HVTT12 – Electro mobility for heavy duty vehicles (HDV): The Siemens eHighway System

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Abstract

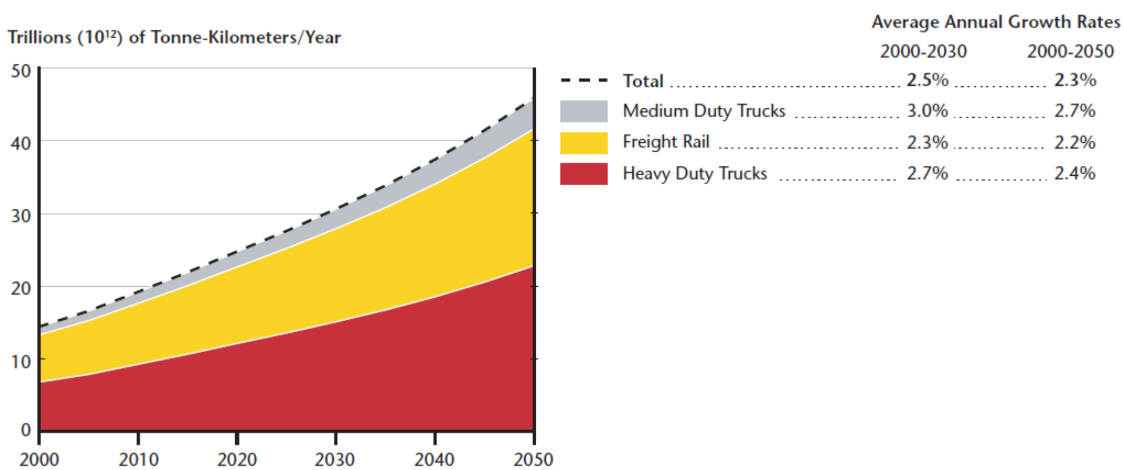
Major studies (e.g. *Mobility 2030; WBCSD 2004*) anticipate an ongoing growth in freight transport for all modes of transport (rail, road, water, air) with the majority of goods still to be hauled by heavy duty trucks in the future. Motivated by the foreseeable shortage of oil resources as well as by local, national and global emission reduction targets, Siemens investigated different solutions for the electrification of heavy duty vehicle (HDV) traffic and started a development project. This paper aims at presenting the outcome of the investigation and the result of the subsequent development project: the Siemens eHighway System, 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; Siemens; eHighway; Catenary System

1. Motivation

Worldwide traffic is predicted to increase for all different modes of transport, passenger traffic measured in passenger kilometres travelled and freight transport measured in tonne-kilometres. 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. In the future a heavily utilized road network will have to cope with a major share of the haulage volume.



Source: *Mobility 2030; WBCSD, 2004*

Figure 1 – Development of global transport volume

Extension and optimization of rail and water transport networks and capabilities are important and sustainable approaches to solve the increasing traffic volume. However, 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 sulphur 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 significantly reduce 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 infrastructure of 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 driveway which supply the energy via compatible interfaces. 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 driveway 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 driveway and the power supply infrastructure.

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

- Electrified lanes shall remain usable for non-electric trucks and passenger cars and should not be 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 (e.g. limitations in range or payload) 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. Siemens eHighway solution

Similarly to typical electrical traffic systems the Siemens eHighway system comprises of four sub-systems: the electrical vehicle/truck, the traction power supply and distribution, the driveway and an operation control centre (see figure 2). The following chapters describe these sub-systems in further detail as they have been prototyped for testing purposes by Siemens.

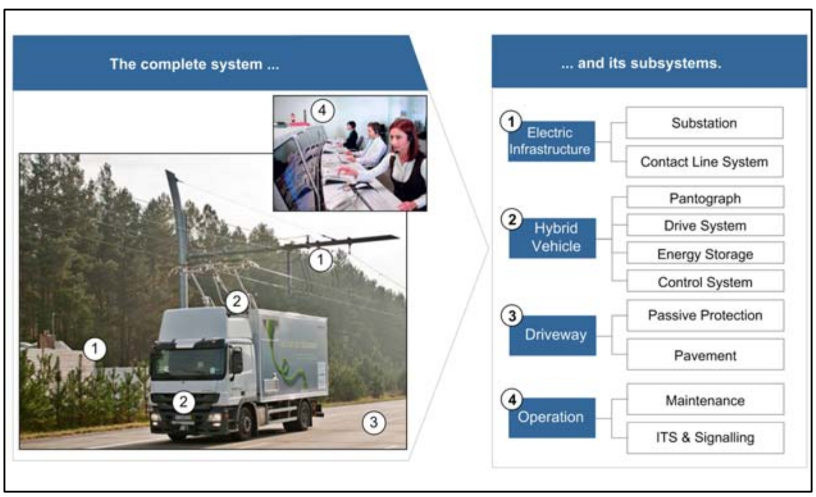


Figure 2 – The eHighway system and its sub-systems

3.1 Electric infrastructure – substation and overhead contact line

The electric infrastructure of the eHighway system described within this document consists of substations supplying the traction power and an overhead contact line distributing the traction power to the consumers (trucks) (figure 3: red marked elements).

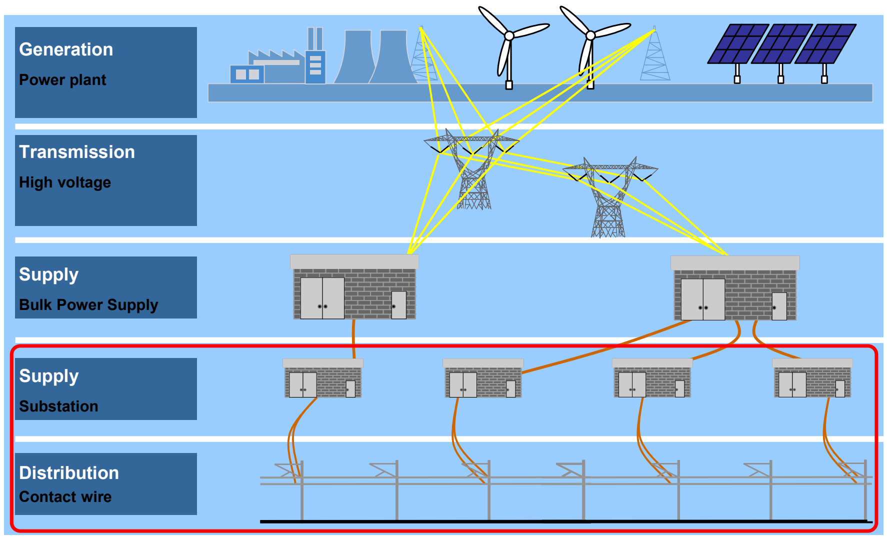


Figure 3 – Electric infrastructure

The major tasks within the system design of the electric 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 electric connection of the substation to the public grid.

The substations include standard components as medium voltage and direct current switchgear, large-capacity power transformer and 12-pulse diode rectifier. Furthermore the substations can be equipped with controlled inverters. Instead of generating waste heat while braking the eHighway trucks generate electric power; this process is called recuperative braking. By applying inverters at the substations this energy can flow back into the public grid via the overhead contact line. Even without the inverter technology, braking energy can be used to recharge on-board energy storage devices or to feed other trucks connected to the same contact line section.

Figure 4 – DC Substation at test track

To limit the visual impact in its field of application, aesthetically appealing designs can be chosen for both the overhead contact line system and the substation. Figure 4 provides an impression of a containerized substation with wooden cladding.

Similarly to trolley bus systems the overhead contact line system is designed as a two-wire-system. This is due to the fact, that in contrast to rail bound systems, the driveway can not be used as conductor for the return current. The contact line is suspended by single poles standing on both sides of the driveway, each of them carrying the contact line system to supply one direction. This configuration can be adapted to the specific needs of the environment in which the system is integrated (e.g. use of portals or mid-poles).

The trucks are equipped with a current collector (pantograph) positioned above the drivers cabin (see chapter 3.2). Corresponding to the operational range of these current collectors two parallel catenary systems are installed above the top of the driveway. Each of the wire systems is providing one electric pole. The height of the system is designed to be above standard vehicle dimensions and clearances. The horizontal position of the overhead contact line along the driveway is, amongst others, assured by tensioning devices installed e.g. inside the masts supporting the overhead contact line system. At civil structures with limited clearances (such as e.g. bridges, tunnels) and to assure the required electrical safety distances the overhead contact line system can be interrupted or special constructions can be applied (e.g. rigid catenary systems).

Figure 5 provides an impression of the overhead contact line system for a highway application. In this case only the right lane was electrified. The lane markings of the highway shown are in accordance with German highway standards for highly frequented routes.

Figure 5 – Overhead contact line, roadway and protective equipment

The electric infrastructure is situated alongside the road and has no direct interference with the road itself. Consequently there are no restrictions to mixed operation with other vehicles. As the trucks are not guided by the system the wear and tear of the road is similar to conventionally used roads. This furthermore means that the maintenance of the road surface is not influenced by the system and that the weight limitation of the trucks is only defined by the bearing capacity of the road and not by the eHighway system (note: similar systems provide traction power to heavy railways).

3.2 HDV with intelligent pantograph and hybrid drive

With regard to the pantograph the challenge lied within assuring the demand of safely connecting to and disconnecting from the overhead contact line within the speed range from 0 to 90 km/h. Furthermore the current collector would have to actively compensate the sideways movement of the vehicle within the lane by using a system of sensors and actuators. Besides 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 diagnostics 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 were mechanically, electrically and control wise integrated in 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 6). The drive system consisting of the main components diesel engine, generator, rectifier, intermediate circuit and energy storage, inverter and electric motor has so far primarily been used for city busses. It 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.

Figure 6 – Vehicle with current collector

3.3 Control system, telematics and road traffic technology

The operation of the system is structured in three main elements: infrastructure, logistics and user management.

Similar to railway electrification infrastructure, the eHighway infrastructure is operated via an operation and control centre, the so-called OCC. From within the OCC the status of the system, substations and the overhead contact line can be monitored and switching operations can be executed.

In terms of logistic operations, the system focuses on the traffic of vehicles rather than on the handling and shipping of individual goods. The initial process is the registration and identification of the users, i. e. the trucks. This process is supported by access control (e.g. via automatic number plate recognition at gate entries) and law enforcement mechanisms. Wayside monitoring and signalling as well as centralized operation control allow for traffic optimization measures.

On-board and wayside metering of energy consumption provides the basis for processing of invoice.

The focus of the first 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. Next to practical trials comprehensive conceptual works were executed on the road traffic and control aspects of this new traffic system. Amongst others studies were conducted 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. These concepts are backed up with practical experiences collected e.g. in rail and road infrastructure projects. 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.

3.4 Operation

With the eHighway system the truck starts its journey and 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 (0-90 km/h). 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.

3.5 Testing

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

Table 1 – 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 braking 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.

4. 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.

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 harbours with freight traffic centres).
- 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.

7. References

- World Business Council for Sustainable Development (2004), "Mobility 2030: Meeting the challenges to sustainability"
- Progtrans (2007), "Abschätzung der langfristigen Entwicklung des Güterverkehrs in Deutschland bis 2050"