

Propulsion System and Power Supply for TRANSRAPID Commercial Lines

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Abstract

The contract for implementing the world's first TRANSRAPID commercial line was signed in Shanghai on January 21, 2001. It is to link the new Pudong International Airport with the Long Yang Road Station on Metro line 2, situated in the Pudong financial centre, from 2003 on. A peak operating speed of 430 km/h is envisaged on this 30 km long line with 3 vehicles consisting of 6 sections each.

The structure of the propulsion system including power supply developed for commercial lines - for which the Transportation Systems (TS) division of Siemens AG is responsible - is presented below. This structure fulfils the application requirements such as modular design, operation of several vehicles on one line, operation velocity and availability. In addition the derived design for the Shanghai Maglev Transportation Project (SMTP) is shown. A short overview of the project progress – as far as propulsion system and power supply are concerned – is given.

1. General Structure of the Propulsion System for Commercial Lines

The Transrapid magnetic railway is driven by a synchronous, iron-based long stator linear motor installed in the route along the line. This is in contrast to conventional railways where the propulsion system is located in the vehicle.

For this reason, it can be particularly well adapted to the local and operational requirements. Consequently, in route areas with high thrust requirements, such as acceleration or gradient sections, the propulsion power is increased and the length of stator sections is reduced. In areas with low thrust requirements, e.g. coasting areas, the inverse approach is chosen.

In recent years, a hierarchical, modular propulsion structure has been evolved. It is based on the system documents agreed between the participating industrial companies and promised by the Eisenbahnbundesamt (German Federal Railway Authority) as part of the TRANSRAPID approval programme. These documents cover a range of parameters in the context of which the entire TRANSRAPID system can be configured to meet the respective project requirements.

The propulsion structure consists of components that are combined in propulsion blocks in substations and in guideway sections along the line. They can be connected to form drive control zones according to the train operation (Figure 1).

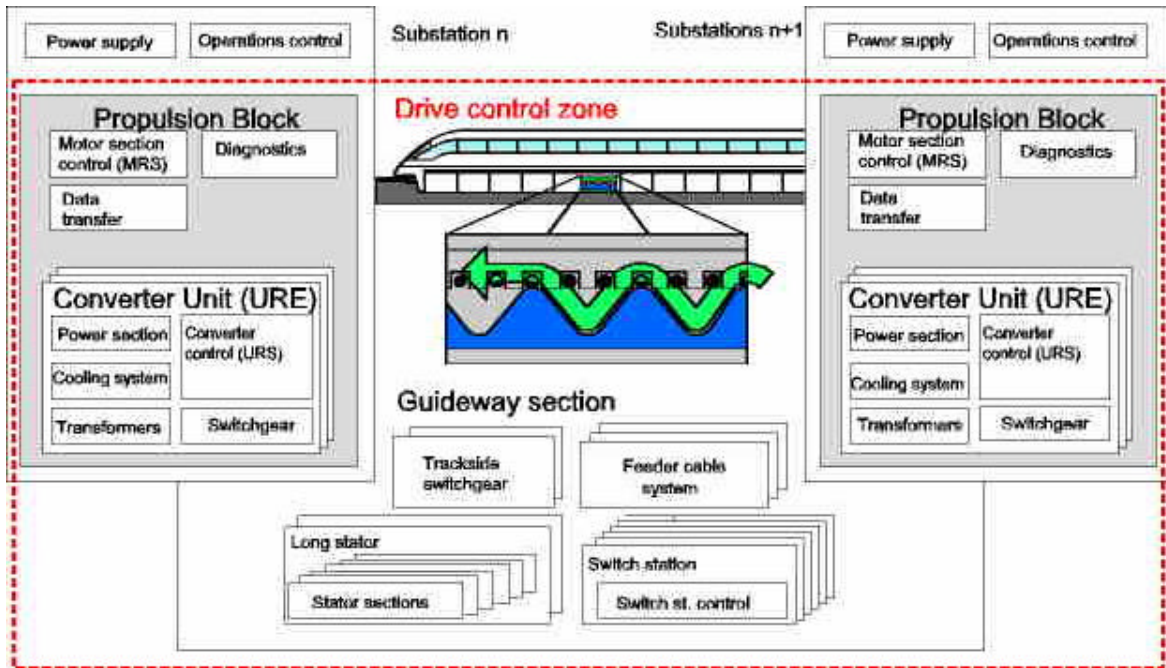


Figure 1: Propulsion Structure

A drive control zone therefore consists of a guideway section and, depending on the feeding process, of one or two propulsion blocks. Its configuration remains unchanged as long as a vehicle is situated inside its segment. It can only guide, accelerate and brake one vehicle.

For longer lines, the drive control zones described above are butt-mounted for each track. In this context, the substations are generally arranged equidistantly in terms of time (not location) along the line. Stop times at the stations are considered here. Second condition is that the same substation location can be selected for both directions of travel in order to reduce costs. The distance between the substations is up to 50 km.

A substation for a single-track route contains one (type I) or two propulsion blocks (type II), their power supply and the decentralised operation control system. With one propulsion block per track, when double-end feeding is used (the stator sections are fed by two propulsion blocks from adjacent substations), at least one drive control zone must remain clear between two vehicles. With two propulsion blocks, the following vehicle can enter a drive control zone after the vehicle ahead has exited it, thus almost halving the headway. The substations for a double-track route are largely doubled single-track route substations.

A propulsion block consists of the converter units, one or two (substation type I) motor section controls, the diagnostic unit and the data transmission equipment. A converter unit is subdivided into a converter power section, input and output transformers, converter control, converter cooling system and converter switchgear.

1.1. Stator Section Switching

Main part of the synchronous long stator linear motor are its stator sections which are located on both sides of the track. Only the stator sections in which the vehicle is actually situated are connected to the feeding converter units by the respective feeder cable systems and switch stations. For commercial lines, two different types of changing from the actual stator section to the next one are designed: the step-by-step and the three step method (Figure 2). Both methods are characterized by locally displacing the right- and left-hand sides of the tracks' stator sections. When changing from one stator section to the next, the current of the feeding converter- and cable system has to be reduced to zero to ensure currentless switching of the vacuum contactors in the switching stations (because of life time reasons).

In the step-by-step method only two different converter- and cable-systems are available. So the reducing of the stator current causes a drop in thrust for the vehicle which cannot be compensated by the other track-side in all cases. Because of this and the combined comfort aspects, in route areas with high thrust requirements (acceleration and maximum speed areas of the track) the three step method is used, which offers a third converter- and cable-system so that the “left” and the “entered” stator sections can be fed in the phase of stator section changing.

The step-by-step method is distinguished by its lower hardware requirements and is especially designed for coasting areas.

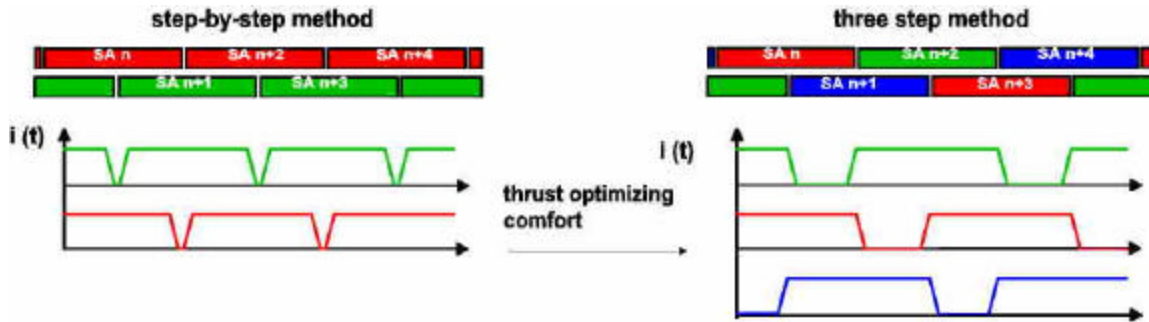


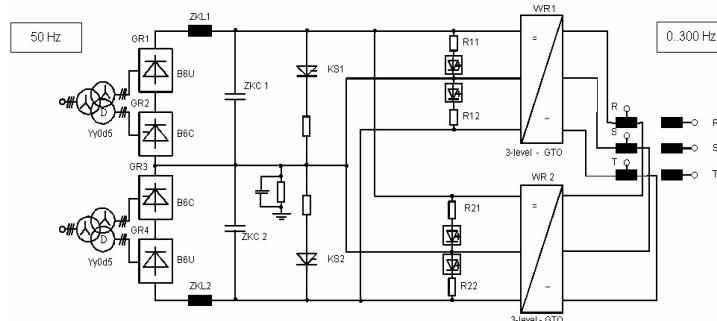
Figure 2: Stator Section Switching Methods

1.2. Benefits of the modular propulsion structure

Key advantage of the presented modular propulsion structure is, that single components can be changed according to the demands of the project without affecting the whole system. For example there are currently three different types of converter power sections (Figure 3) available in order to adapt the converters' output to the vehicle acceleration and velocity demands.

- “High” power converter with a maximum power rate of 15,6 MVA.
These power converters are formed on the trackside by two self-commutated inverters (WR), which are of the 3-level type and are connected via an output transformer. The inverters are equipped with 4 kA GTOs (gate turn off thyristors). In the DC-link, the brake choppers (DBS), derived from the inverter GTO-modules are situated. On the feedingside of the DC-link a rectifier (GR) consisting of six-pulse diode and thyristor bridges is used. For enabling the feeding back of the braking energy to the public power supply, only the rectifier has to be substituted by the same inverters as used on the trackside.
- “Medium” power converter with a maximum power rate of 7,5 MVA. (e.g. for stabling runs in the terminal station).
This type is derived from the “high” power version by using only one trackside inverter.
- “Low” power converter (1,2 MVA) for shunting operations in the maintenance area.
This is also a three-level converter with a similar electrical circuit, but IGBTs (isolated gate bipolar transistors) are used. This converter is not a special development for TRANSRAPID applications, it is an industrial standard converter (SIMOVERT MV[®]).

All converters are water-cooled.



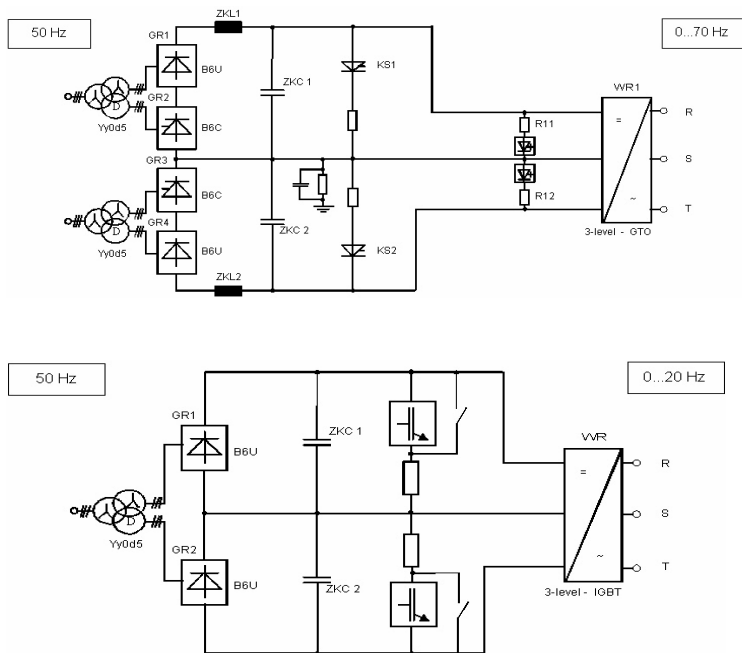


Figure 3: single lines of the different converter power sections:
 upper part: 15,6 MVA “high” power converter
 middle part: 7.5 MVA “medium” power converter
 lower part: 1,2 MVA “low” power converter

Another advantage is the possibility to use standard components (e.g. from industrial applications) for the different “propulsion modules” as far as possible. Examples for this are the use of the industrial control system Simadyn D[®] for the whole propulsion control system or the 20 kV vacuum contactors (Figure 4) which are used in all trackside switchgears (incl. the switching stations): Up to the mid of the 1990th vacuum contactors for this voltage level were not available. To improve the dynamic characteristics of the propulsion system these 20 kV vacuum contactors were developed for TRANSRAPID. Recent years have shown, that also other industrial applications need vacuum contactors of this voltage level, so that they get more and more an industrial standard.

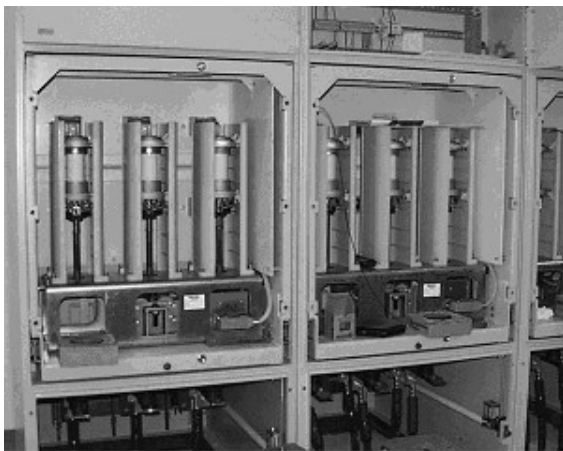


Figure 4: 20 kV vacuum contactors (as integrated in the output switchgear)

2. Structure of the Power Supply System

2.1. General (Layout Criteria)

The task of the power supply system is to supply all components of the TRANSRAPID system with the demanded power. The main consumer naturally is the propulsion system; others are the power rail supply for the on-board supply of the vehicle, the auxiliary power supply for the propulsion control system as well as the operation control system, the guideway switches and the reactive power compensation (Figure 5)

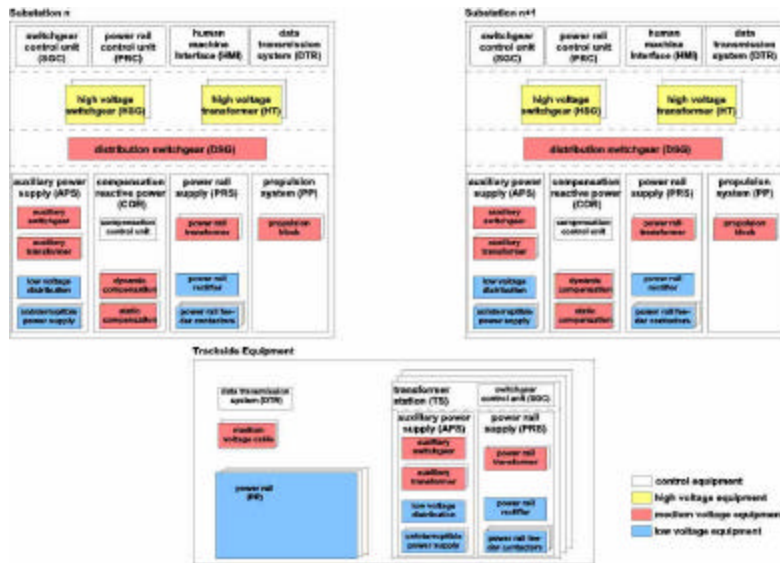


Figure 5: Structure of Power Supply System

The components of the Power supply system (PS) are installed in substations – where the main components of the propulsion system and the decentralized operation control system are installed, too – and in transformer stations, which are both located along the guideway. The distance between the substations and transformer stations mainly depends on the characteristic data of the operating program and system layout, such as speed-time-diagramm, minimum interval between maglev vehicles, stations and auxiliary stopping areas. Furthermore the availability of the power supply system is a very important stipulation for the power supply system layout.

2.2. Substations

Within the substations the link to the public power grid is realized. If a high voltage link is available then one substation for a double track comprises redundant high voltage equipment such as high voltage switchgear (HSG) and high voltage transformer (HT), which transforms the voltage to the used internal medium voltage level. Subordinated is a distribution switchgear (DSG) which distributes the supplied medium voltage to the different consumers such as propulsion system (PP) as the main consumer, the auxiliary power supply (APS), the reactive power compensation (COR) and the power rail supply (PRS). According to the redundant high voltage switchgear the distribution switchgear consists of two busbar systems which can be connected to each other via a tie switch in the case of a fault in the high voltage equipment or public power grid. If there is only a medium voltage link available, the public power grid is directly connected to the distribution switchgear.

The propulsion system is not part of the power supply system itself and was described in chapter 1. Every propulsion block has its own connection to the distribution switchgear.

The auxiliary power supply system (APS) generates the different low voltage types which are demanded by the connected consumers of the propulsion system (propulsion control system, converter cooling system, converter power section and switchgears), of the operation control system, the guideway switches and of the power supply system itself (power supply control system, dynamic compensation, power rail rectifier and switchgears). The APS consists of the auxiliary power switchgear, two redundant auxiliary power transformers, the low voltage distribution and an uninterruptible power supply.

The reactive power compensation contains three parts:

- The compensation control unit (COC) is responsible for the control, monitoring and protection.
- The static compensation (COT) consists of several filter circuits tuned with the frequencies of the harmonics which have to be compensated according to the stipulations of the public power grid and the used type of the propulsion system's converter power section.
- The dynamic compensation (COD) uses converters for compensating the reactive power which is occurrent at the fundamental wave and a tap-changer for compensating load changes.

The power rail supply is responsible for the auxiliary power supply of the vehicle. The demanded power is transformed by the power rail transformer (PT), rectified by the power rail rectifier (PRR) and then supplied to the power rails (PR) via different power rail feeder contactors (PRF) according to the location of the vehicles.

2.3. Trackside Equipment

Power rails and transformer stations (TS) are also situated along the track.

Stations, auxiliary stopping areas and acceleration areas have to be equipped with power rails according to the external power demand of the vehicle. For all power rails which are too far away from the substations, the transformer stations enclose a power rail supply in the same modular design as described for the substations.

For all other consumers along the track of the propulsion system (switch stations), the operation control system (radio masts) and guideway equipment (guideway switches) the transformer stations contain an auxiliary power supply (APS) as used and described for the substations.

The medium voltage supply for the transformer stations between two substations is realized via a medium voltage cable connection from substation n via all transformer station between the both substations to substation n+1.

2.4. Power Supply Control System (PSC)

The power supply control system is a modular and hierarchical system based on standard components for industrial use and consists of a human-machine-interface (HMI), switchgear control units (SGC) in every substation and transformer station, one powerrail control unit (PRC) for every feeding area and a compensation control unit for each reactive power compensation, as well as a modular and structured data transmission system (DTR), which connects all control components.

2.4.1 Human -Machine-Interface (HMI)

The HMI consists of two parts: One is the operating and monitoring system (OaM) which is based upon components of the standard SICAM[®] WinCC system. For detecting and localizing of faults a model-based diagnosis system is used. Both systems use normal PC's as hardware.

As the propulsion system the PSC works automatically according to the stipulations of automatic train operation. This means in normal operation the HMI needs no input by the Operator.

2.4.2 Switchgear control unit (SGC)

The SGC also uses standard components from the SICAM SAS[®] system as central unit. To every central control unit there are allocated several decentral control and protection devices based upon the SIPROTEC[®] and SIMATIC[®] family which are integrated in the switchgear cubicles and connected together via PROFIBUS[®] data transfer.

The SGC has the task to control and protect all switchgears and transformers of the high voltage equipment, the distribution switchgears and the auxiliary power supplies.

2.4.3 Power Rail control unit (PRC)

The Power Rail supply for a TRANSRAPID system consists of several feeding areas. Within one feeding area all Power Rails and Power Rail supply units may be galvanic coupled with each other via the Power Rail feeder contactors. Therefore the Power Rail control unit has the task to

- coordinate the switching of several Power Rail feeder contactors and Power Rail rectifiers (which can be situated in different locations in substations and / or transformer stations along the track),
- detect earth faults and
- protect the system against overvoltage and overcurrent.

The system uses standard SIMATIC® components; one central unit for each feeding area and decentral units for the control and protection of each subordinated power rail supply unit within one feeding area.

2.4.4 Compensation Control unit (COC)

The compensation control unit is subordinated to the switchgear control unit within a substation. It receives general control commands from the SGC and sends status information and actual values back. The control tasks of the components of the reactive power compensation itself are fulfilled independent from the SGC.

2.4.5 Data transmission system (DTR)

The modular and structured data transmission system is responsible for several tasks:

- Data transfer for high-level control tasks between the several switchgear control units and power rail control units as well as the Operating and Monitoring system. This is realized via a redundant Industrial Ethernet ring structure between two substations.
- Data transfer for local control tasks between the decentral control units of the switchgear control unit and the power rail control unit. This is realized via several PROFIBUS® busses.

3. Propulsion System and Power Supply for Shanghai Maglev Transrapid Project (SMTP)

3.1. General

The propulsion system and power supply for Shanghai Maglev Transrapid Project is based on the structures described above and is designed according to the requirements of the transportation system. The main requirements for a transportation system are:

- track length
- passenger capacity
- travel time to destination
- maximum waiting time for passengers at the stations

Therefore the main design parameters for a transportation system are:

- alignment
- comfort criteria
- speed profiles
- operation concept including headway times
- availability, reliability

In relation to these parameters and the necessary input data

- number of vehicles and number of sections per vehicle
 - vehicle data, e.g. aerodynamic resistance
 - comfort criterias, e.g. max. acceleration, max. jerk
 - environment, e. g. climatic data, EMC requirements, sound requirements
 - data of the 110 kV power grid, e.g. short circuit capacity
 - restrictions regarding size or location of power supply or propulsion equipment
- the propulsion system and power supply was designed.

3.2. Alignment

The alignment leads from Long Yang Road Station to the new Pudong International Airport (Figure 6). The track length of the double track is about 30 km and the operation velocity 430 kph. The travel time is about 7.5 min and the service interval between trains is about 10 min.

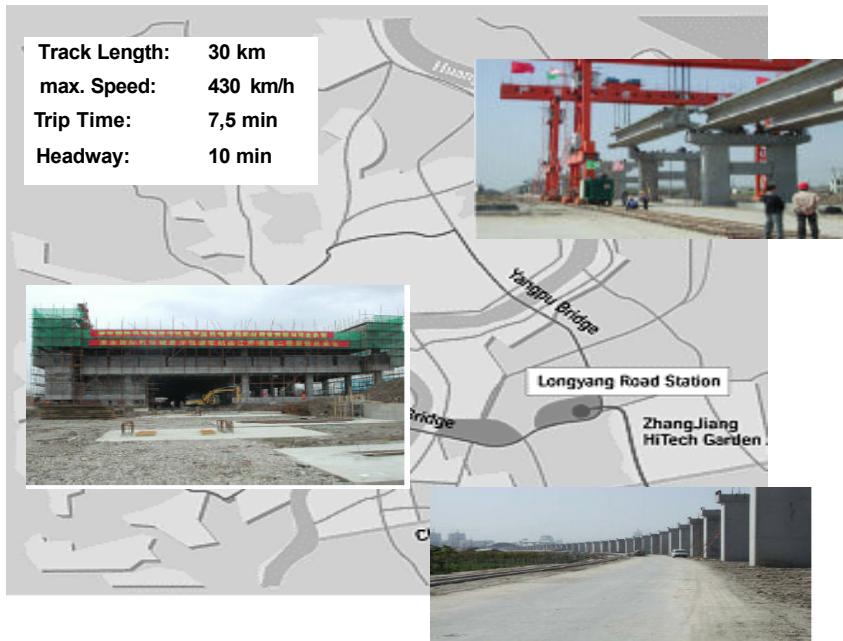


Figure 6: Shanghai Project, alignment

3.3. Technical Concept of Propulsion System and Power Supply

The design of the propulsion system and power supply is a modular design using the “box of bricks” described in the preceding chapters (Figure 7).

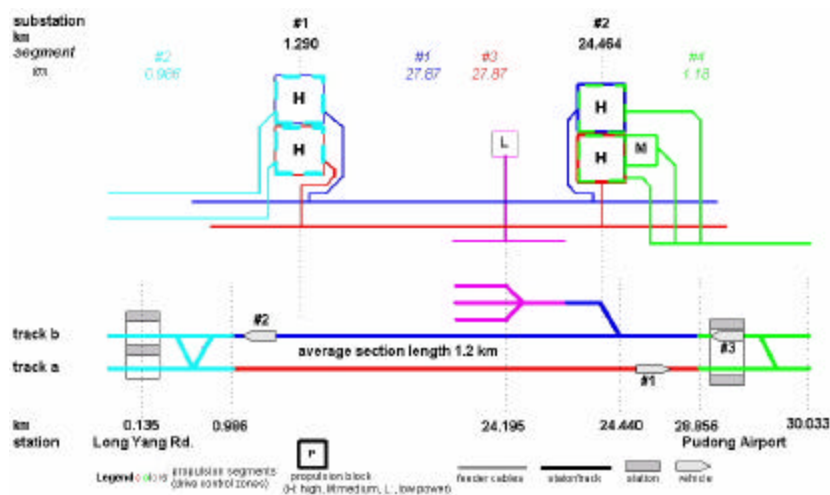


Figure 7: Propulsion Layout

The power supply system consists of two 110 kV substations, one in Long Yang Road and one in Pudong Airport.

Both 110 kV substations use two 110/20 kV-transformers and have a static filter equipment and dynamic compensation system.

The main track is divided in four drive control zones. The average section length of each stator section along the track is about 1.2 km, using the three step method for stator section switching. For the maintenance area an additional drive control zone is necessary.

For the double main track high power propulsion blocks are used, because of the high requirements regarding acceleration and velocity. These propulsion blocks are from type I, this means they can feed two drive control zones according to the location of the vehicle. For the shunting behind Pudong airport station a medium power block is chosen, because the necessary power is lower. For shunting in the maintenance area a low power block is enough to fulfil the requirements in this area.

3.3.1. Propulsion Control System

(Figure x) shows the structure of the Propulsion Control system for the SMTP.

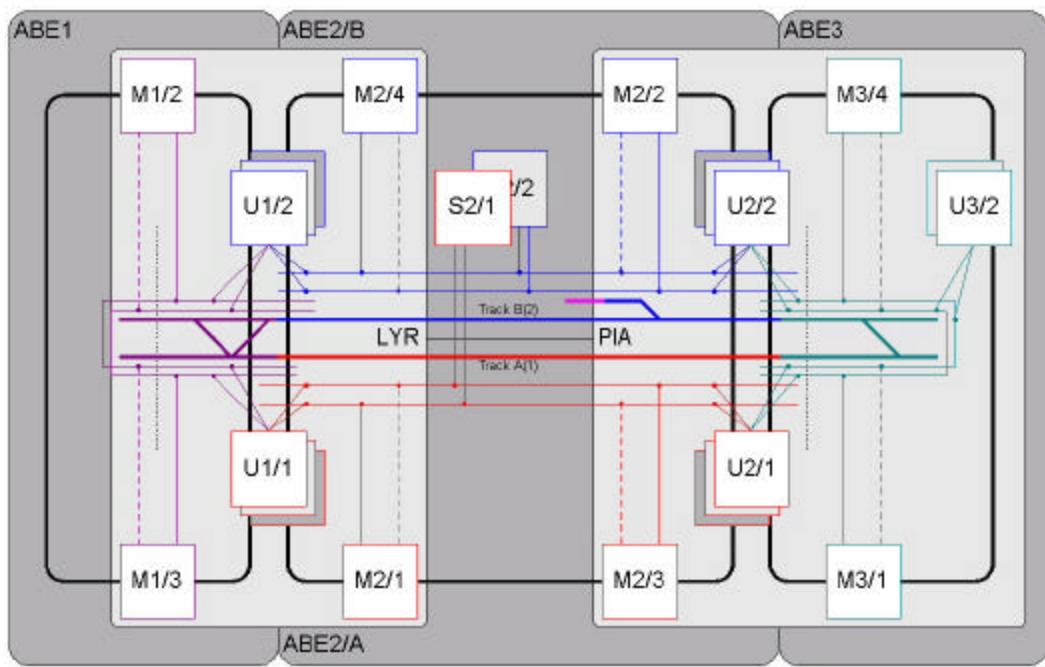


Figure x: Structure of the propulsion control system

According to the Propulsion layout the propulsion control system consists of four drive control zones for the main track (ABE1, ABE2/A, ABE2/B and ABE3). The separate drive control zone for the Maintenance area is not shown in the figure with respect to the clearness. The control components are located in the both substations LongYangRoad (LYR) and Pudong International Airport (PIA) as well as along the track.

Every drive control zone contains two motor section controls (e.g. M2/1 and M2/3 within drive control zone ABE2/A) which are responsible for the closed-loop control, open-loop control and guidance of the vehicle in the assigned drive control zone. Both units are built identical and are redundant to each other. Under vehicle operation at every time one unit – the master – guides the active vehicle, the other – the slave – is passive but synchronized by the master. According to the movement of the vehicle the master role changes from one motor section control to the other within one drive control zone – the master-slave-changeover. The same principle is used for the hand-over of the active vehicle guidance between different drive control zones (e.g. the master role

changes from M1/3 to M2/1 when the vehicle changes from drive control zone ABE1 into ABE2/A). If the actual master has a fault, then the assigned slave takes over the master role automatically.

For the closed-loop and open-loop control of each converter unit a converter control units ($U_{x/y}$) is needed. Because the three step method was chosen for the high power propulsion blocks and the step-by-step method for medium power propulsion block in total 14 converter control units are necessary for the SMTP.

The core functions of the propulsion control system within the motor section control and the converter control units are realized with the digital closed-loop control system SIMADYN D[®]. The control units consists of standard processor-, memory- and communication modules. For the special demands of the closed-loop tasks signal processor modules are used.

Decentral control components in the switch stations ($S_{x/y}$) are responsible for the switching on and off of the stator sections and earth fault detection of longstator and feeder cable. For these peripheral control tasks the SIMATIC[®] S7 system is used.

The backbone for the data transmission of closed-loop and open-loop control data is realized by the communication system Open Transport Network (OTN[®]) and consists of two redundant fibre optical ring structures (fat black line in figure 8) and network nodes with interface modules for the several used data transmission types such as Ethernet and signal processor communication.

A separate PROFIBUS data transmission system is used for the switch station control system (thin coloured lines in figure x), one redundant data link for each drive control zone.

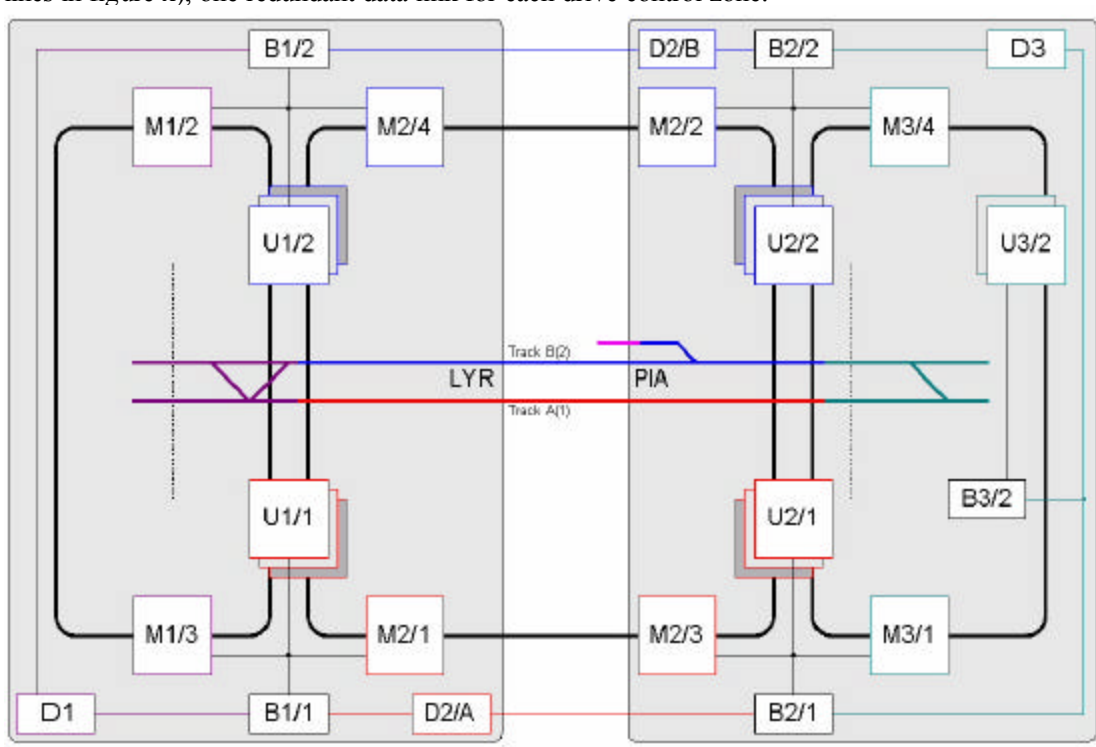


Figure y: Structure of human machine interface

The human-machine-interface (see figure y) consists of two parts, the operating and monitoring system ($B_{x/y}$) and the diagnosis system ($D_{x/y}$). Both are PC based systems.

The operating and monitoring system serves as an interface to the process control tasks –fulfilled by the motor section controls and the converter control units – and as an interface to the diagnosis system. The main features are graphical views of the process state, actual values and displaying of messages including archive functions for both process values and messages. The WinCC software as a wellknown standard for industrial applications is used for realizing this tasks and one terminal is used per propulsion block.

The terminals of the operating and monitoring system are coupled to the process via a local PROFIBUS data link and are global connected with the diagnosis terminal via an Ethernet data link.

The diagnosis system (Dx/y) receives its input data from the operating and monitoring system and is model-based. The advantages of a model-based diagnosis are short training times for maintenance personnel and fast and reliable fault localization. The used system allows online diagnosis for permanent process control as well as offline diagnosis for guided maintenance. One terminal is used per drive control zone.

Not shown in figure 9 are additional terminals of the human machine interface which are located in the operator rooms of the main track and the maintenance area. At this terminals the operator personnel needs global information whether the whole system works fine or not and must not be distracted by too much detailed information. On the other hand the maintenance personnel needs detailed information on a local component of the system in order to localize faults very fast.

As the operating and monitoring system as well as the diagnosis system is cascable and global connected, it is possible to make the necessary information available in different views and at different locations according to the different demands of the several users.

3.3.2. Modular structure of the substation buildings

The modular structure is also applied to the structure of the substation building (Figure 8). One high power propulsion block consists of three converter units (three step method) with its input transformers, input switchgears, converter units, output switchgears and output transformers. The modular structure allows to multiply the propulsion blocks by extending the building in one direction.

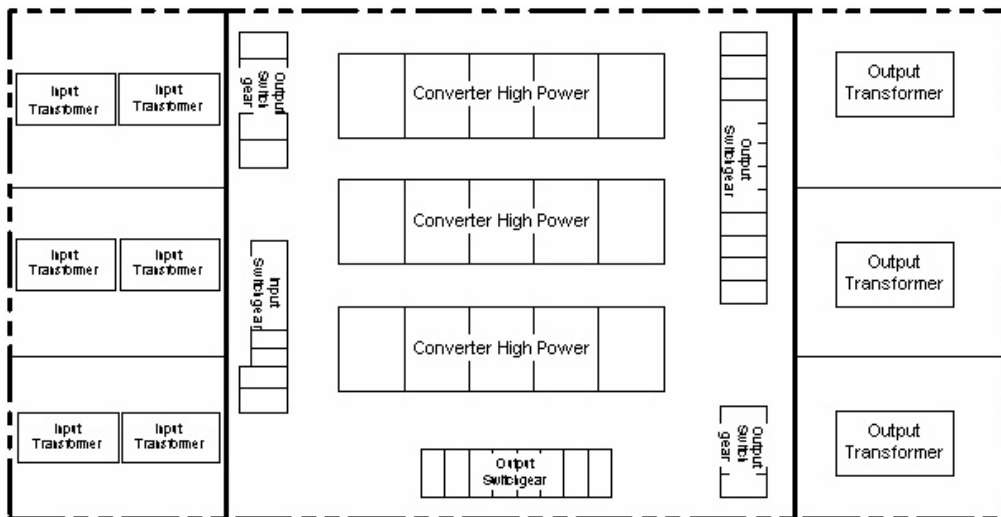


Figure 8: Arrangement of a propulsion block in the substations

3.4. Status at Site

The following photos (Figure 9 - Figure 11) show the status at site in April of this year:



Figure 9: View in the converter room in Pudong Airport substation



Figure 10: Gas insulated switchgear in 110 kV substation Long Yang Road

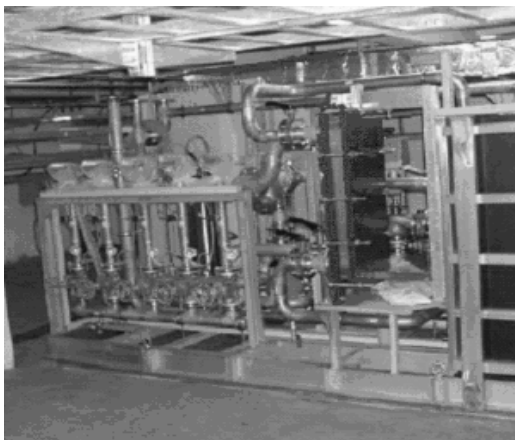


Figure 11: Converter cooling system in Pudong substation

4. Conclusion

The modular structure of the propulsion and power supply system for commercial lines was presented. Derived from this structure is the layout for the first commercial TRANSRAPID project in Shanghai. This project marks the international breakthrough for the TRANSRAPID system. In addition to its transport role, this line is also a measure of the technical prowess of the system as a whole, as well as of the ability of the companies involved to implement a complex transport project within a short space of time - there is a period of not even two years between the signing of the contract and the VIP run set for January 2003.

The goal is a worthy one: a high-speed transport network is currently being developed in China and after successfully finishing the Shanghai project, the TRANSRAPID will have great chances to win other orders. However, there are also firm plans for the use of the TRANSRAPID in Germany, the USA and other countries.

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