle
CVT	Constant Variable Transmission
ES	Electric Scooter
EV	Electric Vehicle
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle
NVH	Noise, Vibration and Harshness
PHEM	Passenger car and Heavy duty Emission Model
PHEV	Plug In Hybrid Electric Vehicle
REX	Range EXtender
SOC	State Of Charge
VLDS	Vehicle Longitudinal Dynamic Simulation
ZEV	Zero Emission Vehicle

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