
 SERVICE AND RELIABILITY

IGBT converters extend life of Re460 locomotives

ABB is supplying state-of-the-art IGBT converters to modernize and extend the lives of the Re460 locomotives of Swiss Federal Railways (SBB).



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Switzerland's railway network is famous the world over. Admired for its network density and the punctuality and frequency of service, the system provides well over one million passenger journeys every day. To further build on the rail network's success and prepare it for the needs of the future, the ambitious "Rail 2000" program was launched in the late 1980s. The project set out to add capacity and reduce journey times. A central part of the plan was the introduction of the Re460 locomotive. 119 of this type entered service between 1992 and 1996 →1. They were equipped with GTO (gate-turn-off thyristor) converters and asynchronous traction motors (both manufactured by ABB), and represented the state of the art at the time.

More than 20 years later, the Re460s are still providing excellent service. They account for about half of all kilometers travelled by SBB trains in passenger service. Each locomotive has covered on average 5.5 million km in its lifetime so far, the equivalent of seven times to the moon and back.

Although the Re460s are of robust construction and designed for a long life, power electronics has made huge progress over the last decades. For example, GTOs have been broadly supplanted by more flexible IGBTs (integrated gate bipolar transistors) in traction applications. SBB decided to embark on a mid-life refit program that will bring the locomotives up to date. The overhaul,

which includes an optimization of overall electrical systems, will ensure a further lifespan of at least 20 years while also improving energy efficiency and maintenance. The improvements are expected to deliver savings of around 27 GWh/year, corresponding to the consumption of 6,750 Swiss households.

ABB expertise

ABB is a leader in the research, development and manufacturing of energy efficient traction converters as well as traction motors and transformers. The company can look back on more than a century of experience in electric railways across the world.

Besides supplying new equipment, ABB has extensive experience in lifecycle service support for rolling stock. For example, in 2008 ABB successfully replaced the GTO-based traction chains of the ICE1 fleet of high-speed trains of German Federal Railways (Deutsche Bahn), using state-of-the-art IGBT converters. Building on the company's commitment to customers and its extensive knowledge and experience, ABB was awarded an order of around CHF 70 million by the SBB in 2014 to supply the latest generation of traction converters for the Re460 fleet. The objective was to provide greater energy efficiency, higher reliability and easy maintenance.



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 01 SBB's Re460 locomotive [Photo copyright SBB CFF FFS].

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 02 Switching topology and waveforms for two and three level IGBT converters. The voltage is shown in black and the current in red.

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 03 Three-level phase-module IGBT converter of the type used for the Re460 refit.

Modernization specifications

The SBB required the refit locomotives to fulfill a challenging set of specifications. These were defined for example by the demanding gradient profile of Zurich's cross-city-line and the environmental conditions of the Gotthard Base Tunnel (neither of these lines existed when the Re460 locomotives were first delivered). The cross-city line called for a redundancy concept: The steep gradients on this high capacity corridor pose a critical risk as a train

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 A higher switching frequency would have led to increased switching losses and acoustic emissions.

failing there would have system-wide repercussions. The refit permits a failed traction motor to be isolated, with the train being able to continue its journey using the remaining three motors. In the new Gotthard Base Tunnel, specific challenges were posed by heat and humidity as well as latest fire safety standards.

Technical solution

Diagnosis of the locomotives showed that the traction motors, transformers and vehicle control systems were in good condition. These elements are thus being retained, with their parameters defining the design of the new traction converters. They also define that the 3.5kV DC-link voltage must be retained.

Two possible converter topologies were considered, both using IGBTs →2. The first variant was a two-level topology rated at 6.5kV. The second was a three-level topology in which the upper and lower levels carry half the overall link voltage with respect to the middle level. This is ABB's preferred technology for retrofitting locomotives to IGBT-based traction converters and was chosen for use in the Re460.

The three-level topology results in a flow of traction current that more closely reflects the desired sinusoidal waveform. The original GTO system also featured a three-point topology: The resulting low level of harmonics influenced the design of traction motors and transformer. Achieving the same level of harmonics with a two-point topology would demand a high switching frequency. This implies greater switching losses as well as increased stress on the insulation materials. Besides the electrical and energy advantages, the solution adopted features low acoustic emissions.

Adoption of 3.3kV three-level typology also avoids the need to connect IGBTs in parallel. Specifically, the grid side converter (there is one such converter for each of the two bogies) is made up of a total of four phase-module units. The two motor-side converters each have three →3. The matching of IGBT modules as necessary in parallel connection is not required.

Power circuitry and mechanical construction

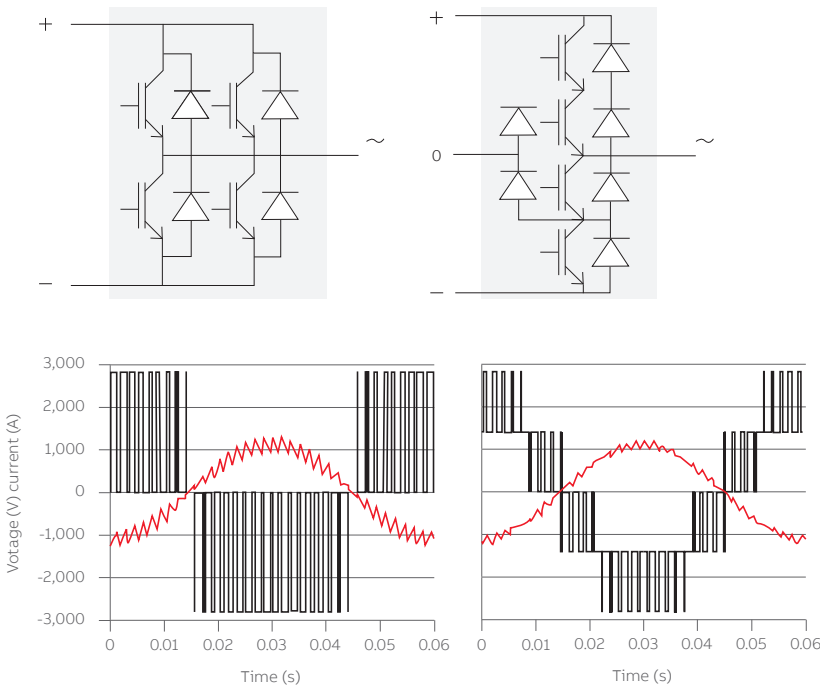
The use of IGBT technology aside, the topology of the power circuit is largely identical to the original. The water-cooled IGBT phase modules are based on ABB’s BORDLINE traction converter platform. The phase modules used in the grid side converter are identical to those in the motor-side converter. The type was also used in other refit projects including the German ICE 1.

The transformer has four secondary-side coils, two of which connect to each of the two respective converters →4. Each coil connects to a rectifier unit, which draws power from the transformer but can also feed it back to the grid when the locomotive is braking.

The DC-side voltage of the converters connects to the DC link capacitors, which smooth it with the help of a resonant circuit tuned to 33.4 Hz. This step is necessary because the 16.7 Hz single-phase railway grid does not feed power continuously. The power is supplied to the motor-side converters in pulses at double the grid frequency.

The DC-link voltage is rectified to three-phase AC by the three-level motor-side converter, creating the voltage wave patterns required to control speed and torque.

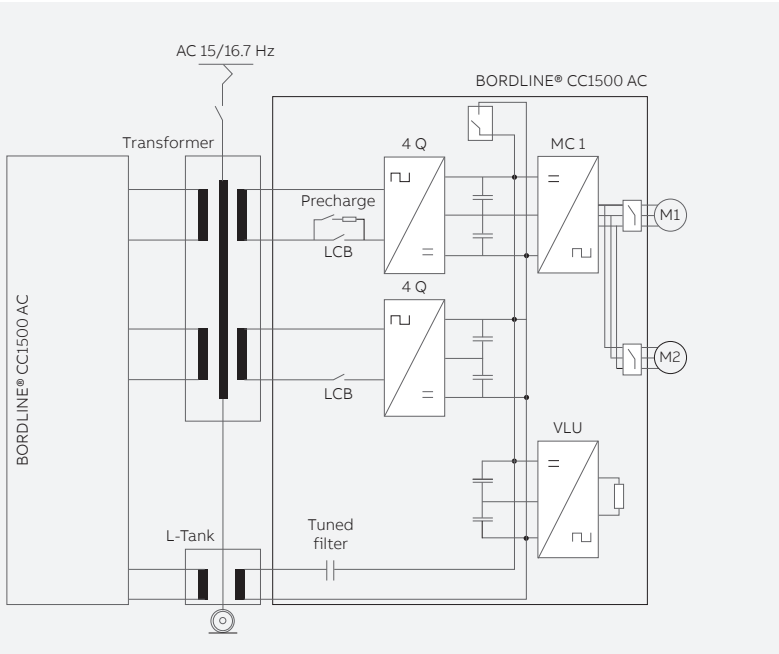
Each of the two traction converters supplies the two motors of one bogie in parallel connection. The new means of motor separation allow a failed motor to be disconnected.



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04 Circuit diagram of the converter.

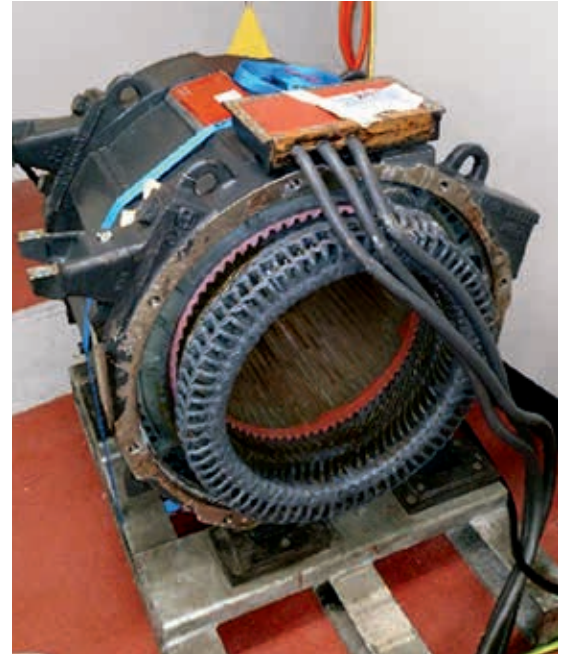
05 Stator of a Re460 locomotive motor on the dynamometer in ABB's lab in Turgi, being tested to determine the voltage on the coil during switching operations.

06 Measurement results of the stator tests. The diagram shows the transient overshoot of local winding voltages during IGBT switching. These must be limited to avoid harm to the motor.

Mechanical construction

The new compact IGBT converters are water-cooled. The previous oil circulation system is being totally replaced by a water-cooling system. The new system reduces energy use as well as being ecological and safe.

The new cooling equipment is lighter and requires less space, freeing room available for additional components or future refurbishments. Ballast is used to offset the disadvantage of the decreased weight for traction adhesion.

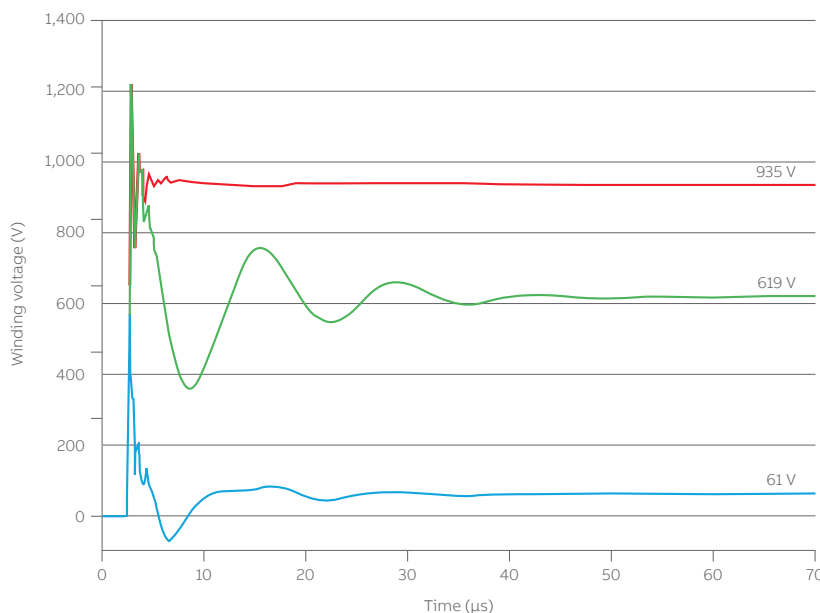


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Control technology

The new converter uses ABB's AC800 PEC control platform, one of the most powerful control systems available. In terms of its interfaces, the MVB (multifunctional vehicle bus) is identical to the one it replaces. Functional adaptations are minimal (one of the few changes is support for the previously described disconnection of individual traction motors).

Internally however, the PEC offers powerful computational abilities. These are used to offer advanced control functionality for the dynamic behavior of traction motors and energy usage.



06 V_{in} : testing voltage applied to the motor
 V_{WM} : voltage measured inside the motor across one winding
 V_{coil} : voltage measured across the first turn of one winding.

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This article was first published in eb – Elektrische Bahnen 114 (2016), Issue 8–9, pages 485–489.

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Further reading
Press release: “ABB wins \$70 million order to modernize locomotives for Swiss Railways SBB”, September 23, 2014.

H. Hepp, “A perfect fit – ABB’s powerful propulsion converters are energy efficient, reliable and very compact, making them suitable for all rail vehicle designs”. ABB Review 2/10 2010, 60–65.

Isber, J. and M. Curtis, “Standardizing the traction motor – ABB’s innovative modular induction traction motor sets new heights in adaptability”. ABB Review 2/10 2010, 66–69.

Moine, V., Hepp, H. and S. Maciocia, “Dedicated service – ABB offers a broad service palette for rail customers”. ABB Review 2/2010, 70–76.

Swiss Federal Railways (SBB) Action plan 2015 www.confederation-exemplary-in-energy.ch, retrieved January 2017

SBB annual report 2015

The control software was created using Matlab Simulink®, supporting an efficient and intuitive implementation while also facilitating any future functional adaptations of the locomotives.

Testing

Extensive tests and measurements were conducted in ABB’s labs in Turgi, Switzerland. These provided an accurate simulation of operating conditions and verified the design configuration while ensuring compatibility with existing components.

The complete substitution of the GTO converters using new IGBT-based traction converters is an efficient and economical way of extending the operating life of locomotives.

Because the existing traction motors had been developed to match the locomotives’ original GTO converters, the new IGBT converters had to be tested with these motors →5. The compatibility of the new output voltage with the existing motor insulation is critical. The three-point topology generates a similar harmonic pattern to the original converters and is therefore unproblematic. Evaluations were conducted in the ABB test laboratory

to ensure that overvoltage does not result from the steeper switching voltage slope of IGBTs →6. These tests were successful.

The first two converters were successfully fitted to a Re460 locomotive in SBB’s Yverdon-les-Bains workshop. This locomotive is presently being tested on SBB railway lines. These tests will continue for a year. In total 202 IGBT water-cooled converters, with an option of 38 more units will be supplied by ABB and fitted by SBB. The refit program will be concluded in 2022.

Ready for the future

The three-level AC train drive systems introduced more than 25 years ago continue to demonstrate energy efficiency and minimal maintenance costs. Like the Re460 itself, these systems reflect basic design eloquence and remain in good mechanical condition, permitting them to continue to operate for another 20 years. Nonetheless, if not addressed, technical difficulties associated with outdated converters, increased down time, higher maintenance costs and the challenges of securing spare parts threaten to negatively impact their operation. The complete substitution of the GTO converters using new IGBT-based traction converters is an efficient and economical way of extending the operating life of these locomotives. IGBT technology elevates the system to that of modern rolling stock with respect to energy efficiency, traction power regulation and ease of maintenance. ●

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