Methodical Design of a Trailer Range Extender for Improving the Range of electric Vehicles

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Abstract

At the Otto-von-Guericke-University (OvGU), an electric car has been designed and constructed. This gives the scientists and students the chance to acquire knowledge in the electric mobility. This includes the development and realization of a Range Extender, too. The experiences and solutions of this project will be presented here.
Keywords: electro-mobility, range extender, methodical design

1 Introduction

"After more than 100 years history of the internal-combustion engine in the road traffic a new technological era in the field of transport could start with the electric mobility. The electrification of the drive train technology is a major adjustment for a sustainable mobility. It offers the opportunity to reduce the dependency of crude oil, minimize the emissions and to integrate the vehicles better into a multimodal transport system"[1]. This could be looked up in the national development plan for electric mobility of German Government by 2009. The aim, which is still fixed in 2014, is that in the year 2020 1 million electric vehicles drive on German roads.

Fig. 1 editha

For this reason a SMART was prototypical rebuilt to an electric car at the Otto-von-Guericke University of Magdeburg. The result a car with motor vehicle registration and the name "editha" (**Fig. 1**) has been developed. The name is a reference to the Otto-City Magdeburg (Emperor Otto gave the city to his wife Editha as a present).

A problem of electric-mobility is the expected range of the vehicles, because it will always be compared to the range of vehicles with combustion engines. In consequence of the battery capacity a range of 100 km is located in the upper realm of possibility. Considered objectively just the weight can be reduced to increase the range. To construct better batteries and more efficient electric motors will only be possible in a few years. A range of 100 km is often sufficient for urban transports.

The driver gets easily to work and back. Also the daily shopping or the detour to the Sports Club won't be a problem. The much bigger problem will be journeys to go for holidays or visiting friends at another town over the weekend. That's the reason for great doubts for many potential buyers. A range of 600 km will be expected here and the using of highways is required. Today it is not possible to travel such distances just with electric energy. Huge battery packages make the car heavy and are very expensive. That's why often a hybrid solution is favoured, which uses a combustion engine and the incredibly high energy density of liquid fuels. In contrast to fixed installed systems and the higher weight of two motors, batteries, fuel tank, etc a Trailer range extender has been designed for the project "editha" on the department of machine design in the Otto-von-Guericke University of Magdeburg. ,. This range extender has the great advantage of modularity, which means that it used when needed but not used in the case when the normal range is sufficient. Then you don't have to transport the increased weight.

The result of the considerations is a trailer with a combustion engine and a generator, which partially provide the electrical flow, to stretch the battery power up to the desired range of 600 km. The technical know-how is the coordination of the components and its adjustment. Starting at a trailer summary weight of 150 kg, which is allowed for a vehicle with lower power, light weighted components had to be found. These components have been adjusted in a way, that the range can be stretched up to 600 km with a full tank and full batteries at the beginning of the ride, and a speed of 87 km/h. It is possible to drive from Magdeburg to Munich without refuel, while driving between the trucks on the highway.

2 Background of e-mobility

2.1 Costs

As mentioned above, one of the main problems of the e-mobility is the range of drive. Also high costs and long charging times are disadvantages, why e-mobility isn't completely accepted by the customers. Regarding the costs, there are studies, which prove that it is possible to depreciate an electric car after about 7 years [6] because of low running costs and longer durability of the components. In these studies the current cost of gasoline and electricity are assumed. These costs and the bad predictable prices here lead to a big blur. If the components are considered, an electric vehicle is built up significantly easier than a vehicle with a combustion engine and should therefore be cheaper. Through the backlog of nearly 100 years development work and often prototypical building of electric cars the ratio is still different. Through mass production the costs of electric vehicles will probably fall and be lower as the conversion costs in current projects.

2.2 Acceptance

The problem to charge the batteries - a charging cycle takes up to 8 hours, are currently analyzed (also in the Otto-von-Guericke-University of Magdeburg) with the target to seek shorter charging times. The network of electric charging stations have to be increased, too and the availability (What will happen, if a charging station has been found, but it is occupied?) have to be discussed. The range is limited by air resistance, rolling friction and the weight of the electric vehicles. To maximize the range an electric vehicle should be light and small, but its wheels should be chosen to be tall and slim. These circumstances disagree with our ideal of beauty, given by the advertising and our known comfort standards. We all should ask ourselves, whether our cars have to be suitable for off-road use (SUV's), how often we do really use 4 - 5 seats and if the look of wide tires and spoilers is necessary.

Studies show that 90% of our daily journeys are less than 100 km long and the driver is mostly on his own. According to a reduction of our requirements to a car we could use smaller, lighter and more efficient.

3 Editha

In 2011 a used SMART with a motor vehicle registration was disarmed and converted into an electric vehicle. This has been made possible through a collaboration of 5 professorships of the OvGU and an external partner. The concept was a purely electric driving operation with a speed up to 100 km/h and a range of 120 km. A number of 54 LiFePo4 batteries have been plugged in in the underbody of a battery box. The battery capacity amounts 15.6 kWh at a voltage of 84V. The installed batteries suffer a high amperage, i.e. they can provide a high discharging current (up to a pulse of 20 C), which corresponds to the normal driving behavior and the requirements in the traffic. The temperature hardly affected the possible discharging current, the capacity is reduced around 26% at -10 °C.

Figure 2 shows two electric motors, have been fitted close to the wheels on the rear axle. Those serve as prime movers [2].

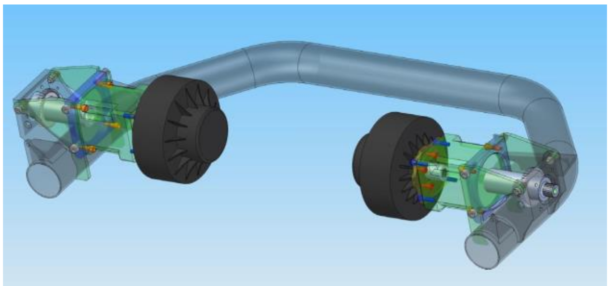

Fig. 2 Rear axle with electric motors and gear boxes

Several concepts have been created and evaluated according to the design theory, which is taught at the Faculty of engineering [3] in accordance to VDI 2225. Based on the missing maturity phase and the involved own development costs Brushed DCs have been implemented close to the rear wheels instead of the best rated wheel hub drive with PMAC. The advantages of this alternative are the very good efficiency (up to 92 %), the low weight and the exclusive use of immediately available components. The DC motors have been fitted via a planetary gear with a ratio of 6:1 directly to the rear axle. Therewith the shortest straight flow of torque has been realized.

Editha's characteristics are:

- maximum speed: 100 km/h
- range: 130 km
- consumption: 12 kWh
- performance: 20.5 kW (26 kW peak)
- battery capacity: 15.6 kWh

The efficiency factors are to see in **Fig. 3**. To convert chemical energy inside of the batteries across electric power up to mechanical energy, which is used for propulsion, is about 77%.

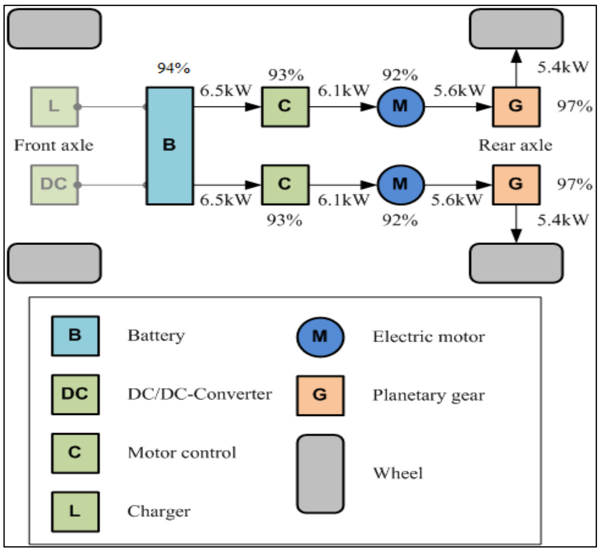

Fig. 3 Tank-to-Wheel [4]

4 Range Extender

4.1 Background

A range extender (RE) is used to stretch the possible distance of drive. Therefor it's necessary to provide energy in addition to the discharge current out

of the batteries.
Several concepts are possible:

- parallel hybrid
- serial hybrid
- mixed hybrid

The additional energy can be added off various sources:

- electricity from a solar panel
- electricity from a fuel cell
- additional battery
- conduct mechanical energy directly into the drive train

Here a serial hybrid, with a combustion engine that drives a generator, which transfers its power directly to the engines was elected. Because the electrical power of the range extender doesn't cover the current consumption it's still necessary to take a portion from the battery. There with it's possible to achieve a longer range up to 4 - 5 times and discharges the battery. Total discharge has to be avoided (LiFePo4 batteries are sensitive to this and grow old fast).

If the creation of electric power is higher as the consumption (e.g. braking with recuperation) power is led into the battery and stored there. The complete power has always been provided by the electric motors. The big advantage here is that the combustion engine works constantly in the optimum operation point. According to a market research and the evaluation of different alternatives, a 2-cylinder engine with 627 cm³ by Briggs & Stratton was elected. The nominal power is 16.8 kW. Because the permissible maximum weight of the trailer of 150 kg is very low, the factor was the weight. The weight of this engine is 35 kg. To determine the optimum operating point, series of experiments with the selected motor have been organized. Multiple operating points to see in **Fig. 4**, have been dictated. There is an operating point for the maximum torque, the maximum performance and the lowest consumption per converted kWh electric power. The Point with the minimum of consumption is chosen as the operating point, because exactly this point is located where the efficiency is in the desired target area.

In this point a mechanical power of 10.4 kW is generated at a speed of approx. 2200 rpm and 2.98 kg gasoline consumed per hour (equivalent to 4. 26 l/h) [5].

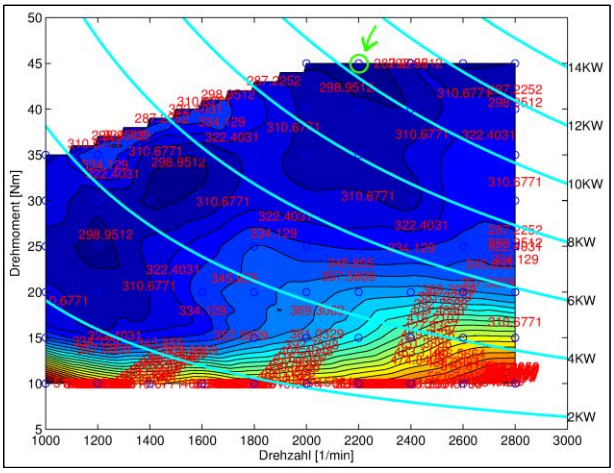

Fig. 4 Gasoline consumption [5]

The range extender has been designed as a module, so that it can be integrated into another vehicle or serves as an electric generator. The module contains additionally a tank, a starter battery, converter, a motor controller and the ECU (electronic control unit). It exist three alternatives for this combination which have been evaluated for the basic design:

- alternative 1 as encapsulated system in the luggage compartment
- alternative 2 on a lightweighted trailer
- alternative 3 on the trailer hook

There are difficulties with to discharge exhaust fumes and heat, the loss of modularity (an internal survey shows that, for comfort reasons a frequent reconstruction won't be accepted) and space problems resulted in the elimination of alternative 1 for the first range extender. Nevertheless this alternative will be reviewed conceptually in the future.

Alternative 3 could not be realized based on the confinement of the maximum vertical load of 35 kg on the trailer hook. But it represents a large potential to reduce further weight, because the weight of the trailer disappears.

To use the modularity as the biggest advantage of the range extender alternative 2 has been implemented and built on a lightweight trailer. We named it trailer range extender. This structure allows to get along without the added weight of the components for power generation in the everyday use (urban transport, short distances up to 100 km a day). Only in case of a large range, the car moves with range extender. Several user concepts are imaginable absorb the additional costs for the module, for instance as a range extender for rent or the opportunity that multiple owners share one range extender. This causes a certain strategy and foresight, but allows the permanently lower weight of the vehicle.

Fig. 5 Opened Range Extender

4.2 Problems

The weight was the limiting factor at the methodological design of the trailer range extender. A maximum towing capacity was approved by 150 kg to reduce the range not more than necessary and not to endanger the capacity on steep rises with the comparatively low power of the electric drive train. The components combustion engine, generator with clutch and the connecting piece with the damping elements have a weight of 64 kg. The trailer including the frame, fenders and for traffic necessary additions (e.g. strip light) weighs 62 kg. Furthermore there are also necessary elements for instance the motor controller (4.6 kg), cables, tank, exhaust pipe and a cover. It becomes clear, that the maximum weight will be exceeded. That's why the sought 20 l tank can't be installed. A 15 l tank is used as a compromise solution (**Fig. 5**). This decision causes the handicap of refueling. To start the combustion engine it is required to use a starter battery, because it is difficult to use the power of the traction battery.

The total weight amounts approximately 170 kg now. To receive the MOT (Ministry of Transport) approval a further iteration loop is necessary.

4.3 Using

More problems become visible while using the range extender. The temperature below the cover was too high, because the heat was not well bled of. This resulted from a sound insulation around the exhaust. The sound insulation has been removed by now. This causes dysfunction in the generator. As well the heat conduction of the motor by the clamping elements into the generator has to be revised has already been minimized.

In summary it has to be said that the thermal and noise emission still have be improved. Also the electromagnetic compatibility is checked to get the MOT approval and it has to be verified that no dysfunction will be caused. The necessary work for it is actually implemented so that the MOT approval can be expected soon.

Fig. 6 Range Extender with cover

5 Conclusions

A task for the future can be to reduce the weight of the components of the trailer range extender. To these lighter and more effective motors, generators and a reduced installation are analyzed. A trailer with only one wheel or a construction of alternative 3 (on the trailer hook of editha) is imaginable. The best weight optimization is to start the combustion engine by traction battery instead of taking starter motor and 12V battery with the range extender. The functions of starter motor and starter battery could be resumed by the traction battery and the conversely working generator. As another project for e-mobility and range extender technology a commercial vehicle is currently reconstructed for the electric use and should be equipped with a fixed installed range extender (alternative 1) below the load space.

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