EVS26
Los Angeles, California, May 6-9, 2012

Electromobility for heavy-duty vehicles (HDV)

Martin Birkner,
Siemens Infrastructure & Cities, Mobility and Logistics,
Erlangen, Germany, martin.birkner@siemens.com

Abstract

Major studies (e.g. Mobility 2030; WBCSD 2004) anticipate an ongoing growth in freight transport for all modes of transport (rail, road, water, air) with the majority of goods being hauled by heavy duty trucks also in the future. Motivated by the foreseeable shortage of oil resources as well as by local and global emission reduction targets, Siemens has started a development project to investigate different solutions for the electrification of heavy duty vehicle (HDV) traffic. This paper aims at presenting the result of the investigation, an open system approach for the electrification of heavy duty vehicles.

Along with a development project to evaluate the technical feasibility a comprehensive study has been conducted concentrating on the economical and ecological implications of the developed electrified highway system. With realizing a first fully operable prototype Siemens was successful in leaving the theoretical concept stage and is currently testing the system on a dedicated test track

Keywords: Electromobility; Heavy Duty Vehicles; Hybrid Trucks; External Power Supply

1 Introduction

Worldwide traffic is predicted to grow for all different modes of transport, passenger traffic measured in passenger kilometers travelled, and freight transport in terms of tonne-kilometers. Increasing wealth pushes the number of passenger cars, especially in the developing regions of the world. Ongoing globalization and connection of economies will come along with a massive growth of freight transport – regional, national and international. Even in developed countries like Germany a growth of more than 110 % is expected until 2050 due to increasing diversification of supply channels and transit traffic (Progtrans; BMVBS, 2007).

The growth is going to cover all modes of freight transport, via rail, road, water and air. Freight rail will continue to grow but will not be able to increase its share versus truck transport, due to the priority of passenger trains on most railway networks – with negligible differences between countries and regions. Also in the future a heavily utilized road network will have to cope with the majority of haulage volume.

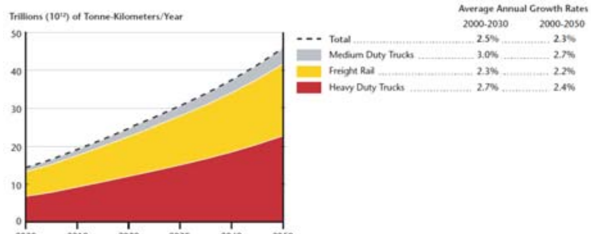

Figure 1 – Development of transport volume

Extension and optimization of rail and water transport networks and capabilities are important and sustainable approaches. However, also for road-bound transport there is the need to develop economically and ecologically reasonable technical solutions to manage the coming challenges.

- The worldwide road transport provides a huge potential for the reduction of greenhouse gas (GHG) emissions.
- Local emissions like particulate matter, nitric and sulfur oxides or noise will be a challenge especially in urban, densely populated areas.
- The increasing consumption of crude oil along with the decrease in production and exploitation will lead to rising crude oil prices that will consequently lead to increasing prices of goods transport.

Solutions for medium and small duty trucks will be developed in the mid-term future. The expected development of high-capacity batteries will lead to a market penetration of battery-powered, plug-in or range extended vehicles. As per today, satisfying solutions for HDV cannot be foreseen.

2 Technology assessment

An evaluation of existing modes of transport performed by Siemens clearly identified the advantages of electrified systems, being amongst others the high efficiency and the general flexibility in power generation. Combined, these factors provide the opportunity to develop efficient transport systems with reduced or even zero CO_2 emissions.

The initial question was to assess the requirements to guarantee a safe, economical and ecological system for electrified trucks on public roads.

The energy required for the propulsion of vehicles can either be supplied by vehicle mounted energy storages or continuous power supply systems. The different types of energy storage (e.g. batteries, fuel cells, ultra capacitors) were found to be continuously improving and increasingly feasible solutions for passenger car application. Compared to cars with internal combustion engines the range might still be limited, however a major share of the use cases for passenger cars (e.g. commuting in the metropolises and major population areas) can be covered by the already existing technology. This is, amongst others due to the comparably low loads which are being transported. A rough calculation asks for one kilogram battery per tonne-kilometer, meaning a 2 t car would need a 200 kg battery to travel 100 km whereas a 40 t truck would need a 20 t battery to travel 500 km!

For heavy goods transport on longer distances operation via on-board energy storage has been ruled out even under consideration of future battery development. Weight and space requirements of the storage components are significantly reducing the payload of the vehicles, recharging processes result in operative limitations and limitations in lifetime are so far not compatible with the operational requirements of HDV transport.

Consequently, technologies for continuous power supply were assessed for HDV applications. Continuous power supply systems can be differentiated in two general principles of energy transmission: conductive and inductive.

Compared to conductive systems inductive system were found to have lower efficiency in power transmission and to require a more complex technology which often interferes with the roadways, thereby increasing the vulnerability of the system and the necessary construction and maintenance efforts.

The conclusion drawn was that the solution for electrified HDV transport must be found by using a conductive system for continuous power supply. The principle options for conductive systems are contact lines situated above, underneath or alongside the vehicles drive way which supply the energy via compatible interface technology. In contrast to e.g. metros roads are within the public space which results in higher safety demands. Conductive systems for continuous power supply which are underneath or alongside the vehicles drive way require complex measures to assure the safety of people and equipment as they are within reach of e.g. pedestrians. Overhead contact lines are a proven technology from railway applications in both urban and inter-urban environments. Furthermore the transfer of this technology to a road application reduces the interaction between the drive way and the power supply infrastructure.

Hence Siemens has been working towards a solution that allows electrifying HDV transport with reasonable initial investment by relying on existing and market-proven technologies and by complying with the following prerequisites:

- Electrified lanes remain usable for non-electric trucks and passenger cars and are not exclusively dedicated to electric HDV
- Electrified trucks should be able to operate without continuous power supply for the last mile or on short non-electrified highway sections.
- No operational constraints should occur for truck drivers and logistic companies
- Proven technologies shall be applied to guarantee minimal investment, reliability and maintenance friendly operation.

The development project was conducted and founded in cooperation with the Federal Environment Ministry of Germany.

3 Economical and ecological implications

The ecological and economical challenges for future road-bound freight transport stated above will be addressed with a sustainable solution. The electrification of HDV traffic will have positive effects on emission (GHG, local emissions) with further potential for reductions by using renewable energy sources for power supply. Due to the forecasted increase of crude oil prices, a positive business case for truck operators can be calculated taking into account additional costs for truck modification and refinancing of infrastructure investment.

4 Siemens eHighway solution

Similarly to typical electrical traffic systems the Siemens eHighway system comprises of four sub-systems: the electrical vehicle, the traction power supply and distribution, the driveway and the operation control center. The following chapters will describe these sub-systems in further detail as they have been prototyped for testing purposes by Siemens.

4.1 Electrical infrastructure: Substation and overhead contact line

Analyzing the eHighway system in the direction of the flow of energy towards the consumer the first subsystem is the traction power supply and distribution. This electrical infrastructure consists of substations supplying the traction power and the overhead contact line distributing the traction power to the consumers. The major tasks within the system design of the electrical infrastructure were the definition of the voltage level, the dimensioning of the substation components and the overhead contact line as well as the configuration of the electrical connection of the substation to the public grid.

Figure 2 shows a container substation which includes standard components as the medium voltage and direct current switchgear, the large-capacity power transformer and the 12-pulse-diode rectifier. Furthermore it is equipped with a controlled inverter allowing to feed the recuperated breaking energy of the vehicles back into the public grid.

Figure 2 – DC Substation at test track

In an attempt to increase the public acceptance of the system and to limit the visual impact in its later field of application both for the overhead contact line masts and the substation aesthetically, appealing designs where chosen.

Similarly to trolley bus systems the approximately 1.500 m overhead contact line system of the test track had to be designed as a two-pole-system. In contrast to rail bound systems, the return current flow can not be provided by the driveway.

Corresponding with the operational range of the current collector of the vehicle two parallel catenary systems where installed 5,15 m above the top of the driveway and with a horizontal distance of 1,35 m. The horizontal position of the overhead contact line along the driveway is, amongst others, assured by tensioning devices installed inside the masts.

Figure 3 provides an impression of the overhead contact line system. Only the right lane was electrified. The marking of the highway was done in accordance with German highway standards for highly frequented routes.

Figure 3 – Overhead contact line, roadway and protective equipment

Future investigations and developments must include the definition of the preferable hights of the contact line. With the aim of reducing the amount of interrupts the hights should be compatible with the clearance and the required electrical safety distances of bridges and gantries. Furthermore the interaction of the carbon contact strip of the current collector with the high-strength contact wire is to be evaluated in order to define the most suitable combination of materials. For highway applications the system will need to serve for up to 500 current collector passages per hour.

4.2 HDV with intelligent pantograph and hybrid drive

In terms of the electrical infrastructure mainly standard components have been used which had to be adjusted primarily for aesthetic purposes. In contrast to this the drive system of the vehicles and the foremost the newly developed pantograph required significant innovation.

With regard to the pantograph the challenge lied within safeguarding the demand of safely connecting and disconnecting with the overhead contact line within the speed range from 0 to 90 km/h. Furthermore the current collector was to actively compensate the sideways movement of the vehicle within the lane by the use of a system of sensors and actuators. Next to the mechanical and electrical design engineering efforts have been invested in the detection of the contact line and the processing of the data provided by the integrated sensors. Additionally a HMI (human-machine-interface) realized as a touch panel and a diagnostic and configuration system were developed for the interaction with the driver.

Based on theoretical concepts, the pantograph design took shape in a process of extended laboratory tests and resulted in two prototypes which could be mechanically, electrically and control wise integrated in the two test vehicles. After a short commissioning phase the current collector was tested intensely on the test track and proved to be working reliably under the given environmental and traffic conditions.

Two standard 18 t trucks equipped with hybrid drive systems and loaded with ballast were used as test vehicles (see figure 4). The drive system consisting of the main components generator, rectifier, intermediate circuit and energy storage, inverter and motor has so far primarily been used for city busses and proved its functionality successfully in over 1000 applications. For operation under an overhead contact line system this drive system needed to be adapted by means of an interface box including contactors, arresters and fuses.
The energy storage serves to bridge short losses of contact and to avoid a decline of performance during the change of driving mode.

Figure 4 – Vehicle with current collector

4.3 Control system, telematics and road traffic technology

The focus of the research project was to assess the general technical feasibility of an electric traction system consisting of an overhead contact line infrastructure and a truck equipped with a pantograph. Nevertheless, next to these practical trials comprehensive conceptual works were executed on the road traffic and control aspects of this new traffic system. Amongst others studies on a concept for the measurement of energy consumption and settlement systems, on the integration of the electrical vehicles in the existing traffic processes in normal and exceptional operation, on the user registration and on the technical feasibility of authorization concepts. Furthermore first practical experiences have been collected on these matters on the test facility.

These and other technologies can serve to increase the safety and performance of this traffic system.

4.4 Operation

The truck drives in hybrid diesel operation on the "first mile" until reaching the electrified section of its route. After entering the electrified section the truck connects to the overhead contact line at any given speed. Upon connection, the diesel engine automatically switches off and the electric drive is directly supplied with energy from the contact line. When overtaking or driving into sections which are not electrified the vehicle is changing to diesel propulsion mode without loss of traction force at any speed. Thereby energy storage equipment on the vehicle bridges the time required for restarting the diesel engine or allows for driving short passages (e.g. narrow bridges) without overhead contact line or diesel operation.

4.5 Testing

The test facility for the Siemens eHighway solution was commissioned and a series of test cases have been successfully performed:

Figure 5 – Table: Overview of executed tests

Test Run / Test Process	**Amount / Distance**
Number of test runs	1700
Distance electrically driven on the test track	1500 km
Distance driven in diesel hybrid operation on the test track	2500 km
Distance driven in diesel hybrid operation on public roads	4500 km
Emergency breaking processes at various speeds	70
Test runs driving over obstacles of various sizes	150
Night drives	50
Test runs with trailer (total weight of truck: 40 tonnes)	500

Weight and volume of the additional on-board equipment of the first test vehicles are still significant as the focus of the first test vehicles was to evaluate the general functionality of the system. Optimization potential was identified and will be realized in the forthcoming development phase aimed to develop a system without constraints on axle load rating and load capacity.

5 Fields of Application

The Siemens eHighway solution is an open system suitable for a variety of applications, amongst others:

- Shuttle service for bulk cargo transport with dedicated vehicles (e.g. connecting single mines with shared loading facilities)
- Shuttle service for cargo transport (e.g. containers) with multiple operators (e.g. connecting harbors with freight traffic centers)
- General application on the core network of public roads for long distance transports

The efficiency of the system increases with the share of mileage driven by using the energy supply via the overhead contact line. However, the concept includes a multitude of different propulsion systems for last mile/distribution services based on the hybrid drive of the truck. This allows for e.g. standard diesel operation, alternative fuels and zero emission operation by energy storage (ultra capacitors/batteries).

6 Conclusion

The following milestones have been successfully achieved:

- Assessment of technological solutions and design of preferred system.
- Assessment of economical and ecological benefits.
- Piloting of Siemens eHighway system and successful testing.
- Completion of the test program accomplished with full load at full highway speed.

Acknowledgments

Siemens would like to acknowledge Dr. Michael Lehmann, System Integration Engineer – Siemens Infrastructure & Cities, Mobility and Logistics for his contributions to this report.

References

[1] World Business Council for Sustainable Development, *Mobility 2030: Meeting the challenges to sustainability,* 2004

[2] Progtrans., *Abschätzung der langfristigen Entwicklung des Güterverkehrs in Deutschland bis 2050,* 2007

Authors

Martin Birkner earned his diploma in mathematics from Ludwig-Maximilian University, Munich with a major in financial mathematics and statistics. Martin joined Siemens in 2008, being chosen by Siemens' corporate CFO Joe Kaeser as the first member of his Finance Excellence Program. Program Manager for Innovative Mobility Solutions.