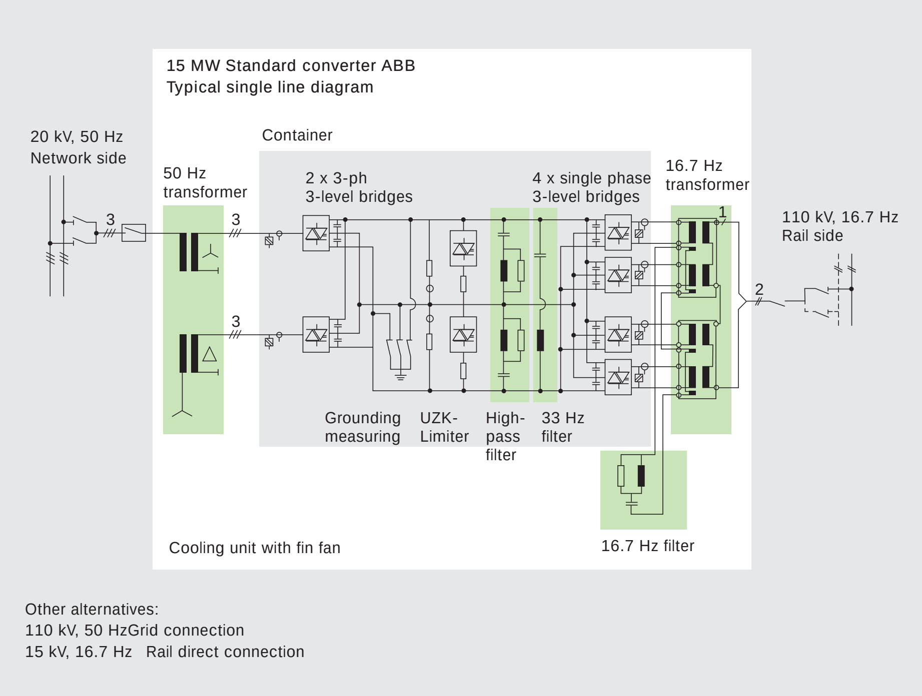
Static converters, dynamic performance

Providing railway grids with the right frequency

GERHARD LINHOFER, PHILIPPE MAIBACH, NIKLAUS UMBRICHT – There are significant differences between railway electrification and national grids. One of these is that AC-electrified railways generally use only a single phase, whereas domestic grids generate, transmit and distribute three-phase power. Furthermore, frequencies are in many cases different from those of the national grid. Even when the same frequency is used, this is not necessarily synchronized. Nowadays, large frequency converters based entirely on power electronics are used to transfer electricity between national and railway grids. ABB has installed numerous 15 MW frequency converters, for example the railway power supply to the new Swiss Lötschberg tunnel. Today, even larger power classes are implemented, in particular the 413 MW station being built for E.ON in Germany – the most powerful static converter so far.

1 Single line diagram of a converter station



Electric railways have a huge demand for power. In fact many operate their own high-voltage power grids and some even operate dedicated generating plants. Few railways, however, are totally autonomous: Power must be exchanged with the national grids. Today, three main power systems are used for electric mainline railways.

- In countries or regions where railway lines were electrified relatively recently, the catenaries are often fed from the public grid at a frequency of 50 Hz (or 60 Hz), mostly at a line voltage of 25 kV.
- In some countries, where railways were electrified much earlier, direct current (DC) was chosen (typical line voltages are 1.5 and 3 kV).
- Other countries use single-phase alternating current with a low supply frequency. These include the East Coast of the United States, using 25 Hz, and Norway, Sweden, Germany, Austria and Switzerland, using 16.7 (formerly 16 ²/₃) Hz.

In the past, rotary converters were used to exchange power between single-phase railway grids and three-phase national grids. They basically consisted of two electrical machines with a different number of pole pairs arranged on a common mechanical shaft. In a more recent development, frequency converters based on power electronics became suitable for this purpose. In fact, the total power of such static frequency converters taken into operation over the past 15 years is about 1,000 MW. Approximately two-thirds of these were supplied by ABB. Converters totaling more than 800 MW are presently being built or have been ordered.

From the point of view of the converter (be it rotary or static), the interconnection of a three-phase and a single-phase grid is more demanding than the interconnection of two three-phase grids. One principle reason for this is the fact that the power in the single-phase grid oscillates at twice the grid frequency, whereas in the three-phase grid it is basically constant. In the case of rotary converters, the ensuing torque and power fluctuations are absorbed and damped by the rotating masses. The resulting vibrations must however be absorbed by their mechanical anchoring and foundations. This leads to additional complexity in the design of both the machine and its foundations.

In the case of static frequency converters, the oscillation is filtered using a capacitor bank and an inductance that are tuned to twice the operating frequency of the railway grid.

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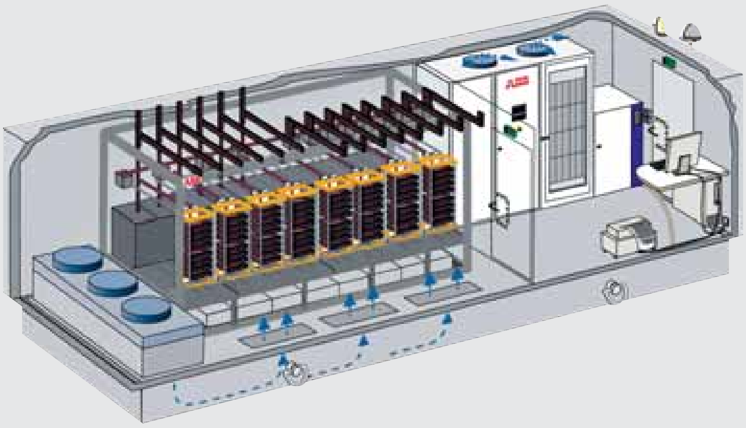
2 Converter container



Components of the converter container
- Space cooling system
- Converter and voltage limiter modules with control electronics close to the converter
- DC-link bus bars and capacitors behind the converter modules
- Bus bar feeders to the transformers
- Power distribution for auxiliary power and instrumentation and control system (control, measurement and protection)
- Uninterruptible power supply for the instrumentation and control system
- Local operation using HMI and event printer

Another challenge lies in the fact that the static converter not only has to act as a voltage and reactive power source, but must also be able to handle – without interruption – the transition from interconnected system operation to island operation in case of disturbances in the grid. Furthermore, it must be capable of acting as the sole power supply to an isolated section of railway, and be able to subsequently resynchronize with the rest of the railway grid after the disturbance has been cleared.

Long tradition of static converters

ABB can draw on a long history of static converter technology. The first railway power supply converters with powerful turn-off semiconductors in the form of GTOs (gate turn-off thyristors) were taken into operation in Switzerland in 1994. Since then a new semiconductor element, the integrated gate-commutated thyristor (IGCT), was developed that features a much more advanced switching capability, lower losses, and a low-inductance gate unit as an integrated "component." The compact design led to the development of standardized converter modules and permitted converters of various power classes to be built. Today, more than twenty converters in the 15 to 20 MW range are in operation and performing to the customers' fullest satisfaction.

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15–20 MW: converter station for the Lötschberg rail tunnel

One of these deliveries was the Wimmis converter station for the new Lötschberg rail tunnel (Switzerland) [1], through which trains are able to operate at 200 km/h. In 2005, ABB supplied four converter units for this railway. The customer was the Bernese Power Utility (BKW), which was at the time responsible for providing electrical power to the railway. Each of the four converter blocks, with a power of 20 MW, first converts the three-phase supply from the 50 Hz network into DC (direct current). The energy is briefly stored in a DC link before being changed by an inverter into a single-phase, alternating voltage with a frequency of 16.7 Hz.

The single line diagram of a complete converter station such as the one installed for the Lötschberg tunnel in Switzerland is shown in → 1. It features the following components:

50 Hz converter

This converter consists of two standard three-phase, three-level units. Two phases are combined in one stack to form a double-phase module. The converter is realized in a real 12-pulse configuration. Hence, only 12-pulse characteristic harmonics ($n = 12k \pm 1$; $k = 1, 2, 3, 4\ldots$) are generated.

16.7 Hz converter

This converter consists of four standard two-phase, three-level units. Two phases are combined in one stack assembly to form a double-phase module. The 16.7 Hz converter is implemented in an eight-step configuration. The converter output voltage levels are summed by means of series connection of the line-side transformer windings of the four offset-pulsed three-level H-bridges.

Voltage limiter

Should the DC link voltage exceed an upper threshold, it is discharged via a resistor until a lower threshold is reached. The voltage limiter control works independently of the control system for the converter on the two-phase AC (railway-side) and the three-phase AC (mains-side). This ensures that the DC link voltage remains within the defined range at all times.

DC link

All double-phase modules of the converter are connected to each other on the DC side by a common bus bar. This carries the individual converter module connections for the directly coupled DC

Footnote

1 See also "Switzerland by rail" on page 31 of this edition of *ABB Review*.

Supplied in a weatherproof container, the converter and the associated control system are fully wired and tested.

link capacitors, the DC link filter banks and voltage measurements.

The DC link forms the connection between the 50 Hz and 16.7 Hz converters. It consists of the following main components:
- Directly coupled capacitor bank as energy storage
- 33.4 Hz filter to absorb the power fluctuation from the railway grid
- High-pass filter to absorb the higher frequency harmonics from the railway grid, in particular the distinct third and fifth harmonics of the railway grid

Converter container
Supplied in a weatherproof container, the converter and the associated control system are fully wired and tested. The cooling system is located in a separate container. Both containers are mounted onto a common support base. A cross-sectional view of the converter container is shown in ➔ 2.

50 Hz transformer
The transformer of the 50 Hz converter feeds the two IGCT-based three-phase bridges. A three-phase transformer consists either of a three-limb core in double-tier design with intermediate yoke or of two three-limb cores contained in one tank.

16.7 Hz transformer
The transformer of the 16.7 Hz converter is used to add up the four partial voltages to a nearly sinusoidal single-phase voltage with a rated frequency of 16.7 Hz. The transformer consists of four single-phase units. The rectangular partial voltages are generated from a DC voltage source (DC link) with the help of four single-phase IGCT converter bridges using the pulse-width modulation method and are fed to the four valve-side windings of the transformer. The adding up and adaptation to the railway grid voltage occurs in the high-voltage winding. A filter is connected to the series-connected tertiary windings or to the railway grid.

The world's largest rail converter station is now under construction in Datteln, North Rhine Westfalia, Germany.

Line filter
On the 16.7 Hz side, a filter is used to reduce the very low harmonic distortion caused by the converter to even lower values. On the 50 Hz side, this is also required in some cases.

Remote control
In the case of the static converters at the Swiss Lötschberg project, the whole system is remotely controlled by an ABB system-control computer, known as ALR [2], which captures and analyzes the data from the four 20 MW converters and the two rotary converters via standardized interfaces. The ALR continually calculates the optimum use of the available production units (static and rotary converters) on the basis of the power demand in the railway network or based on manual settings. Thus, the necessary power reserve can be connected to or disconnected from the network by the control computer within a matter of seconds.

All control, regulation and safety functions are equipped with the proven, fully digital power-electronic control system [3]

Footnotes
2 ALR is an abbreviation for Anlageleitrechner (system control computer).
3 On earlier installations: PSR (Programmierbarer Schneller Rechner), on current installations: AC 800 PEC.

3 The Wimmis converter station for the new Lötschberg rail tunnel

The two × 30 MW converter station in Timelkam, Austria

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from ABB. This system is designed for use in precise and very fast servo loops for converter/inverter systems. The operator workstations of the ABB MicroSCADA power control system in the central control room guarantee the reliable display of the measured values and calculations as well as the operation of the supervisory circuits and sequences of all parts of the system. Hot standby operation of the supervisory power control system components (ALR and operator workstations) guarantees very high availability of the system.

The installation is shown in → 3. The 50 Hz transformer can be seen on the left-hand side, including the 50 Hz filter circuit above the transformer (mounted on a portal). The single phase 16.7 Hz transformer is on the right-hand side and the converter container is in the middle between the transformers.

Increase of unit power to 30 MW

Due to the modular design, other power classes can be implemented very easily (in steps of 15 MW). The additional converter modules are connected in parallel. This converter generation sets new standards in terms of performance, footprint and short erection and commissioning times. Positive feedback shows that ABB's standardized railway converter is well suited to meet customer needs.

Following the successful introduction of the 15–20 MW converters, customers sought a further increase of unit power. ABB thus developed another standard frequency converter for 30 MW with optional overload capability, depending on application and environmental conditions. Two or more 30 MW units can be combined in parallel to achieve higher power ratings per station.

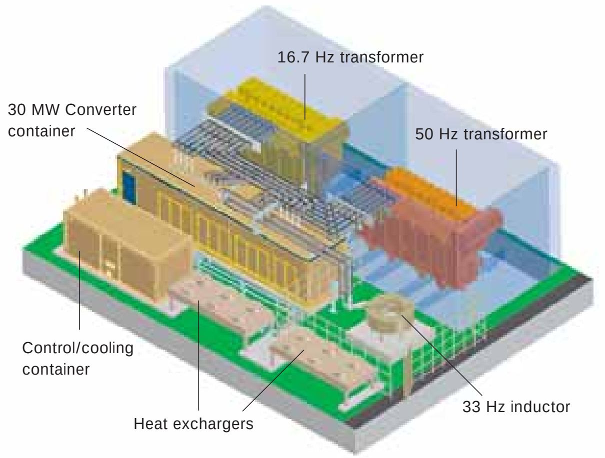
30 MW: converter station Timelkam

At the end of 2007, the Austrian Railway System ÖBB ordered a new rail converter station for installation near the town of Timelkam in the province of Upper Austria. The station comprises two independent 30 MW converter stations, which are fed from the national grid at 50 Hz / 110 kV and convert this to 16.7 Hz / 110 kV. A total of 60 MW of electric power is thus available for the railway grid with no transportation losses thanks to its proximity to the power generation facility. The first 30 MW converter went into commercial operation in July 2009 → 4.

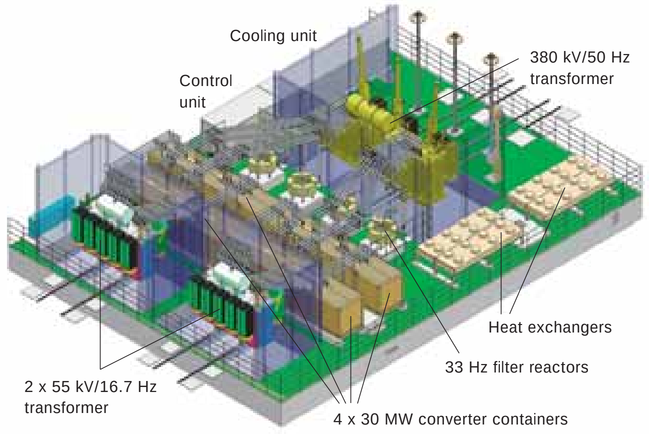
413 MW: Datteln converter station

The world's largest rail converter station is now under construction in Datteln, North Rhine Westfalia, Germany. The station was ordered by the German power supplier E.ON in 2007 and will provide a power rating of 413 MW. It will replace existing 16.7 Hz generators of the power plants Datteln 1–3, which have reached the end of their economic and technical lifespans. The converter station will receive power at 50 Hz from the new nearby Datteln 4 power station and feed power at 16.7 Hz into the 110 kV network of the German Railways (DB). The Datteln node is one of the most important "supply points" of DB's grid. A very high availability is therefore required of the converter station. ABB is responsible for the entire engineering of this project, ie, the design of the converter system, specification of all the components and

4 30 MW converter station



5 One of the four converter units (103 MW)



development of control and protection software. Since it is a turnkey project, installation and commissioning is also part of the project scope.

The scope of supply for ABB includes four independent converter stations each with a rated power of 103 MW, obtained from four standard 30 MW converters. The built-in overload capability allows the customer to still receive the nominal power of 413 MW even if one of the four converter stations is not in service. Each converter unit has the following main components:

– One converter transformer on the 50 Hz side
– Four converter containers including intermediate circuit filters
– One control container
– One cooling container (housing the cooling system)
– Four water/air heat exchangers
– Two series connected converter transformers on the 16.7 Hz railway side

Apart from the technical challenge presented by this major project, logistics and good planning are essential to enable the equipment to be delivered on time. The long contract duration (completion is scheduled for 2011) accompanied by a rigid timetable is a distinctive feature. This project may also pioneer further applications: Four converter blocks with 103 MW each set a new standard in terms of power for static frequency converters ➔ 5.

Outlook

ABB is market leader for this type of system. The modular approach allows a flexible response to various power requirements. In coming years there will be an increased demand for 15 MW converter units as many rotary converters reach the end of their lifespan. ABB is committed to following up on its recent successes by further advancing this technology.

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References

[1] Gaupp, O., Linhofer, G., Lochner, G., Zanini, P. Powerful static frequency converters for transalpine rail routes. ABB Review 5/1995, 4–10.
[2] Lönard, D., Northe, J., Wensky, D. Statische Bahnstromrichter – Systemübersicht ausgeführter Anlagen. Elektrische Bahnen 6/1995, 179–190.
[3] Mathis, P. Statischer Umrichter Giubiasco der Schweizerischen Bundesbahnen. Elektrische Bahnen 6/1995, 194–200.
[4] Steimer, P., Grüning, H., Werninger, J., Dähler, P., Linhofer, G., Boeck, R. Series connection of GTO thyristors for high-power static frequency converters. ABB Review 5/1996, 14–20.
[5] Steimer, P., Grüning, H.P., Werninger, J., Carroll, E., Klaka, S., Linder, S. IGCT – a new, emerging technology for high-power, low-cost inverters. ABB Review 5/1998, 34–42.
[6] Meyer, M., Thoma, M. Netzkompatibilitätsstudie und -messungen für die Umrichteranlage Wimmis. Elektrische Bahnen 12/2006, 567–574.
[7] Jampen, U., Thoma, M. Statische Frequenzumrichteranlage Wimmis. Elektrische Bahnen 12/2006, 576–583.