A perfect fit

ABB’s powerful propulsion converters are energy efficient, reliable and very compact, making them suitable for all rail vehicle designs

HARALD HEPP – In modern rail vehicles driven by electric motors, all movement is controlled and powered by traction converters built on insulated gate bipolar transistor (IGBT) semiconductors. ABB is a leading supplier both of power semiconductors and of a very broad portfolio of power electronic systems and applications, in particular of motor drives for all industry segments and power ranges. In the past ten years, ABB, leveraging a unique combination of power electronics expertise, brought new, highly successful traction converters to the railway market that excel in energy efficiency, reliability, compactness and service-friendliness. In the global market, ABB is one of the very few independent suppliers of traction converters or even complete traction chain packages. ABB is not building rail vehicles but supplying key power sub-systems.

1 ABB's 2.3 MW BORDLINE Compact Converter used to drive three axles in dual-system CoCo locomotives

If one compares the electric traction motors in trams, motor coaches or locomotives to muscles in the human body, the traction converters would be both the heart and the cerebellum. As the heart, the converter ensures the proper energizing bloodstream, and as the cerebellum it takes care of smooth and precise movement and coordination through sophisticated control algorithms. Speaking more in the language of railway electrics, a traction converter provides the exact voltage wave patterns for the traction motors to control their speed and torque as well as the energy flow to the wheels – or from the wheels back when the vehicle brakes in regenerative mode. A state-of-the-art energy-efficient 1.5 MW converter from ABB (BORDLINE™ CC1500_AC) for double-deck EMU trains of Stadler Rail is shown on page 60. The traction converter is the "intelligent link" between, on the one side, the energy supply through catenary, transformer or Diesel-generator, and the traction motors on the other side.

Motor-side challenges

On the motor side, the traction converter receives input signals from the motors, for example phase currents, speed, and motor temperature. This information is combined with the driver's or vehicle control's commands which tell the converter how the train shall start, accelerate or brake. Control algorithms process these signals in milliseconds, taking into account the motor characteristics in different regimes of the motor frequency/load diagram. In reality, however, a drive control system for rail vehicles is much more complex. The system has to cope with wheel slippage, which depends on weather conditions, slope, and the wear of the rail track and wheels. Another challenging aspect can be the coordination of different motor axles of the vehicle. As an example, ABB converters showed benchmarking traction effort in field trials with a new multi-system CoCo locomotive of the Spanish system integrator Construcciones y Auxiliar de Ferrocarriles (CAF) S.A. ➔ 1. The most essential functions of the drive control are the protection algorithms that make sure that the control reacts properly, reliably and safely in all imaginable irregular states of the complete propulsion system.

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One of the key advantages of ABB traction converters is that they are built on the AC 800PEC control platform [1], probably the most powerful modular controller for high-speed performance on the market ➔ 2. This control platform is also used in ABB wind converters, high-power industrial drives, plant automation, high-power rectifiers and many other applications. The AC 800PEC software is implemented on three performance levels, and this provides an excellent range of control and communication functionality in cycle times that extend from the sub-microsecond to the millisecond level. The controller is complemented by a variety of input/output modules as well as engineering and service tools ➔ 3.

2 ABB's control platform AC 800PEC, which is employed in ABB traction converters

3 A BORDLINE CC1500_AC control frame with the AC 800PEC controller, reflecting a neat and lean hardware structure

Several teams of ABB hardware and software engineers dedicated entirely to working on traction converters, develop traction-specific hardware configurations and software modules, and tailor them to the customer's vehicles and projects. Compared to most other commercially available traction control systems, the application software in the AC 800PEC is built in a way that speeds up train commissioning significantly. The commissioning engineer can adjust parameters and algorithms in real time to ensure smooth and powerful motion over all speed and load ranges. Often the system integrators and rail operators are surprised at how quickly new vehicle designs using ABB converters and drive control come to life when they are powered and started for the first time.

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Line-input-side challenges

Since the train is an often fast moving system, the catenary contact is not perfectly stable. Hence, the converter has to compensate for fluctuations in input power. In weak electrification networks, like for instance in some parts of India, adapting to varying line voltages, is an even greater challenge.

Traction converter control should not only optimize the output voltage waveforms for the motors but it should also make sure that the traction chain does not cause perturbations, oscillations or higher harmonics on the input side. In diesel-electric vehicles, the converter control needs to minimize distortions in the generator waveform to reduce wear and optimize energy efficiency. For electric trains, line-input control is even more important in order to avoid safety-relevant interference with signaling installations. In certain networks, as described above, good traction converters in operation can even have a stabilizing effect on the line voltage level and waveform.

An example for these challenges is the system perturbation code in the Norwegian 15 kV/16.7 Hz rail network. The rail infrastructure agency Jernbaneverket demands a specific damping of low-frequency oscillations that arise through the load of trains running on long-distance parts of the network and the regulation of small hydropower plants feeding these lines. ABB traction converters, because of their powerful converter control programming, were more than capable of meeting these requirements by simply adapting software already running on

4 Adapted ABB control software on board a Stadler FLIRT train from Switzerland is given a test run in Norway

converters designed for trains in Switzerland. Test runs in Norway with a Swiss FLIRT train from Stadler Rail convinced the Norwegian State Railways (NSB). Today, ABB has orders for 300 BORDLINE CC750 Compact Converters and 150 ABB traction transformers for NSB ➔ 4.

Designed to fit any vehicle design

In most rolling stock projects, the vehicle design imposes challenging constraints on the physical dimensions of traction converters, transformers and motors. Through very compact and lightweight constructions, the ABB equipment gives more freedom for the vehicle design. In principle, traction converters and transformers can be mounted in the machine room (see the converter in the title picture), under the floor ➔ 5 or on the roof of the rail vehicle ➔ 6. The traction converter design can also substantially reduce the size and weight of the transformer.

How can ABB traction converters achieve this compactness and high power-density? The recipe comprises internal liquid cooling, smart power module design and great care with the construction of the aluminum or stainless steel housing. Requirements for robustness of traction equipment are extremely tough; hence a wealth of expertise in materials selection and processing, welding and riveting technology, FEM analysis, cooling technology and other fields is necessary to achieve the weight reductions that ABB can offer in traction projects.

Internal liquid cooling for traction converters, for instance, is a technology that ABB has developed and optimized with great care in the last ten years. The advantages are manifold, ie, the temperature distribution in all parts of the converter is highly uniform, enhancing the lifetime of the power semiconductors. Power modules can be built so small and lightweight that one person can handle them. No machine room or other cooling air flow needs to enter the converter, and control electronics and power modules can be cleanly sealed from ambient dust, dirt and humidity.

Designed for retrofit

In refurbishment projects, the challenges of fitting traction converters to the existing vehicle are much tougher than in new designs because all interfaces, such as the train control system, the line-input side, motors, the cooling system, available space, and all fixings and connections are pre-defined. Nevertheless, these complex projects can have a high return on investment provided the converter supplier can offer a powerful modular platform with strong engineering and project management support. This can be illustrated with the retrofit solution for ICE1 high-speed trains in Germany with ABB converters. More details about this retrofit project can be found on page 70 of this issue of ABB Review.

Multi-system trains that know no borders

Nowadays rail vehicles increasingly need to cross borders of different electrification systems, eg, between countries with different DC and AC rail networks or between urban transport systems and mainline rail services. Coping with different input line voltages is a particular technical challenge for traction chains. ABB has come up with several smart and

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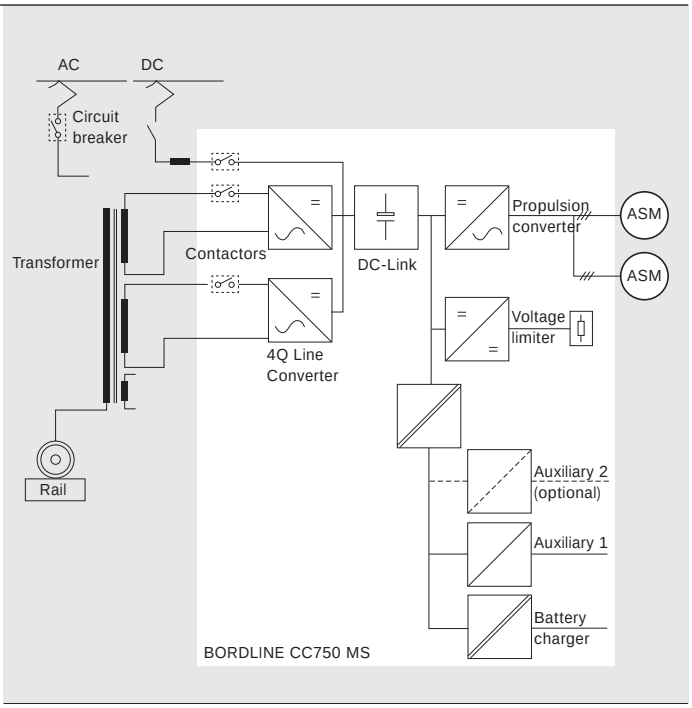
5a Powerful ABB multi-system under-floor converters for narrow-gauge vehicles



5b Single-line diagram of this converter

ABB builds low-voltage and medium-voltage power electronic drives for all kinds of applications.

versatile solutions for such multi-system trains.

Consider, for example, Italy and Switzerland. Treni Regionali Ticino Lombardia (TILO), a subsidiary of the Swiss Federal Railways (SBB), is an operator of regional train services between Switzerland (15 kV AC 16.7 Hz electrification) and Italy (3 kV DC electrification). Between 2005 and 2009, TILO ordered a total of 31 FLIRT trains (3 MW) from Stadler Rail with ABB traction packages (the transformer was designed by ABB Sécheron and Compact Converters) that can run in both networks without interruption. The dimensions and most modules correspond to the pure AC version which SBB has bought for Switzerland in more than 80 trains since 2002. By doing this, SBB and TILO now reap the benefits of optimum service and spare part management, and reduced total fleet cost. It also showcases the satisfaction of SBB with the ABB solution. The same multi-system traction package design was also ordered by Südtiroler Transportstrukturen in 2007 for eight trains commissioned for service between Italy and Austria (15 kV AC).

For historical reasons, the mountain rail operator Rhätische Bahn (RhB) in Switzerland has different line voltages in their network. While most of it is powered by 11 kV 16.7 Hz, the line across the Bernina pass, listed in the UNESCO world heritage, one of the world's steepest adhesion lines with a 7 percent incline, has 1 kV DC electrification.

In early 2010, the first powerful dual-system mountain trains from Stadler Rail, called "Allegra", started commercial service after successful test runs in the last six months. For these narrow gauge trains, ABB developed under-floor mounted Compact Converters that comprise two 350 kW propulsion converters, galvanically insulated auxiliary converters and a battery charger, all in one very robust cubicle. Each train is equipped with four BORDLINE Compact Converters and two under-floor traction transformers – LOT1250 – designed by ABB Sécheron. Deliveries of 60 converters and 30 transformers will continue into the second half of 2010.

A unique market position

ABB builds low-voltage and medium-voltage power electronic drives for all kinds of applications: to propel ships; power wind tunnels; or control large and small motors in sophisticated industrial processes. These drives save huge amounts of energy, enhance automation, improve process quality and reduce mechanical wear. Related power electronic technology is used to feed energy from wind generators or photo-voltaic plants into the power grid or to stabilize power networks. Continuous innovation in these

6 Highly integrated BORDLINE Compact Converters that are mounted on the roof of tramways and narrow-gauge regional trains

The roof-mounted BORDLINE Compact Converters of ABB are examples of complete and highly integrated power-electronics sub-systems that consist of two motor inverters, two auxiliary converter outputs, a battery charger, a braking chopper and all control electronics. They are suitable for use on tramways and narrow-gauge regional trains at line voltages of between 600 and 1,500 VDC. They are characterized by adaptable mechanical, electrical and logical interfaces to the vehicle, very low weight and small dimensions. These types of roof-mounted converters have already been sold to public transport operators in Switzerland (Basel, Berne-Solothurn, the Lausanne region and the greater Zurich area), Germany (Bochum, Mainz, Munich, Nuremberg and Potsdam), Austria (Graz), China (Changchun), France (Lyon) and Norway (Bergen).

6a BORDLINE Compact Converter for light rail vehicles

6b Compact Converter that is mounted on the roof of narrow gauge EMUs

BORDLINE CC750 for EMUs. To date, Stadler Rail has bought more than 2,500 of this class of converter for FLIRT and GTW trains.

ABB applications also benefits from the fact that ABB is one of the leading suppliers of power semiconductors.

More and more rail vehicle manufacturers and fleet operators are turning to ABB for drive solutions, even those who have some converter production in-house. ABB's flexibility means customers can procure single components only – according to the customer's specifications – or they can buy complete optimized, energy-efficient and cost-effective traction chains. ABB leaves the application specification and system integration to the train manufacturer. However, leveraging economies of scale, ABB can optimize and standardize on the subsystem and module level.

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Reference
[1] Johansen, E. Design patterns: Co-design patterns for advanced control with AC 800PEC. *ABB Review* 2/2006, 62–65.

Further reading
Hepp, H., Cavalcante, F., Biller, P. Performance on track: Electric power on trains – designed by ABB to make journeys more comfortable. *ABB Review* 2/2008, 25–29.