The compact converter

A new generation of compact low-voltage IGBT converters for traction applications

Peter Dähler, Gerold Knapp, Armando Nold

In Switzerland, one rarely needs to travel far to see a multiple-unit train supplied by the rolling stock manufacturer, Stadler Rail. Most prominent are the successful FLIRT and GTW type regional trains, whose high levels of performance and comfort are widely appreciated. What fewer people realize is that the power converters of these units are supplied by ABB. The compact low-voltage IGBT converter CC750® is an integral part of the success story.

Regardless of the power supply under which it is called to operate, this compact and versatile converter supplies the correct voltage and frequency to the traction motors as well as the on-board power supply for lighting, braking and other auxiliary systems. ABB's CC750® uses the latest generation of semiconductor modules and a high-performance programmable control platform.

Ingenuity on the move

The purpose of a converter is to adapt the power from the catenary (overhead cable) to the voltage and frequency desired for the operation of the motor at the desired speed and torque. ABB's CC750® is the converter that powers the traction motors of Stadler Rail's FLIRT[1] [1,2] and GTW[2] trains 1, which are used by Swiss Federal Railways (SBB) and many other operators. The CC750® also feeds the on-board power supply for lighting, braking, and HVAC systems. It uses the latest generation of low voltage IGBT[3] modules and is equipped with a programmable fast-control platform.

The CC750® was presented in a recent *ABB Review* article [3]. Whereas this report focussed mainly on the CC750®'s AC 800PEC control system, the present article will discuss the converter itself.

A Compact Converter CC750 AC system consists of an input transformer, two drive converters with integrated auxiliary power converters and battery charger and ABB's AC 800PEC [4] control system 2. The CC750® can be used with many common catenary configurations such as 15 kV / 16.7 Hz and 25 kV / 50 Hz and also combinations of different systems (for cross-border services). Configurations with either two or four converters per train exist, providing a total traction power of 1.3 MW or 2.6 MW at wheel. The converters can be placed within the vehicle or mounted on the roof or under the floor.

Advanced control technology allows the converters to be operated without a series resonant circuit in the DC link, resulting in a substantially lighter drive system. .

Each converter in its own cabinet

A key feature of the CC750® is the vibration-proof mounting of each converter in its own cabinet 3. The water-cooled converter is located in a closed cabinet with internal forced air circulation and an air-to-water heat exchanger.

The control hardware is mounted on a swivelling frame to facilitate easy access to the power part.

The DC link capacitors 4 are situated directly behind the IGBT modules, forming a low-inductance capacitor bank.

The connectors for water cooling as well as the interface to the vehicle control are located at the top of the converter.

Semiconductors in drive converters

The compact converters are rugged units incorporating modern IGBT technology. Each individual unit is built on a PowerPak 4 Power Electronics Building Block (PEBB). Both the grid and motor converters are furnished with integrated semiconductors and gate drivers. On the grid converter side, a parallel connection of two power modules is required to handle the maximum current. In contrast, one power module is provided per phase on the motor side.

> Regardless of the power supply under which it is called to operate, this compact and versatile converter supplies the correct voltage and frequency to the traction motors.

Both inverters are operated over the whole speed range with a single standard PWM (pulse-width modulation) pulse pattern using a carrier frequency of 2 kHz. The distortions of the sinusoidal phase currents on both the grid and motor side of the converter are very low 5.

In the event of fast transients, such as pantograph bouncing, a voltage-limiter restricts the DC-link voltage to 800 V.

No tuned Filter in DC link

In contrast to state-of-the-art single-phase converter designs, no tuned filter is installed in the DC-link.

Instead, to absorb power fluctuation from the single-phase grid, the DC-

1 Regional railways are gaining in attractivity and efficiency through the deployment of modern lightweight railcars:
a FLIRT[1] train of Swiss Federal Railways (SBB) and
b GTW® train of THURBO (Thurgau-Bodensee Bahn). Both use CC750® power converters from ABB

Ingenuity on the move

link capacitance has been enlarged significantly to maintain a voltage ripple even at full load. Due to the high energy density of the electrolytic capacitors in the DC-link, the cost and volume of the DC link components was reduced massively compared to a standard solution using a tuned filter.

Protection in case of semiconductor failure

A large DC-link capacitance 4 is advantageous for DC-link voltage stability. It does however, pose fresh challenges in terms of short-circuit protection. An autonomous desaturation switch-off, as is frequently-used today to intervene in the event of a semiconductor failure, is insufficient in preventing a total short-circuit of the DC-link when additional energy from the connected phase (eg, grid or motor) is flowing into the faulty semiconductor. A heavy IGBT fault, shorting the entire DC link, will lead to the failure of the second switch of the affected half-bridge through excessive arcing and voltage transients. Consequently, further measures are required to prevent extensive mechanical damage to the IGBT and surrounding equipment in such a situation:

> The 50 kVA three-phase supply is fully overload and short-circuit proof and provides a low-distortion sinusoidal output voltage.

Desaturation detection switch-off is retained as a first attempt to clear an IGBT failure that shorts one switch of the half-bridge. This switch-off is only successful if the short-circuit energy of the connected phase is small, eg, an auxiliary converter IGBT failure, or a motor converter IGBT failure if the motor is operating at low speed and torque.

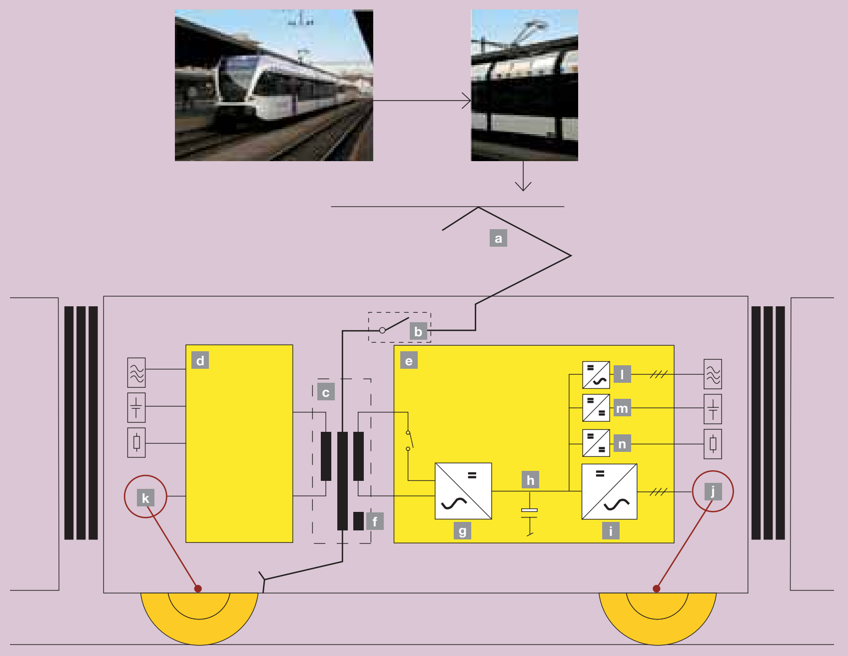
Rather than wait for the breaker to open, a short-circuit detection unit detects the fault within microseconds and signals this to the control system, which then takes remedial action. This can reduce the mechanical damage to the system from a heavy explosion to local damage in the causal semiconductor switch – without rupturing the semiconductor casing.

Following a heavy IGBT failure, the faulty semiconductor, as well as the fuses and the thyristor of the DC link crowbar 6, must be replaced. But these protection components (fuses and thyristor) are low-cost components.

The benefits offered by this protection system include the elimination of impact on neighbouring parts (deposition of conductive remains on isola-

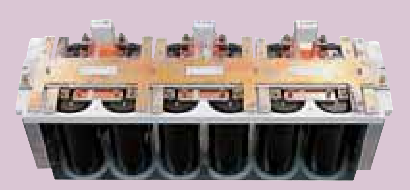
2 Traction converter arrangement on THURBO GTW with two CC750® units delivering a total of 1.3 MW of traction power

- a pantograph (15 kV, 16 2/3 Hz cantenary)
- b main circuit breaker
- c transformer
- d and e CC750® power converter units
- f auxiliary transformer winding for train heating supply
- g grid inverter (390V input)
- h DC-link (750V)
- i traction inverter (480 V / 0 – 170 Hz, 750 kVA traction power)
- j and k asynchronous traction motor
- l three-phase auxiliary supply (50 kVA / 3 × 400 Vac)
- m battery charger (12 kW / 36 Vdc)
- n brake chopper



3 The control hardware of the CC750® swivels aside to permit access to the power part

4 DC-link capacitor bank – the high-density capacitors contribute to operational stability, but the greater energy stored requires precautions



tion surfaces), which also simplifies the job of cleaning them afterwards. The repair time is further shortened by the good accessibility of the components to be replaced. Additionally, the reinforcement of walls and measures to channel plasma in case of such an incident can be reduced or eliminated, simplifying the construction without compromising on passenger safety. Finally, the noise impact of such a heavy semiconductor failure is significantly reduced.

Auxiliary supplies

The auxiliary supplies 2l–n are integrated into the main converter cubicle, making the CC750® converter a complete system for the entire traction and auxiliary power demand of the train vehicle.

These supplies are fed directly by the main traction DC link and use the same semiconductor family and protection layout as the main traction unit. The sharing of the large DC link with the main converters means short interruptions of the feeding catenary do not affect the operation of the auxiliary supplies.

The 50 kVA three-phase supply 2l is fully overload and short-circuit proof and provides a low-distortion sinusoidal output voltage. The 12 kW battery charger unit 2m feeds the 200 Ah vehicle battery and can easily be adapted to different battery charge algorithms. It also feeds the 36 V vehicle line, which supplies the vehicle control, door drives, lighting etc.

Field experience

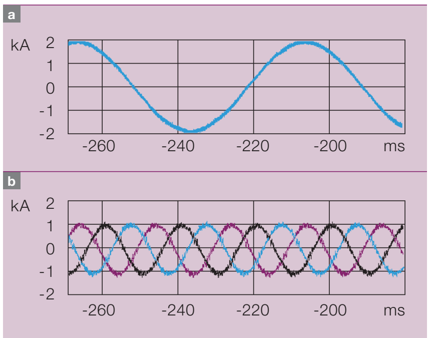
Due to the very stable control structure and the large DC link capacitance, the system has proved very reliable, even in the event of pantograph bouncing or poor track conditions. The protection system of the converter has proved to be an effective measure in avoiding mechanical damage in the converter cubicle in the event of semiconductor failures. Nevertheless, improvement of the reliability of semiconductors in general is an ongoing task to ensure that modern converter systems meet the high reliability and availability standards expected by customers.

Due to the high switching frequency of IGBTs, a simple PWM modulation strategy can be applied.

Utilizing the latest generation of low-voltage IGBT modules, a compact and low-cost design of the entire converter system for use in local transit vehicles is achieved. Due to the high switching frequency of IGBTs, a simple PWM modulation strategy can be applied with no need for complex transitions between different modulation strategies. The control system is set up with a new in-house platform using FPGA technology and MATLAB®/Simulink® based programming environment. Thanks to these advanced tools [3], high-quality software can be provided and modifications can be easily implemented, even during operation.

Peter Dähler
Gerold Knapp
Armando Nold
ABB Switzerland Ltd
Turgi, Switzerland
peter.daehler@ch.abb.com
gerold.knapp@ch.abb.com
armando.nold@ch.abb.com

5 The 2kHz PWM (pulse width modulation) minimizes current distortion of grid a and motor b currents (measurement at 50 km/h vehicle speed and 80 percent motor torque)



6 A short-circuit in the DC-link can cause considerable damage. Protection assembly with IGBTs, busbar, fast short-circuit detection and DC crowbar

References

[1] Peter Bruderer Stadler Rail Bussnang, Description of FLIRT train, Railvolution 4/2004 pages 58–72
[2] Steffen Obst, Ruedi Beutler, Der FLIRT – das Resultat hoher Kundenanforderungen, Eisenbahntechnische Rundschau, 12/2005 pages 767–771
[3] Armin Eichmann, Andreas Vollmer, Fast control in a traction application (Roll and Control – The AC 800PEC control platform in a broad range of applications), ABB Review 2/2006 pages 26–28
[4] Ernst Johansen, Design patterns – Co-design patterns for advanced control with AC 800PEC, ABB Review 2/2006 pages 62–65

Footnotes

1) FLIRT: "Flinker Leichter Innovativer Regional Triebzug" or "Fast, Lightweight Innovative Regional Train"
2) GTW: "Gelenktriebwagen" or articulated railcar
3) IGBT: "Insulated Gate Bipolar Transistor"