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EcoTrain: the Erzgebirgsbahn's new hybrid railway vehicle

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Abstract

Climate change is one of the greatest challenges of the 21th century. To counteract increasing temperatures and to decrease the dependency on fossil fuels various projects are currently conducted aiming at the private and all the different industrial sectors. One of them is the EcoTrain project which is an undertaking of a consortium of several project partners lead by Deutsche Bahn. Working closely with DB RegioNetz Verkehrs GmbH, the Erzgebirgsbahn, the TU Dresden, the Fraunhofer IVI as well as the TU Chemnitz, these partners explore and work on new approaches to finding solutions for an energy-efficient mass transit vehicle. The EcoTrain project aims at developing a hybrid railcar for the Erzgebirgsbahn: A standard class 642 rail vehicle is going to be converted to a cutting-edge and innovative hybrid railcar. Later on, this prototype will serve as basis for converting the entire Erzgebirgsbahn railcar fleet. This paper deals with the development of a drive train concept for the EcoTrain. Three different approaches to hybridization are explained in conjunction with their respective advantages and disadvantages. The hybridization concepts are assessed and the drive train concept of the EcoTrain is introduced. Furthermore the simulation tool IVIsion which was used to dimension the drive train components is explained along with the achieved simulation results. The paper concludes with an introduction to the so-called energy management module which is developed by Fraunhofer IVI. This module predicts the vehicle's movement along the track and calculates recommendations for energy flow and driving style based on the schedule and current position.

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Keywords: Railway; hybrid drive; energy management; fuel reduction; Erzgebirgsbahn

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1. Motivation

Climate change currently presents itself as one of the greatest challenges of the 21st century. In their 2014 synthesis report, the Intergovernmental Panel on Climate Change (IPCC) observes that "Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems." Intending to make a considerable contribution to limiting global warming, the German Federal Government adopted the "Aktionsprogramm Klimaschutz 2020" (Action Program for Climate Protection 2020) in 2014. The aim of this program is to reduce the amount of greenhouse gases emitted in the period from 1990 to 2020 by at least 40 percent. In order to achieve this goal, a large number of measures have been introduced spanning diverse sectors such as energy management, industry, transportation, and even agriculture and forestry. In the transportation sector, urban public transport takes a leading role in the pursuit of these goals. A multitude of past and current projects have analyzed the suitability of hybrid and full-electric propulsion concepts and their challenges in terms of operational procedures and infrastructure. The AutoTram® Extra Grand and EDDA-Bus projects, which were both conducted at the Fraunhofer IVI, are only two examples of many. Such vehicles enable partial or entire abstention from conventional combustion-engine energy generation. In conjunction with renewable energies, significant emission reductions can be achieved. This becomes apparent with regard to exhaust gas emissions as well as noise emissions.

Nomenclature

ENG	combustion engine
GEN	generator
AUX	auxiliaries
AC	alternating current
DC	direct current
EXT PWR	external power
EA	energy accumulator
DLC	double layer capacitor
BAT	battery
TM	traction motor
FD	final drive
HE	high-energy
HP	high-power
W	wheels

2. Project partners and objectives

The EcoTrain project is an undertaking of a consortium of several project partners lead by Deutsche Bahn. Working closely with DB RegioNetz Verkehrs GmbH, the Erzgebirgsbahn, the TU Dresden, the Fraunhofer IVI as well as the TU Chemnitz, these partners explore and work on new approaches to finding solutions for an energy-efficient mass transit vehicle. The Erzgebirgsbahn was founded in 2008. Its daily rail transport services cover the Erzgebirge (Ore Mountains). The following routes for passenger traffic operate on a regular basis:

- Chemnitz – Aue
- Zwickau – Johanngeorgenstadt
- Flöha – Olbernhau
- Flöha – Annaberg-Buchholz – Cranzahl

The railway network has a total length of 217 km and comprises 68 train stations and stops. The routes feature the challenging profile of a branch line with the characteristics of a low mountain range. On these winding routes the trains vanquish up to 450 m in altitude and longitudinal inclinations of up to 4 ‰. The typical speed ranges from 60 to

80 km/h. Occasionally, on the main route to and from Chemnitz, a speed of 120 km/h can be reached. The vehicle fleet of Erzgebirgsbahn consists of 16 Siemens Desiro Classic diesel railcars that are listed at Deutsche Bahn as class 642. Of this vehicle type 237 pieces have been delivered to Deutsche Bahn and more than 300 identical or similar vehicles are run in Germany, Bulgaria, Denmark, Greece, Austria, Rumania, Slovenia, Hungary, and the USA.

Fig. 1. Class 642 of the Erzgebirgsbahn.

The class 642 is an articulated railcar with the wheel arrangement B'(2)B'. It is powered by two diesel engines of 275 kW and 315 kW respectively. Each diesel engine is paired with a hydro-mechanical gearbox. The entire drive units are mounted on an auxiliary frame and installed as so-called power packs below the high-floor area on both vehicles' rear-ends. The hydro-mechanical gearbox has five gears and a torque converter. The class 642 reaches a top speed of 120km/h and has a permissible vehicle mass of 88t. In the Erzgebirgsbahn configuration the vehicles have 121 seats and standing room for 90 passengers. Four air conditioners control the interior climate of the passenger compartment. Their compressors are mechanically driven by the combustion engine.

The EcoTrain project aims at developing a hybrid railcar for the Erzgebirgsbahn*:* A standard class 642 rail vehicle is going to be converted to a cutting-edge and innovative hybrid railcar. Later on, this prototype will serve as basis for converting the entire Erzgebirgsbahn's railcar fleet. A holistic approach ensures the economic efficiency of the hybrid railcar. The hybridization of the drive train as well as energy management of the auxiliary units will lead to reduced fuel and energy demand. Further aspects that hold out the prospect for high economic efficiency are the reduction of operating and maintenance costs as well as the implementation of an anticipatory energy efficient vehicle control system and the strict realization of an energy-saving operation mode. Additional saving potentials are anticipated by installing an eco-friendly and fully electric air-conditioner with the eco-friendly cooling agent CO_2. Regarding infrastructure, the above mentioned goals shall be achieved by developing recharging options for the energy accumulators along the routes.

3. Various way of hybridization

The drive train of EcoTrain will exhibit electric power transmission. This transition from mechanical to electric power transmission is a deep intrusion into the original vehicle. However, it will allow to integrate electric traction motors as well as electric energy accumulators into the drive train, thereby creating the conditions necessary for hybridizing the drive train. The electric energy can be stored in various kinds of energy accumulators. A distinction is made between electrochemical, electrostatic and mechanical storage methods.

Using energy accumulators, the kinetic energy of the vehicle that would be converted to thermal energy in the brake system of conventional vehicles can be regained and used e.g. for traction tasks or for operating auxiliary drives. Besides the reduced use of primary energy (diesel consumption) further benefits derive from reduced engine operating hours, partial electric driving without operating the diesel engine or from the possibility to reduce the installed power of the diesel engine (so-called downsizing). Moreover, auxiliary drives can be converted to be electrically operated. In diesel-mechanical traction units, auxiliary drives are often directly powered by the combustion engine. Operating the auxiliary drives needs to be demand-oriented and independent of operation of the diesel engine for augmenting the overall efficiency of the vehicle.

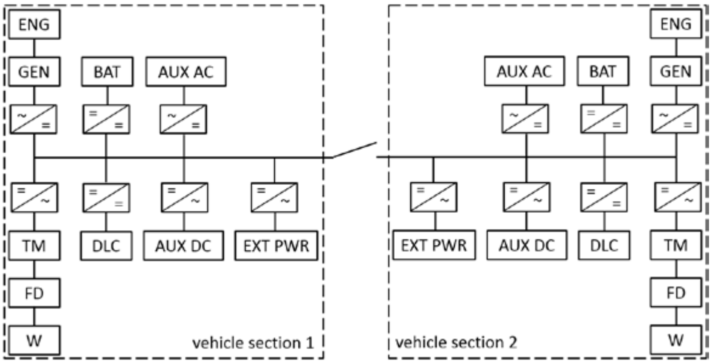

Fig. 2. Serial hybrid drive train with two combustion engines.

Hybrid drive trains subdivide in three major groups: serial hybrid, parallel hybrid and power-split hybrid drive trains. There are numerous variation options for the drive train components as well as for their electrical or mechanical integration into the drive train. Each variation is characterized by specific properties that have to be weighed against each other in view of their advantages and disadvantages and depending on their operation purpose. Within the framework of EcoTrain 11 variations of hybrid drive trains were examined and evaluated. This number is disproportionately higher than with common hybrid road vehicles as additional design variants arise from the vehicle concept combined with two possible separate drive systems.

Figure 2 shows a serial hybrid drive train. Each vehicle section is equipped with an engine-generator-unit (ENG, GEN) that supplies the electric intermediate circuit using power electronics. Attached to the intermediate circuit there are further components such as auxiliary systems (AUX AC, AUX DC), external power connectors (EXT PWR), one or, possibly, several energy accumulators (DLC, BAT) as well as the electric traction motor (TM) that drives the wheels (W) via a final drive (FD). The stated electrical components are attached to the intermediate circuit by power inverters and converters. All drive train components are present in each vehicle section. The vehicle sections form, each on its own, an autarchic system. The intermediate circuit of both vehicle sections can be electrically linked. The substantial advantage of this electrical coupling is that it allows power transfer between the two vehicle sections. Thus, in the case that drive train components malfunction the availability of the vehicle is enhanced. However, additional electrical wires must be led over the structurally limited area of the Jacobs-type bogie. The cable routing is impeded by the need to be able to separate the vehicle sections during maintenance. Another advantage of the electrical coupling lies in the possibility to distribute the drive train components asymmetrically to both vehicle sections. By omitting one diesel engine downsizing is realized and valuable construction room is won for integrating the necessary energy accumulators. Higher performance of the diesel engine can compensate a certain share of the reduced propulsive power. In terms of propulsion, the serial hybrid drive train has several benefits. The operating points of the diesel engine can be decoupled from the operating points of the traction motors. Thus operating the diesel engine along the characteristic curve of optimal efficiency is ensured. The energy accumulators provide an additional degree of freedom when it comes to generating the necessary drive power. Unfavorable operating points of the combustion engine with high fuel consumptions can be avoided by a situational or predictive power control of the energy accumulators. Thanks to the steady power output of the traction motors the passenger comfort is significantly improved. Since the design of the traction motors is based on the maximum traction power demand a partially purely electric driving can be realized. This can e.g. substantially reduce the noise emissions inside as well as outside the vehicle when entering or exiting a train station. The multiple power conversions and the corresponding conversion losses have to be taken into account when the operating points of the diesel engine as well as the usage of the energy accumulators are defined. However, the drive concept facilitates comparatively simple control concepts for the power flow in the intermediate circuit.

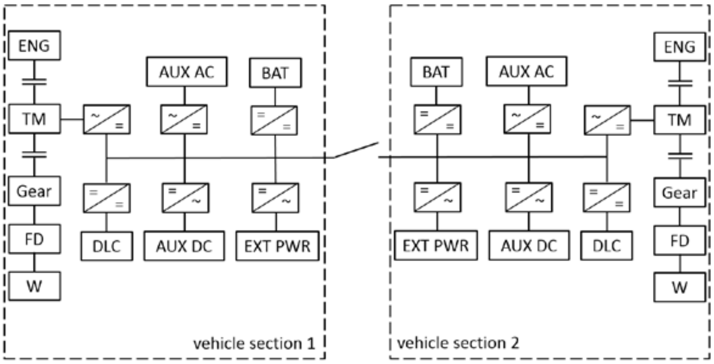

Fig. 3. Parallel hybrid drive train with two combustion engines.

Figure 3 shows the schematic structure of a parallel hybrid drive train. In this case the hydro-mechanical drive is supplemented by an electrical machine that is positioned between the diesel engine and the gearbox input. The double-sided set-up of the coupling ensures the disconnecting of the diesel engine from the drive train. This is of particular importance when braking in order to relieve the drive train from the drag of the diesel engine. Advantages of the parallel hybrid drive train are the high degree of efficiency of the mechanical gearbox and an electrical intermediate circuit. As with the serial hybrid, the latter allows the electrification and needs-oriented activation of auxiliary users as well as the integration of energy accumulators. The electrical machines can be used to compensate the typical changes in traction power that occur after shifting procedures and to harmonize the overall tractive force. Provided its satisfactory continuous output, the electrical machine can be used for partially purely electric driving. In comparison to the serial hybrid the power control is more complicated when it comes to propelling and braking. As mentioned with the serial hybrid, both vehicle sections can be identically structured and work autarchically. By electrically coupling the vehicle sections the above mentioned benefits arise. With regard to the conversion of the EcoTrain the parallel hybrid shows substantial disadvantages. They are a result of the limited construction room. Due to lack of space caused by the dimensions of the diesel engine as well as of the gearbox the necessary second coupling cannot be integrated in the drive train. Moreover, the dimensions of an electrical machine with a continuous output of more than 200 kW exceed the available construction room.

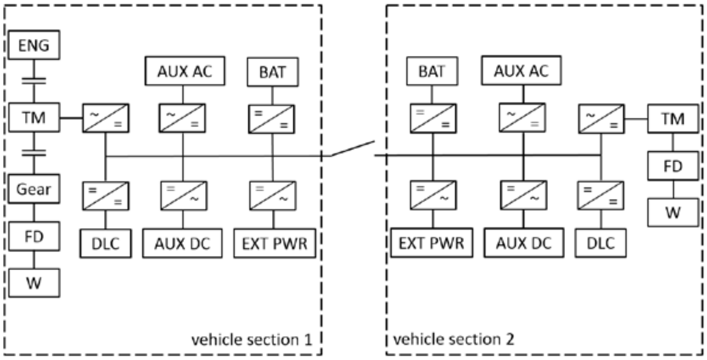

Fig. 4. Combination of serial and parallel hybrid.

The vehicle configuration of the class 642 also allows a mixture of both hybrid types. Figure 4 presents a drive train that has a parallel hybrid drive train in the vehicle section 1 and an electrical (hybrid) drive train in vehicle section 2. In vehicle section 2 the diesel engine and the gearbox were omitted. This reduces the investment as well as the maintenance and servicing costs for the diesel engine. Moreover, the mass of the drive train is reduced. In order to make the energy generated by the diesel engine available to vehicle section 2 both vehicle sections have to be coupled electrically. The energy accumulators can be concentrated in vehicle section 2. This will result in an optimized mass balance. A substantial disadvantage of this drive-concept are the unequal drives of both vehicle sections as this increases the investment as well as the maintenance and servicing costs. Moreover, the control of the drive train is much more elaborate than with the previously presented serial or parallel hybrid drive trains.

Table 1. Evaluation of the drive train variants. Higher numbers stand for better suitability.

Evaluation criteria	Serial hybrid without coupling, two identical drive trains	Serial hybrid with coupling and one diesel engine	Parallel hybrid with coupling	Mixture of parallel and serial hybrid
Fuel consumption	1	3	2	3
Diesel engine operating hours	1	3	1	3
Pollutant emissions	1	3	1	3
Possibility to operate the diesel engine at best efficiency point	2	3	1	2
Evenness of the traction force curve	3	3	1	2
Use of recuperation	3	3	2	2
Power control	3	3	3	1
Mass distribution	1	3	1	3
Component distribution	1	3	1	3
Maintenance costs	1	3	1	3
Sum	17	30	14	25

Table 1 shows the results of an evaluation of various drive trains with respect to different evaluation criteria. The evaluation has been conducted considering the technical and technological framework conditions for converting the existing diesel coach of the class 642 as well as the specific operating and application conditions of the Erzgebirgsbahn as first-time user of the EcoTrain prototype. That is why the evaluation results cannot be generalized and transferred to other vehicles without reassessment.

The evaluation shows that a serial hybrid drive train with a diesel engine and distributed energy accumulators is the optimum for the vehicle EcoTrain. The design of the drive train is presented in figure 5. Vehicle section 1 contains the diesel engine as well as the generator. The traction drive consists of an electric machine and the final drive and is identical for both bogies. The energy accumulators are located in vehicle section 2.

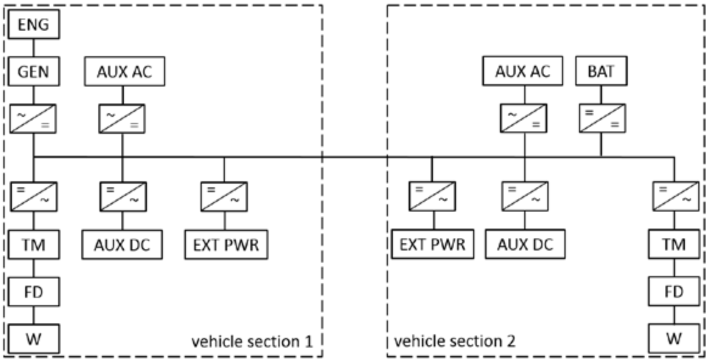

Fig. 5. Design of the drive train for the EcoTrain.

4. Dimensioning of the hybrid drive train

Based on the drive design the Fraunhofer Institute for Transportation and Infrastructure Systems IVI evaluated the hybrid drive train energetically and dimensioned it using the simulation tool IVIsion. This tool has already been proven to be efficient in a large number of similar projects and has been developed at Fraunhofer IVI. It includes several program modules for data processing, calculation of drive systems as well as for evaluating the calculation results. The module IVIdrive offers more than 100 preconfigured drive trains for conventional, parallel and serial hybrid as well as for purely electrical drive systems. The program library contains all essential drive train components as well as a comprehensive selection of auxiliary units and systems. For each component information on management and control is given and can be configured according to any specific application. It is suitable for the calculation of both road and railbound vehicles.

In principle, IVIsion has two areas of application – concept analysis and detailed calculations. Concept analysis refers to simplified design calculations that resort to the preconfigured drive trains and operational strategies. By entering only few parameters the module allows to quickly compare concepts using the same data base. Detailed calculations take additional components into account, such as the cabin system. The use of real-life component-characteristics further increases the accuracy. The detailed calculations provide a basis for analyzing the energy management and optimizing operational strategies.

The program works according to the principle of forward simulation, which means that a freely parameterizable driver model constantly compares the target and actual speed. The position of the throttle and the brake pedal is then adapted based on the speed difference. The values of the pedals are transcribed to target performance values of the drive components. The power will be distributed depending on the chosen drive train, the drive train strategy and drive train control. The objective of drive train control is to monitor the performance limits of drive train components as well as the technical and physical limits of energy and power transfer. Ultimately, realistic driving profiles emerge.

The simulation model allows switching between time- and route-accurate simulations. This switching can be done manually or automatically depending on a certain situation. The route-accurate simulation makes it possible to accurately enter train stations/stops. This is of great significance for public transportation, especially with regard to selective recharging. Furthermore, the module “Environment and Traffic” allows changing the environmental conditions, so that, for instance the influence of the outer temperature on the power flow within the vehicle can be examined.

In order to be able to directly compare the later results of the EcoTrain project, in a very first step, IVIsion was used to parameterize a conventional diesel coach of the class 642. The parameter set for this vehicle was based on manufacturer and operator information. In order to verify the simulation results, test drives were part of the EcoTrain project. In these test drives, a conventional railcar of the class 642 has been fitted with measuring equipment that analyzes speed and fuel consumption. This way, after adapting the driver and auxiliary system model in IVIsion the difference between the actual and simulated fuel demand was at most 3%. In addition to the conventional vehicle a hybrid vehicle based on the class 642 was parametrized. Variation calculations for trips on the route network of the Erzgebirgsbahn have been performed concerning the drive train configuration, the energy accumulator configuration and strategy, the drive train control, the auxiliary system as well as the payload.

The EcoTrain’s diesel engine has an output of 390 kW and uses an appropriately dimensioned generator to feed the intermediate circuit. The diesel engine uses a characteristic diagram to archive highly correct fuel demands. The same has been done for the efficiency of the electrical machines (generator and traction motors). These characteristic definitions take the construction type of the electrical engines into account. The control of the diesel engine has been adjusted in a way that makes sure that the engine works permanently at the characteristic line of optimal fuel demand. Additionally, a start-stop operation has been implemented that deactivates the combustion engine during braking procedures and vehicle standstill. The electrical traction motors drive the wheels by a reduction gear and the final drive. Each traction motor has an output of 250 kW for acceleration and of 280 kW for deceleration. Within the scope of the design calculations electro-chemical and electro-static energy accumulators have been examined in the EcoTrain. Their design is essentially limited by the maximum permissible mass of 5.000 kg. In simulations, both single and dual energy accumulators (a combinatory of electro-chemical and electro-static accumulators) have been demonstrated. With regards to the electro-chemical energy accumulators, no specific cell chemistry has been defined during the design process. Instead, the calculations have been performed based on characteristics of high-energy (HE) and high-power (HP) energy accumulators. Furthermore, load-dependent losses in the energy accumulators and the appendant converters have been depicted. However, the thermic simulation of the energy accumulators that is an optional module in IVIsion has not been activated. For the design calculations the energy accumulators were working in the so-called boost operation mode. During boost operation, the energy accumulator feeds power into the intermediate circuit when the power requirement of the traction and auxiliary system exceeds the available power output of the diesel engine. During recuperation, the energy accumulator absorbs energy that the traction motors fed into the intermediary circuit. In the boost-mode the diesel engine-generator unit does not provide any additional charging to the energy accumulators. The power demand to cool the traction motors, the power electronics and the diesel engine has been defined as 39 kW. For additional auxiliary systems a power demand of 40 kW has been defined.

Below, the results of the design calculations are described in detail. All results are based on measured velocity profiles, thereby establishing comparability between measured and simulated fuel consumptions of the vehicle of the class 642 and the simulated consumption of the EcoTrain vehicle. For the simulation, the route Chemnitz to Cranzahl was chosen. From Chemnitz to Cranzahl the route runs through the Ore Mountains where an altitude of 420 m has to be overcome.

Table 2. Class 642 vs. EcoTrain with HE energy accumulator.

Vehicle	Route	Fuel consumption		Energy turnover in the energy accumulator		
		[l/100 km]	[%]	Difference [kWh]	Withdrawal [kWh]	Inflow [kWh]
Class 642	Chemnitz Hbf – Cranzahl	98,8	100,0			
	Cranzahl – Chemnitz Hbf	60,2	100,0			
EcoTrain	Chemnitz Hbf – Cranzahl	89,9	91,0	-60,1	90,4	-25,5
HE 100 kWh	Cranzahl – Chemnitz Hbf	47,4	78,7	-18,1	71,4	-52,1
EcoTrain	Chemnitz Hbf – Cranzahl	90,1	91,2	-52,8	91,6	-36,3
HE 150 kWh	Cranzahl – Chemnitz Hbf	47,5	78,9	-11,1	72,4	-60,7

Table 2 shows the simulation results of the conventional class 642 and the EcoTrain with a HE energy accumulator with varying energy content. The column “difference” gives figures on the changes of the energy content between the beginning and the end of the trip. The columns “withdrawal” and “inflow” state the summed energy quantity that has been withdrawn from (operation propelling) or fed into (operation recuperation) the energy accumulator. These values allow an evaluation of the energy turnover in the energy accumulators. Considerable fuel savings can be recognized, especially during the downhill-leading route from Cranzahl to Chemnitz. In both directions, the traction tasks require energy from the energy accumulators. However, a significant difference between the two directions is recognizable. The energy turnover (the energy withdrawn from and fed into the energy accumulator) is of particular interest. The withdrawn energy is at a similar level for both sizes of the energy accumulators, since the capacity of both energy accumulators exceeds the energy quantity demanded during the trip. The situation is different when we regard the energy inflow. The nominal capacity clearly is connected to a higher permissible charging power or higher permissible charging current. This means that the charging current reaches higher values during recuperation, which again leads to a higher energy turnover.

Table 3. Class 642 vs. EcoTrain with HP energy accumulators.

Vehicle	Route	Fuel consumption		Energy turnover in the energy accumulator		
		[l/100 km]	[%]	Difference [kWh]	Withdrawal [kWh]	Inflow [kWh]
Class 642	Chemnitz Hbf – Cranzahl	98,8	100,0			
	Cranzahl – Chemnitz Hbf	60,2	100,0			
EcoTrain	Chemnitz Hbf – Cranzahl	89,4	90,5	-52,6	89,7	-35,3
HP 100 kWh	Cranzahl – Chemnitz Hbf	47,3	78,6	-13,4	71,1	-57,2
EcoTrain	Chemnitz Hbf – Cranzahl	84,0	85,0	-38,7	78,7	-38,7
HP 100 kWh, AUX 20 kWh	Cranzahl – Chemnitz Hbf	44,8	74,4	-3,3	58,6	-55,3

The results for the HP energy accumulators is presented in the table above. In contrast to the HE energy accumulator the table merely shows the results for 100 kWh. When comparing the 100 kWh HE energy accumulators with the 100 kWh HP energy accumulators it can be noticed that the energy consumption is at a similar level for both routes. However, significant differences become recognizable when considering the energy inflow that is very close to the energy inflow of the 150 kWh HE energy accumulator. This can be explained by the significantly higher permissible charging current of the HP energy accumulator. At same energy content and identical charging level the HP energy accumulator greatly outperforms the HE energy accumulator. Smaller differences in the energy quantities can be traced back to differing masses or charging levels. In order to illustrate the great influence of auxiliary systems on the energy flow the table also exemplifies the results for a 100 kWh HP energy accumulator with only half of the auxiliary system power (20 kW). It becomes clear that both the fuel demand as well the amount of withdrawn energy is reduced while the energy inflow into the energy accumulator stays almost the same. This is one of the system advantages of the hybrid vehicle EcoTrain. The transition to electrically-driven auxiliary systems makes it possible to selectively control individual components in order to further enhance the overall efficiency of the vehicle. The conventional vehicle of the class 642 does not allow such an intelligent management of the auxiliary system as they are mainly directly linked to the diesel engine with a fixed ratio. The simulations conducted with IVIsion have shown that, from a driving dynamics point of view, a HP energy accumulator of 100 kWh meets all requirements. However, after taking economic and service life considerations into account it was decided to equip the EcoTrain with a 150 kWh HP energy accumulator.

5. The energy efficiency module

The power control of a conventional diesel coach is subject to the influence of the driver. The driver usually controls the train based on the time table and his experience and intuition. Potentials for saving fuel or driving with foresight are characterized more by accidental occurrences and are usually not reproducible. This statement is, in principal, also true for a hybrid vehicle like the EcoTrain. The vehicle driver will set the tractive power, but in a hybrid vehicle power can be provided by various sources. In comparison to the energy content of the diesel fuel the energy content of the electrical energy accumulator is much lower. In order to sustain the performance of the vehicle it is therefore essential to actively control the energy accumulator. The current condition of the vehicle and its drive system has to be taken into account as well as route and environmental conditions. In addition the future system status needs to be assessed, too. For this we need to predict the power and energy demands. Fraunhofer IVI is therefore developing an energy efficiency module (EEM). The main tasks of the EEM are:

- Calculating energy efficient vehicle movements
- Incorporating the train schedule and the current schedule conditions
- Evaluating the performance of the propulsion system

- Incorporating the charging infrastructure to recharge the energy accumulator
- Recommending a target state of charge depending on the routes and situations
- Recommending a power split between the diesel engine and the energy accumulator
- Recommending a pre-control of the auxiliary systems
- Presenting a recommended driving strategy to the vehicle driver

The EEM software runs on an industry computer installed in the vehicle and is embedded in the drive train control concept. It is based on the following principle: operational safety is more important than punctuality or energy efficiency. Passenger safety is an absolute commitment. Energy efficient driving will be realized under the precondition of punctual railway traffic. This is how the EEM works: During the start-up of the vehicle the EEM is started and the communication channels to the vehicle control computers are activated. Then the initialization routine starts and a parameter file containing vehicle and system settings will be loaded. The parameter file is in standardized XML format and can be edited. This guarantees an easy adaption of the EEM to the drive train and the requirements of the vehicle operator. The parameter file contains information regarding:

- vehicle efficiency
- limits to vehicle deceleration
- handling of delays and driving time reserves
- purely electric driving
- engine start-stop
- energy accumulator
- final state of charge of the energy accumulator
- charging of the energy accumulator by the diesel engine
- auxiliary systems
- graphical output

The initialization finished when the day’s schedule, the relevant route, the timetable, and infrastructure information has been loaded. Then the systems calls up the current drive train data and performs a pre-calculation of the speed profile, the performance and the charging state of the energy accumulator based on the current position and timetable situation. If travel time permits the results of the calculation of the speed profile will be used to drive energy-efficiently. In case of a delay the driving profile will be tightened within the permissible limits. Every stop on the route can be associated with a recharging infrastructure with a specific minimal duration for making the connection and charging. Depending on the timetable situation the EEM determines the usage of the charging infrastructure during its pre-calculation. Once the driver reaches the charging station a signal will prompt the driver to initiate the connection. The calculation of the power flow and energies are performed with regard to:

- the permissible and predetermined limits of the charging state of the energy accumulator
- the charging state of the energy accumulator necessary to fulfil the traction task or to absorb the energy from recuperation
- the necessity to recharge the energy accumulator by the diesel engine

Several strategies exist for diesel engine-driven recharging. The recharging strategies as well as their prioritization are parametrized with the configuration file. Control parameters can be deduced from the calculation results and are transferred to the vehicle’s drive train control computer. The calculated system conditions (target values) are continuously compared to the current system condition. If the difference between real and target values exceeds predefined thresholds the EEM starts to recalculate the target values. This calculation is performed rather quickly allowing rapidly changing system conditions to be met adequately. Moreover, there is a permanent graphical output of recommended actions to the vehicle driver.