

# Optimization of the Transrapid Propulsion System

Markus Engel

*Siemens AG, TS LM TRA PP*

Jürgen Nothhaft

*Siemens AG, TS LM TRA S, Erlangen, juergen.nothhaft@siemens.com*

**SUMMARY:** Maintaining the proven structure of the propulsion system of the Transrapid [1], its components are optimized in a development program. The goal is to meet the requirements of future commercial lines. In the following, the current status of the development is described.

**ABSTRACT:** Originally the Transrapid was designed for long distance applications. In recent years applications as an airport link have been discussed increasingly (e.g. airport connector Munich). For these applications but also to stay at the state of the art for long distance applications (e.g. Shanghai – Hangzhou) the whole system Transrapid including its subsystems has to be modified. Therefore but also to improve the economic efficiency of the Transrapid, the German Federal Ministry of Transportation, Building and Urban Affairs (BMVBS) has started a Further Development Program, called WEP [2]. After the phase “Concept development” and an advanced contracted phase for development and construction (treating exclusively with the new vehicle, the standardized converter unit and the innovation of the propulsion control system) the main contract was signed on 19<sup>th</sup> August 2005. It is divided in the phases:

- Development and construction (phase II)
- Building and testing (phase III)
- Approval (phase IV)

From 2003 on the following components / functions of the propulsion system have been upgraded within the WEP-program:

- Segment overlap
- Safe stopping segments
- Standardized converter unit
- Innovation of the propulsion control system (PRC)

The first two mentioned topics are carried out in cooperation with the colleagues responsible for the operation control system (OCS). Details of these WEP-topics are reported in the following, focusing on technical aspects:

## 1 SEGMENT OVERLAP

The segment overlap is a new feature of the Transrapid System. Up to now one basic principle of the Transrapid system is that within a propulsion segment – which is corresponding to a segment of the OCS – only one maglev vehicle may be moved at a time (fixed block system). This feature implicates some operational restrictions, especially if the segment boundary is located in a station area: In the design-phase of the station area it has to be decided whether the station area is part of the segment, in which the vehicle drives towards the station (refer to Figure 1, upper part) or whether the station area belongs to the segment, which the vehicle requires for leaving the station. Independently from the decision,

one segment is occupied during the dwell time of the vehicle at the station. So operation within one segment is disabled for driving a new vehicle during the dwell time. This results in an increased headway - if the division into segments is given – or requires a greater deal of components (i.e. an additional propulsion and OCS segment) if the headway has to be reduced.

To meet the requirements of low restrictions for operation and of cost reduction a segment overlap has been designed, i.e. the station area can be assigned to two segments: first to the one, in which the vehicle arrives at the station. When the vehicle stops the assignment of the station area is changed to be part of the segment for departure (refer to Figure 1, lower part).

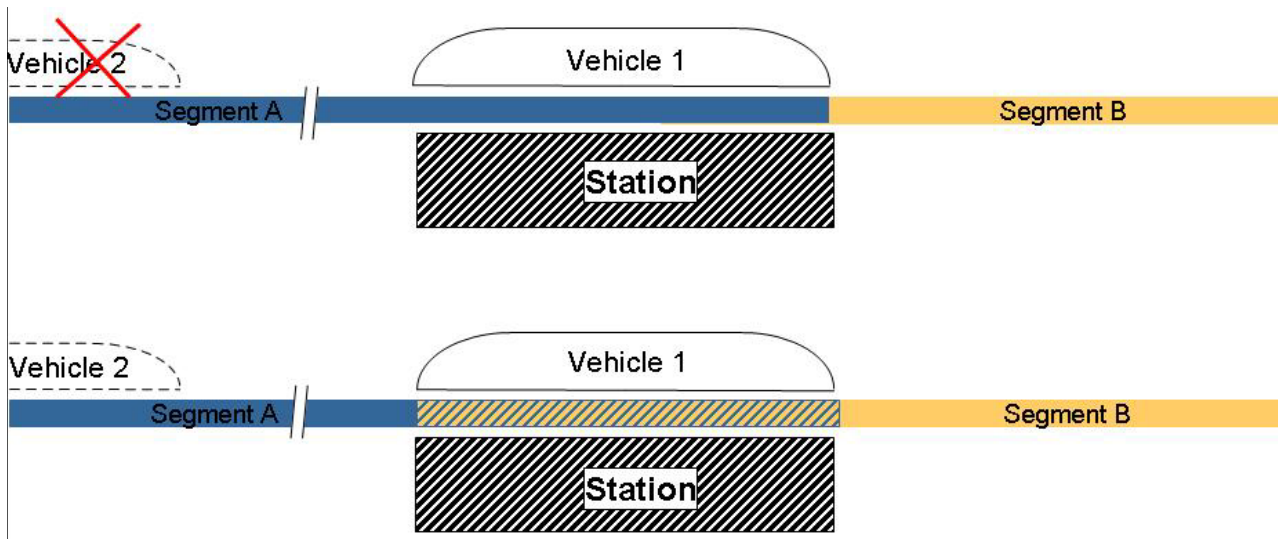


Figure 1: Principle of the segment overlap

To achieve this, the propulsion system has to take care that the stator sections of the station area can be switched to both propulsion segments. The operation control system has to prevent that a stator section is assigned to the two overlapping segments at the same time (which could e.g. result in an uncontrolled feeding of the stator section from the converter units of both propulsion segments). Furthermore, OCS has to deal with the changing length of the OCS segments. Therefore the required algorithms have to be developed and implemented.

The necessary components for testing the segment overlap will be installed at the Transrapid test facility in Emsland (TVE) at the end of 2006. First functionality tests are planned in midyear of 2007.

## 2 SAFE STOPPING SEGMENTS

In regular operation the Transrapid is automatically controlled. It has to be assured that the vehicle stops before a danger point in all cases. Therefore the vehicle has to stop a distance before the danger point in order to allow the system to detect a potential lapse and react in a safe way. This distance is called "safe stopping segment". Reducing the length of safe stopping segments means - among other things - reducing cost for the guideway and its equipment.

The lapse to be considered is that the vehicle is accelerated during the braking phase or is accelerated in the wrong direction when starting at a stopping point. The wrong acceleration is effected by different ways:

1. Value of a wrong current fed by the propulsion system
2. Time until the vehicle velocity exceeds the maximum speed profile, i.e. the wrong acceleration is detected by the OCS (including possible

inaccuracies in the detecting process of the vehicle position and speed)

3. Reaction time of the OCS and of the propulsion system in being shut off.

Within the development topic different approaches are optimized:

1. A wrong current detection at the trackside is implemented: Wrong currents will be detected at the faulty converter unit and will be shut off within the propulsion system in a safe manner avoiding the outer loop of an intervention of the OCS.
2. The methods for detecting the vehicle position and speed as well as for calculating the maximum speed profile within the OCS are improved.
3. Using an "electronic safe propulsion shut-off (SIAB) converter lock" instead of the existing two-stage concept:

Nowadays, when the OCS initiates a propulsion shut off, the decentral propulsion shut-off module (DPS) sends a signal to the propulsion control system which controls the current to zero. But this switch off is only an operational measure not a safe one. Therefore, in the second stage a safe current detection is necessary, which informs the DPS if the control action was successful. If not, the DPS cuts off the converter unit from the trackside and from the public power grid using separate SIAB-switches in order to prevent a further driving as well as a braking of the vehicle by the propulsion system (in this case the vehicle is decelerated by an independent onboard brake). To assure this in a safe way, the SIAB-switches have a proven switch ability and two of them are switched in series on each side

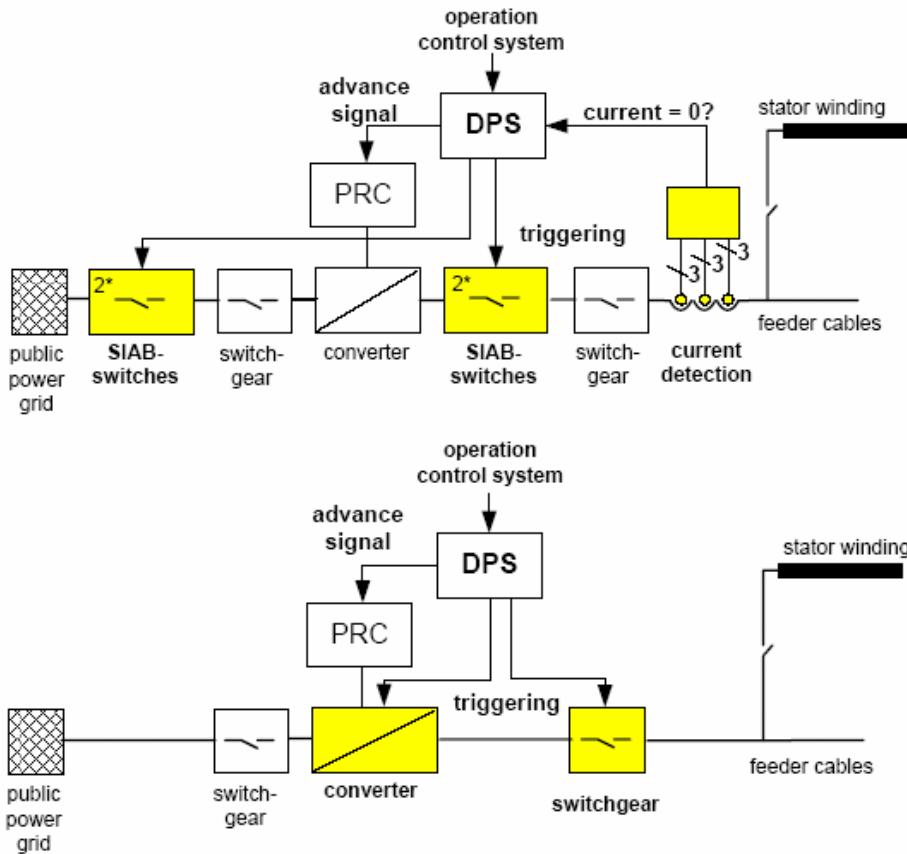


Figure 2: Safe propulsion shut-off

With the new electronic SIAB, the DPS-signal will cause a safe shut off of the converter by blocking the ignition pulses (converter lock). Furthermore, the braking of the vehicle has to be prevented by opening the trackside propulsion switches thus also creating a galvanic isolation of the converter unit to the track. So less components are necessary and the second loop is avoided.

Another way to reduce the length of a safe stopping segment is to improve braking forces when a lapse occurs. To achieve this, a braking winding can be used. Instead of the motor winding short-circuited winding sectors are installed in the stator packs: The faster a vehicle passes the braking winding the bigger is the caused braking force. By dimensioning the resistance of the braking winding the possible braking forces can be designed according to the necessity at the installation spot. Within the development work the effects on the algorithms used in the OCS as well as in the propulsion control system have to be implemented.

All approaches to reduce the safe stopping area will be implemented and tested at the TVE in 2006 and 2007.

### 3 STANDARDIZED CONVERTER UNIT

#### 3.1 Development of the converter power section

In order to be able to benefit from effects of standardization, the new converter unit is based on the standard converter Sinamics SM 150 for industrial purpose.



Figure 3: Converter power section

Similar to the converters used up to now [1], the new one is also designed as a water-cooled DC-link converter. Its inverters consist of three-level phase-modules. That's why the proven control sequences regarding the oscillation capability of the trackside feeder cables can be adopted without changes. The innovation is the semiconductor itself: The hard-driven GTO (HD-GTO or IGCT – Integrated Gate Commutated Thyristor) is used. Compared to the GTO, used up to now, the IGCT offers the following advantages:

- The ignition pulses for the semiconductor are no longer generated by a separate gate unit. Instead of this, the ignition device is directly added to the semiconductor. That's why they can be conducted hard, i.e. with short switch times.
- Due to the optimized semiconductor characteristics significantly less elements for the snubber circuit are necessary in the phase module.
- Moreover, the IGCT offers reserves concerning the current ability, especially in the frequency range used in industrial applications of 50 Hz to 150 Hz

Comparable to the previous converters the new one is specified with the following basic data:

Table 1: Electrical data of the converter power unit

Output power	$\geq 15$ MVA
Output voltage	$\leq 4.3$ kV
Output current	
Direct pulsing mode:	$\geq 1000$ A <sup>1</sup>
Transformer mode:	$\geq 1200$ A
Output frequency	300 Hz

The converter is already built as „Active-Front-End“ (AFE) in standard configuration, i.e. feeding back of the braking energy of the vehicle to the public power grid is possible. Therefore, from the technical point of view, the braking resistors have to be designed only for the closed-loop control of the DC-link voltage respectively as protection device. Moreover, the actively driven semiconductors at the side of the public power grid allow control of the reactive power at the connection point to the power grid. That's why no additional active compensation for reactive power (for example, in the Shanghai project each substation is equipped with two compensation converters of 6 MVA each) is necessary thus reducing the required room in the substations, too.

The assembly of the converter is optimized as far as size and ease of maintenance are concerned: In each inverter cabinet three phase-modules and part of the DC-link capacity are installed (refer to Figure 3). For an AFE-converter four inverter cabinets are necessary. Moreover, a fifth, equally constructed cabinet is integrated, which is equipped with two braking chopper modules.

In addition to the mentioned technical aspects, the measures lead to a reduction of the investment costs, too.

### 3.2 Development of the periphery components and of the control system

When specifying the periphery components of the converter unit, especially the experience of the Shanghai project was considered:

#### Input switchgear:

A standardized switchgear of the type NXPLUS C is used, which is SF<sub>6</sub>-isolated. Because of a changed configuration of the input transformer only one 20 kV switch is needed for feeding the transformer (instead of two in former converter units). For current measurement LEM-transducers with an increased precision are employed in order to detect reliably DC-components in the current of the AFE-converter at the side of the public power grid.

#### Input transformer

The input transformer consists of two single transformers which are connected in series on their high voltage side. The two windings on the low voltage side are designed in a star-triangle configuration which results in a twelve-pulse current load on the side of the public power grid. The transformer is built as a dry-type transformer, i.e. no additional safety measures – e.g. a tub for oil collecting - are necessary in contrast to oil-cooled transformers. Moreover, no maintenance measures are required.

#### Output transformer

Also the output transformer is designed as a dry-type transformer, consisting of three one phase transformers.

<sup>1</sup> Related to one inverter

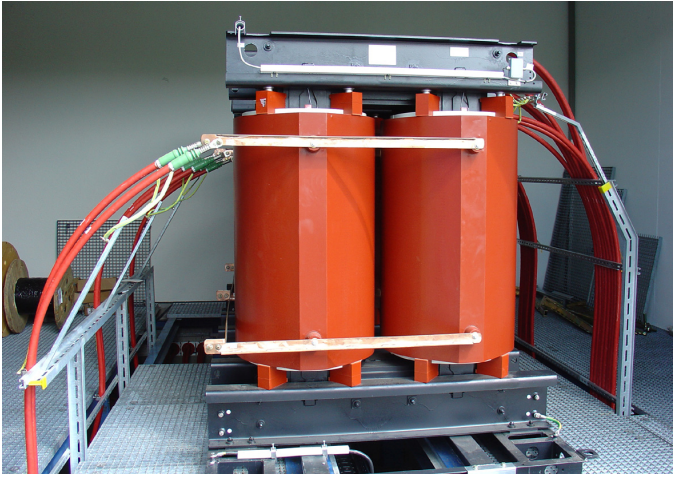


Figure 4: Output transformer

### Output switchgear

As the output transformer has only one transmission ratio a switching cubicle can be saved. Contrary to the previous output switchgears the new one is SF<sub>6</sub>- instead of air isolated. That's why the necessary room for the switchgear is reduced. However, this doesn't apply to the two switching cubicles of the safe propulsion shut off (SIAB): Because of safety reasons for this application switches have to be used which offer proven reliability rates. But these switches will be eliminated at all in the near future within the scope of the developments concerning the "safe stopping segments" (refer to Figure 2).

### Converter cooling system

When designing the converter cooling system a simple and modular construction was in focus: Therefore, the primary and the secondary cooling circle are designed as separate units with an own control unit for each one. The primary circle is determined only by the cooling requirements of the converter power unit. That's why a project specific engineering of the primary cooling circle is no longer necessary. The separate cooling circle of the secondary side allows the adjustment according to the environmental conditions. Another target was to reduce the number of measuring instruments: For example each new converter cabinet is only monitored by a sensor for pressure-difference instead of a temperature- and a flow rate-sensor in former converter units.

But the biggest issue of the development phase was the adjustment of the control system for feeding back the braking energy to the public power grid. This was done on the previous Simadyn D control system in order to separate it from the development topic "Innovation of the propulsion control system". Of course, the new converter unit had to be integrated in the operating and monitoring system (WinCC), too.

Before delivering to the TVE, all the new software modules were tested in the Siemens test laboratory in order to assure short commissioning times at the TVE.

### *3.3 Commissioning*

After production of the components for the converter unit and their assembling in the substation 3 of the Transrapid test track, the functional commissioning of the new converter unit started at the beginning of 2006. The aim of the commissioning was to achieve the complete functionality of the converter unit and its testing within the scope of the complete propulsion system of the TVE. Focal points of the testing were:

- Control of all static and dynamic modes of operation (e.g. operation with and without load as well as reaction in the case of trouble)
- Feeding back of the braking energy into the public power grid, concerning the continuous load chances due to the stator section switching.

The following main interfaces had to be considered:

- Decentral operation control system including the safe propulsion shut off.
- Power supply of the two substations of the TVE (including the demands of the public power utility concerning the energy recovery).

The commissioning was divided into the following steps:

- Commissioning of the periphery components of the converter as mentioned before. Especially important in this step are the correct cabling of the components and the testing of measurement and protection functions.
- Operation of the converter with a so-called "commissioning transformer", which allows the feeding of the converter with a small voltage compared to the rated voltage. So the principal functions of the converter power section can be tested without a significant risk of destroying components in case of a fault.
- Operation of the converter with rated voltage, but still without load to test the protection devices.
- Operation of the converter with feeding the motor, but without driving the vehicle. In this commissioning step the parameters of the trackside cable systems are detected in order to optimize the control system.
- Feeding back of energy which was delivered over the feeder cables from the assigned converter unit in the other TVE-substation.
- Commissioning of the converter unit in the whole Transrapid system. In this final step the

operation with the vehicle is performed, testing all relevant features of the propulsion system like e.g. double-end feeding.

Due to the well-tested software and the support of all parties involved in the operation of the test track, the commissioning could be finished within two months. To illustrate the operation of the converter unit, results of the tests concerning energy recovery are shown in Figure 5:

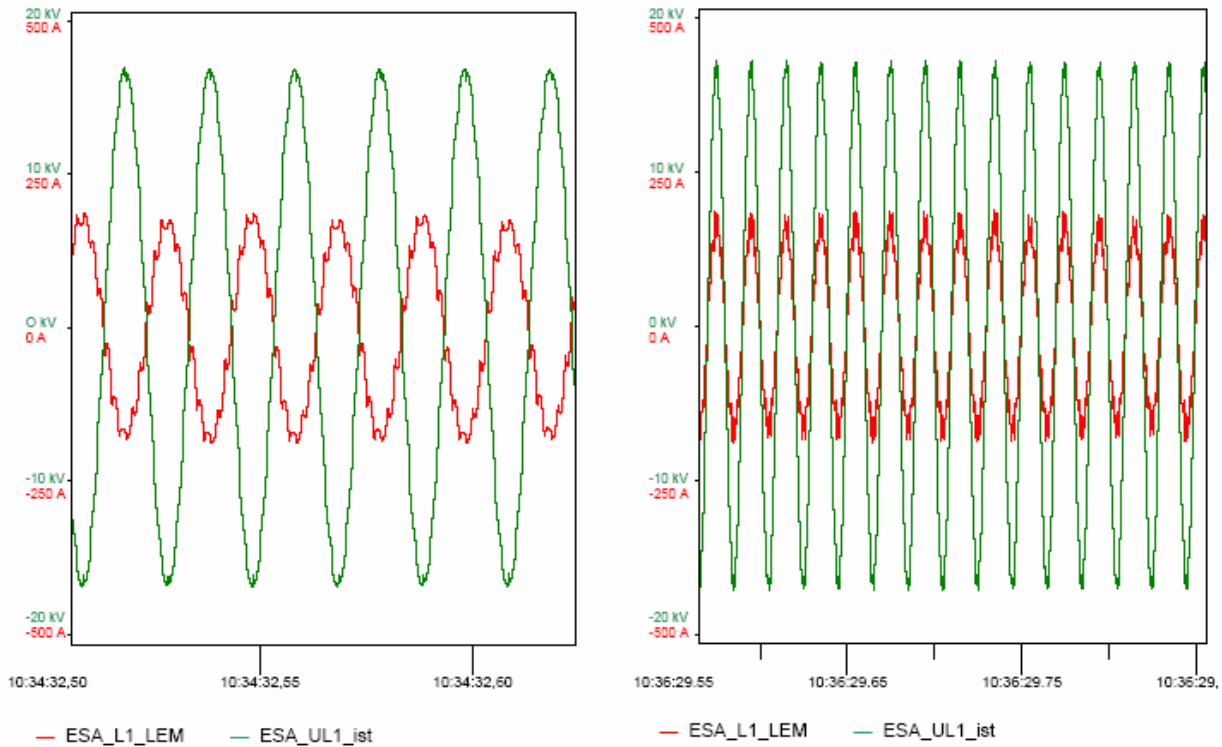


Figure 5: Energy recovery and energy consumption of the new converter unit

In both figures you can see voltage (green) and current (red) of one phase over the time as measured in the input switchgear: In the left figure, voltage and current have an electrical shift of  $180^\circ$ , i.e. energy is fed back to the public power grid. In the right figure voltage and current are in phase, i.e. energy is drawn from the power grid.

After the commissioning a so-called “system test” was performed together with an independent expert of the federal railroad authority (EBA): The architecture as well as the functions of the new converter unit were tested in different test cases which were agreed upon before. The results of this system test are the basis for the type approval by the federal railroad authority. The type approval is strived for the whole innovated converter unit. So the approval process will be continued when the new converter control system based on Sicomp is in operation at the TVE in 2007.

## 4 INNOVATION OF THE PROPULSION CONTROL SYSTEM

### 4.1 Initial situation and general conditions

In the course of diverse earlier development projects, the existing analog propulsion control system was converted into a digital propulsion control system in the early 90s. Only a few platforms were capable of providing the functionality that was required at that time. The Simadyn D control system was chosen on the strength of its scalability, multiprocessing capability, interface variability and stability.

This control system offers the advantage that the necessary functionality can be configured within a graphical user interface by connecting a number of standard modules, e.g. for controllers or communication tasks, that are available in libraries.

Since then, the following functional requirements for the propulsion control system have changed substantially:

- Extension of the interface to the operation control system for multi-vehicle and multi-track operation
- Double end feeding and flexible use of converter units in more than one propulsion segment

In this context, the following non-function requirements apply:

- Maximum availability with the resulting requirements for redundant functions
- Cost-effectiveness with respect to investment and maintenance costs

The functional requirements and even the availability requirements could still be met with the Simadyn D platform, but it was only possible by means of a relatively high hardware and software effort (see chapter 4.3).

Two factors, however, have caused this situation to change:

- In view of the significantly increased functionality and availability requirements, only a relatively small part of the application software (about 20 %) can still be covered by the configuration of standard modules. Therefore, the by far greater portion of the software consists of application-specific functions that are programmed in a high-level language. Integrating such programmed functions into the configuration environment of the Simadyn D platform is only possible if a high number of intermediate – in some cases manual – work steps are performed. This increased programming effort results in an unacceptably high time expenditure and, in certain instances, also limitations in the testability.
- Today, the rapid development in the processor, communication and programming technology markets has made solutions possible that were unthinkable only a few years ago. This is primarily true with regard to the possibility of using open standards in the control environment where, in addition to the processing power of the processors, particular emphasis is placed on the real-time capability based on the available operating systems and communication technologies. Despite their low numbers, such applications benefit from the low and ever-decreasing prices of technologies and components from the consumer and office sector.

This situation made innovation of the hardware platform of the propulsion control system inevitable. The selection criteria the right platform and porting the existing software are described below.

#### 4.2 Approach and purpose

The first step consisted of an assessment of the requirements for an innovative hardware platform.

This was followed by a comparison of diverse current platforms on the basis of the established requirements and by a decision concerning the platform to be used. The result of this platform selection process is described in chapter 4.3.

In the actual development phase the existing software / hardware architecture was checked for suitability on the basis of the established requirements and adjustments were made where necessary. The modular structure of the propulsion control system enables the functionality to be ported and enhancing new functions to be added in step-by-step fashion. The major aspects of this task are outlined in chapter 4.4.

The implementation of the required functionality also calls for development of hardware modules concurrently with the porting of the software. The scope of this work is described in chapter 4.5.

In order to ensure the successful execution of a development project of this size, accompanying processes are also necessary.

Therefore, to achieve the necessary test coverage for the required module, integration and system tests, a suitable test facility is planned and implemented in which the software can be subjected to manual and automatic tests within a realistic environment. The configuration and operating principle of this test facility are described in chapter 4.6.

When all measures are concluded, an innovated platform for propulsion control will be available that

- is ready for certification,
- meets the requirements both for mainline and regional traffic and
- reflects state-of-the art technology.

#### 4.3 Choice of platform Sicomp IMC

It became clear during the work leading up to the choice of platform that the key requirements would not be placed on the hardware itself but rather on the associated software environment. Furthermore, there are requirements for software creation which have a limiting effect on the choice of a suitable hardware platform.

In a detailed study, several platforms of general suitability were compared with each other on the basis of predefined requirements in order to derive a weighted decision matrix. The system architecture of the chosen Sicomp IMC platform is described in detail below.

The Sicomp IMC platform from Siemens consists of PC-based industrial microcomputers that use Euro-card modules. The modules are installed in a 19-inch rack (see Figure 6). This enables single to three-tier configurations.

A commercial PC operating system is used. This allows programming to be performed in all customary PC languages and using the tools that are available for the purpose.

The propulsion control system requires a real-time operating system to be able to execute the necessary control functions. With Siemens, the Sicomp IMC is usually combined with the RMOS real-time operating system that allows programming in C/C++. The necessary basic tools are available for RMOS to enable the development and debugging of the software (compiler, debugger, profiler, LAN tools). These tools also permit online debugging of the user software.



Figure 6: Sicomp IMC

A variety of processor modules is available for Sicomp IMC. The currently most powerful module uses a 1600 Hz Pentium M. Comparative measurements with the previously used Simadyn D platform have shown a 15- to 20-fold increase in processing power. TCP/IP and Profibus interfaces as well as digital inputs and outputs, etc. are available as modules for the system.

#### 4.4 Software development

The requirements for the software functionality were determined first in the course of the current development work, during which – in addition to the inclusion of all requirements from the terminated system projects for Transrapid Shanghai and Transrapid test facility in Emsland– special emphasis was placed on the analysis of the requirements that result from the operator requirements of DB AG (German railways) for the Munich project and other planned application projects. The software / hardware architecture was derived from the determined requirements while taking the existing system into account. To minimize the risk, it was subjected to a review by independent experts, which has confirmed the correctness of the chosen architecture.

##### 4.4.1 Operating system and development environment

The RMOS real-time operating system from Siemens was chosen for the Sicomp IMC platform. The reasons for this choice include

- the availability of the necessary drivers to address the individual modules and
- the maintenance of the operating system, the tools and the drivers by the hardware supplier.

This permits the application development to focus on the core tasks while relying on a stable interaction of the hardware with the chosen operating system.

The new implementation of the software for the propulsion control system is carried out on PCs using the Windows operating system, object-oriented based on the UML (unified modeling language) using a comprehensive tool for the analysis and design phase: The tool of choice is Rhapsody from iLogix that is based on the C++ programming language. It supports both the OOA phases (acquisition of requirements, modelling of the static structure, description of dynamics) and the further development of the model into the finished software (OOD). For this purpose, Rhapsody provides a powerful configurable “real-time framework” that already includes basic functional software patterns such as multi-threading, event handling, executable state charts, etc. and reuses them in the generation of the application code.

##### 4.4.2 Software architecture

The requirement to achieve the greatest possible independence of the user software of the hardware has resulted in a three-layer architecture at the highest abstraction level:

- Operating system layer
- Operating system abstraction layer
- Application layer

This corresponds to a design pattern for a powerful software architecture that is widely used and described in the relevant literature.

##### Operating system

The operating system layer essentially includes the operating system functions as described in chapter 4.4.1 but also the drivers that are necessary to address the (communication) modules used.

These are non-Transrapid-specific software functions.

They are mostly implemented and provided by the producer of the operating system.

## Operating system abstraction

The software functions of the operating system abstraction layer also do not include any Transrapid-specific features.

The necessity of using a software layer for operating system abstraction is a direct consequence of the requirement of maximum hardware independence and results in the following functions:

- Encapsulation of operating system calls
- Abstraction of the communication mechanisms

However, the concept of hardware independence by abstraction is limited, especially in control applications with very high real time requirements. This limitation is caused by the fact that every additional software layer adds to the access times of a higher-level layer when accessing functions or data of a lower-level layer.

Regarding the fast closed-loop control circuits of the propulsion control system this requires that time-critical control functions are either directly implemented in hardware or that the timing of the interfacing between control data communications, hardware and software must be optimized for implementation as a user function using the functionality of the operating system.

Chapter 4.5 describes how these requirements are implemented for the innovative hardware platform.

### Application

The application layer contains all functionalities that must be Transrapid-specific due to the existing functional requirements.

For the porting, the existing functionalities must be implemented using the core algorithms. In some cases, the following was derived from the requirements analysis, in addition to the implementation of the existing functionality:

- optimization potential with respect to functional content and distribution to different software modules and
- necessity to develop new functions that have not existed or been necessary before.

The optimization of existing functions is characterized by:

- the further modularization of the software to avoid code portions that need to be maintained more than once,
- the optimization of the diagnostic functionality through embedding of the documentation and integration of guided maintenance and
- the improvement of the redundancy functions.

The following essential functions have either not been feasible in the existing implementation due to limits of the system capabilities or have become

necessary due to advances of the state of the art and are therefore newly developed:

- remote download and teleservice
- implementation of section turnouts or crossings
- extension of the protective role of the track protection

### 4.5 Hardware development

Due to the requirements for the real-time performance of the distributed propulsion control system, it is not possible to cover the entire functionality with the modules that are available on the industrial PC platform. In addition to the functionalities of the motor and converter control system, this applies particularly to

- the control data transmission over the so-called Open Transport Network (OTN) like it is used in the motor control unit (MCU) and in the converter control unit (CCU),
- the external interface to the radio system for the transmission of the vehicle position, used in the MCU,
- the interfacing to GPS receivers for time synchronization, used in the MCU and CCU as well as
- the interfacing of converter units that are used in the CCU, the converter power section and the converter switchgear.

Due to the advances in the development of integrated circuits, a design could be chosen that covers the core functionalities of all interfaces mentioned above with a single module, the so-called Serial Communication Module (SCM).

The following figure shows how the SCM provides the necessary interfaces in different application locations.

Major components of the SCM Basic Module (see Figure 7) include a Field Programmable Gate Array (FPGA) and four bidirectional optical channels with a bandwidth of 100 Mbps. Due to the performance of the FPGA used, all other required functions, which used to rely on additional special hardware components (e.g. Ethernet MAC or PCI Bus interfacing), can be directly implemented in the logic of the FPGA. This offers two major advantages over conventional discretely designed modules:

- The installation location of the SCM can – with the hardware design remaining unchanged! – be adapted to the specific installation location in a highly flexible manner simply by adjusting the FPGA functionality. In this manner, when using the SCM in the MRC or CRC, it is possible to implement the interfacing to the PCI Bus as logic within the FPGA. When the SCM is used in the

converter power section, the same physical interface serves to exchange the required signals for this application (ignition pulses and actual values) with the SCM power section adapter. Moreover, the optical channels can form a “regular” Ethernet, e.g. for the transmission of control data or a cyclic transmission of closed-loop control data, depending on the configuration but always on the basis of a physical Ethernet design.

- This makes the chosen solution largely independent of the development of the hardware technology in the PC area and the associated discontinuations of components. This is true as long as the required functionality does not exceed the capacity of the chosen FPGA. But even in this case, “only” a redesign of the SCM itself would be necessary while the implemented logic functions can usually be retained.

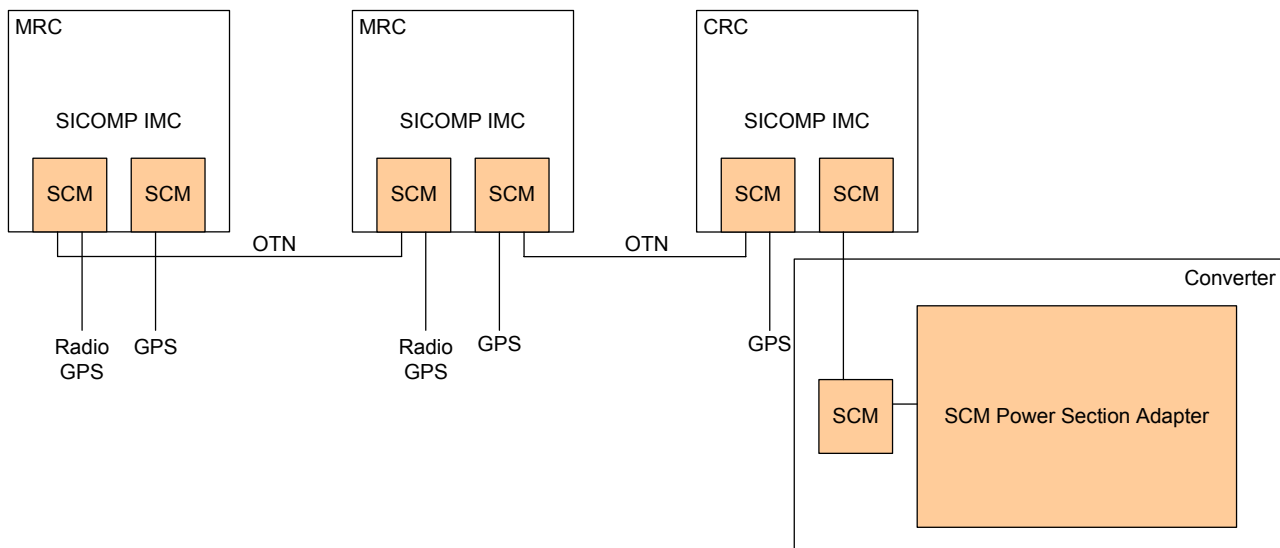


Figure 7: Application locations of the SCM

Besides the adaptation of the peripheral interfaces, the capacity of the chosen FPGA also permits the implementation of time-critical user-specific control functions.

#### 4.6 Test environment

An appropriate test environment is indispensable in order to achieve suitable software quality. The modular and hierarchical structure of the propulsion control system calls for adequate test facilities and procedures.

The design of the test facilities must consider that all kinds of propulsion configurations have to be covered and that testing must be as realistic as possible. For this reason, a test system is planned and built in parallel with the porting of the software. This test system consists essentially of the original equipment that is used in the system. However, to achieve a sufficiently high test coverage and depth,

it is necessary to have models of all those components that interface to the components of the propulsion control system. This applies both to the external interfaces that are located outside the propulsion subsystem, such as to the operation control system or the vehicle, and to the internal interfaces to converter units and switchgear. Since this is not an economical solution for all installed propulsion segments, different development stages of the interface models are used.

The complexity of the entire software system means that a restriction to manual tests is not suitable to obtain the desired test coverage due to the high time consumption involved. For this reason, it is planned that tests can be performed automatically and can also be evaluated automatically with respect to predefined acceptance criteria.

#### 4.7 Current status and outlook

To date, the essential functionalities of the operating system abstraction layer and the basic functions of the motor control unit have been ported and successfully validated on the test facility.

The development and testing of the hardware modules are completed, and all module types are being operated on the test facility.

The test facility has been built to a degree that all units that are intended for use in the system as well as the necessary interface models are available for development and validation.

All conversions necessary at the TVE for testing the new platform are scheduled to be completed by the end of 2006 so that the planned tests for the validation of the overall functionality in the original environment can be done in step-by-step fashion until autumn 2007.

#### SUMMARY

The new features which will be realized in the WEP topics “Segment overlap“ and “Safe stopping segments” were shown.

In the context of the WEP topic “Standardized converter Unit”, the conducted developments were demonstrated both on the new “ML2” converter power section itself and on the peripheral components. Moreover, the final commissioning results were presented.

In the same manner, the basic approach was outlined for the topic of “Innovation of the propulsion control system”. It was made clear that the activities aimed at innovation of the hardware platform are largely determined by the development of the associated software. Moreover, and in addition to the choice of the hardware platform, special hardware modules are required to implement time-critical closed-loop control tasks.

Given these WEP-developments, the propulsion system is well-equipped to meet the challenges of projects both for short and long distances. The developments will be used in the next projects, i.e. probably for the Shanghai–Hangzhou line and the airport link in Munich.

#### REFERENCE LIST

[1] K. Blank, M. Engel, R. Hellinger, D. Hoke, J. Nothhaft: Propulsion System and Power Supply for the Transrapid. In: ZEVrail + Glasers Annals 128 (2004), special issue, pp. 64 - 79

[2] W. Dörries, V. Bienert: Further Development Programme for the TRANSRAPID of the Federal Ministry of Transportation. In: Building and Housing, 18th International Conference on Magnetically Levitated Systems and Linear Drives, Shanghai 2004, proceedings, pp. 23 – 31

[3] U. Henning, D. Hoke, J. Nothhaft: Development and Operation Results of Transrapid Propulsion System. 18th International Conference on Magnetically Levitated Systems and Linear Drives, Shanghai 2004, proceedings, pp. 759 – 770