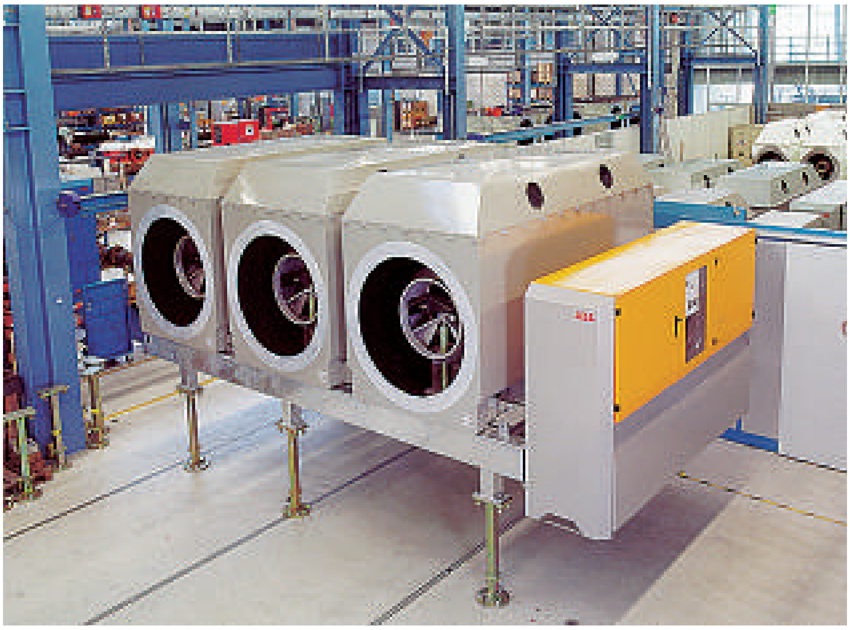
SF_6 generator circuit-breaker system for short-circuit currents up to 200 kA

Lukas Zehnder, Jochen Kiefer, Dieter Braun, Thomas Schoenemann



Generator circuit-breakers are the 'big boys' of the breaker world; they have to be.

A fault of up to 200 kA somewhere in the field is bad enough, but close to a generator it can lead to an event of literally seismic proportions – the fault current can be of such a magnitude that the induced magnetic forces cause solid steel shafts to bend and crash.

ABB HEC 7/8 SF_6 breakers are designed for this demanding task. They can handle anything even the world's biggest power stations can throw at them.

But just how do you break such a huge current so close to the generator? And how can the breaker effectively deal with the arc that is produced?

The past twenty years have seen rapid change in the generator circuit-breaker field, from the first breaker to use SF_6 gas as an arc-extinguishing medium in the 1980s to the newest breakers, described in this article, rated at 24,000 A (naturally cooled) and 38,000 A (with forced air cooling) and able to handle short-circuit breaking currents of up to 200 kA.

Thanks to these developments, modern special-purpose generator circuit-breakers using SF_6 gas as arc-extinguishing medium are now available for generating units with ratings up to 1500 MW.

Master of all trades

A modern breaker has to perform many tasks:

- Synchronize the generator with the main system
- Separate the generator from the main system
- Interrupt load currents (up to the full load current of the generator)
- Interrupt system-fed and generator-fed short-circuit currents
- Interrupt currents under out-of-phase conditions (up to 180°)

A generator circuit-breaker's performance must be far better than that of an MV breaker; the positioning of the generator circuit-breaker system between the generator and the main transformer, where its performance directly influences the plant output, places very high demands on its reliability.

Also, modern generator switchgear consists of much more than just an interrupter unit: All the associated equipment can nowadays be integrated in the generator circuit-breaker enclosure, for example a series disconnector, grounding switches, a short-circuiting switch, current transformers, single-pole-insulated voltage transformers, protective capacitors and surge arresters. Depending on the type of power plant, additional items such as starting switches (for gas turbine and hydropower plants) and braking switches (for hydropower plants) can also be integrated 1.

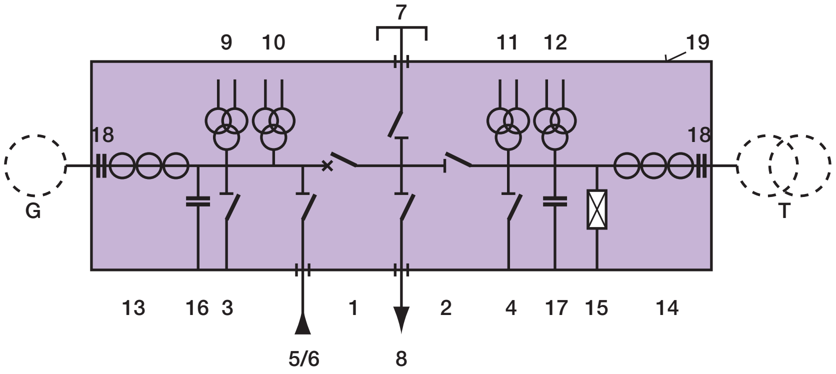
High availability and low cost

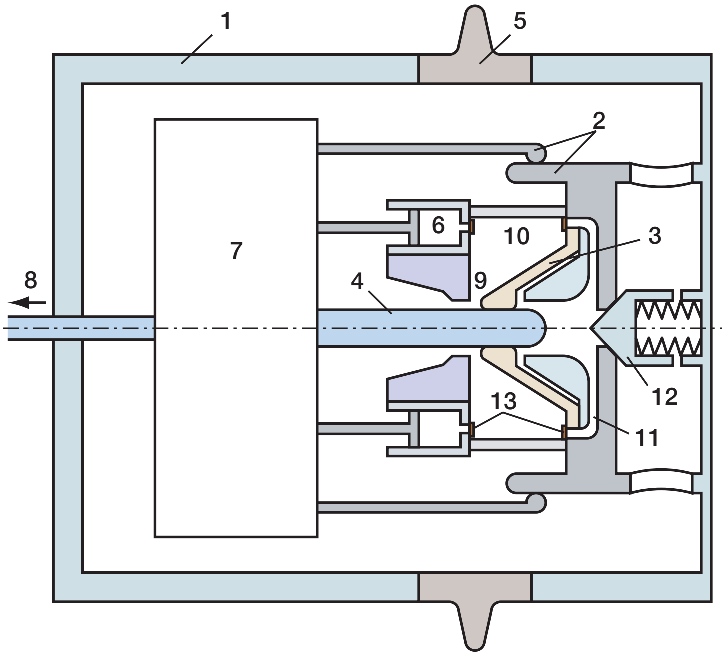
Not surprisingly, all power plant operators give a top priority to having the highest possible plant availability at the lowest possible cost. Modern SF_6 generator circuit-breaker systems help achieve this:

- The differential protection zones of the generator, the main transformer and the unit transformer can be arranged to achieve maximum selectivity.
- Generator-fed short-circuit currents are interrupted within a maximum of four cycles, as opposed to several seconds using rapid de-excitation equipment.
- The overall availability of the power plant auxiliary equipment is increased.
- Synchronizing at the generator voltage level with the help of a generator circuit-breaker is considerably more reliable than synchronizing with a high-voltage circuit-breaker [1].
- Rapid changeover to the auxiliary supplies during unit start-up and shut-down, with the associated high inrush currents and resulting stresses, is eliminated, thus avoiding possible damage to the drive motors of pumps, fans, etc.
- Use of generator circuit-breakers allows plant auxiliary supplies to be drawn directly from the HV transmission system at all times, ie also during the critical start-up and shut-down phases. This is considerably more reliable than other sources.

1 General layout of ABB's generator switchgear

1	*Circuit-breaker*	8	*Starting switch ('back-to-back')*
2	*Disconnector*	9–12	*Voltage transformers*
3, 4	*Earthing switches*	13, 14	*Current transformers*
5/6	*Starting switch (SFC or 'back-to-back')*	15	*Surge arrester*
7	*Short-circuiting switch/braking switch*	16, 17	*Surge capacitors*
		18	*Terminals*
		19	*Enclosure*





2 Cross-section through the arcing chamber, with the contact closed

1	*Housing*
2	*Main contact system*
3	*Arcing contact system (segmented part)*
4	*Arcing contact system (pin)*
5	*Insulator*
6	*Piston(s)*
7	*Gearing*
8	*Drive*
9	*Heating gap*
10	*Heating volume*
11	*Gas-return channels*
12	*Overpressure valve*
13	*Non-return valves*

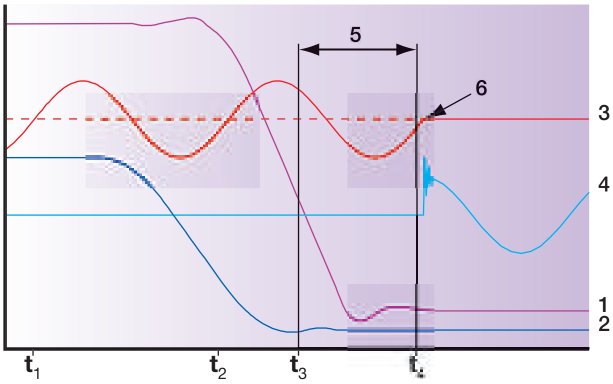
■ Rapid interruption of generator-fed short-circuit currents reduces consequential fault damage and shortens repair times.

The higher plant availability and increased profit for the operator make a modern generator circuit-breaker an excellent investment, with a generally very short payback time.

3 Contact movements and current versus time curve

1	*Movement of arcing contact*
2	*Movement of main contact*
3	*Current curve*
4	*Voltage across breaker*
5	*Pressure build-up phase*
6	*Arc extinguished at zero current*

t_1	*Drive tripped*
t_2	*Main contact system separates*
t_3	*Arcing contact system separates*
t_4	*Arc extinguished at zero current*



The circuit-breaker

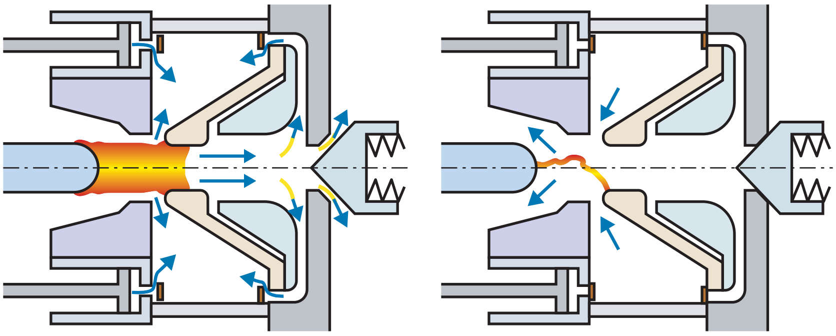
Besides conducting and interrupting operating currents, the circuit-breaker – a chamber filled with SF_6 gas under pressure – has the job of interrupting AC fault currents, eg short-circuit currents five or ten times the value of the rated current, within about 50 milliseconds.

The pressure chamber in which the current interruption takes place consists basically of two metal housings, which also act as electrical conductors, and the insulator.

Both contact systems – the main contact system and the arcing contact system – as well as the associated concentrically mounted blast pistons are coupled to internal gearing which is connected to a high-speed drive situated outside this chamber.

The gearing is designed such that, during breaking, the main contact system parts a few milliseconds before

4 Cross-section through the arcing chamber showing the hot gas flow paths (arrows) during the pressure build-up phase (left) and the current's passage through zero (right)



the arcing contact system, ensuring that the full current is broken by the latter. The arc created when the arcing contact system separates is extinguished the instant the alternating current next passes through zero 3.

During making, the procedure is reversed; the rising voltage leads to an arc in the closing arcing contact system just before contact is made; the main contact system then closes to carry the full current.

Arc extinction principle

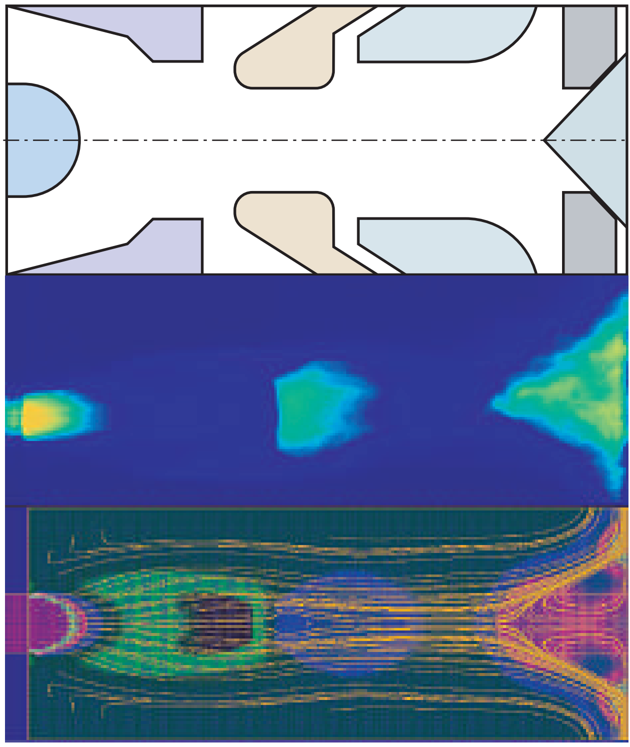
Like its smaller brothers (*see Table on page 38*) the HEC 7/8 utilizes the self-blast principle to extinguish the arc, ie the energy required by the gas stream for arc extinction is derived from the arc itself.

The energy released by the arc's creation leads to a very rapid and large local pressure and temperature rise. The convective and radiative heat from the arc causes a sudden rise in pressure in the 'heating volume' between the arcing contact system and the piston 4. It is from here that hot gas is blasted to extinguish the arc the next time the alternating current passes through zero.

A further contribution to the pressure rise is provided by the magnetic field pinch effect in the arc's interior, being manifested as a force acting in the direction of the center of the arc path. This current-generated magnetic force, in turn, causes a strong axial flow out of the arc, basically a plasmajet which shoots outwards and is partly diverted into the heating volume 5.

When *very* high currents are flowing during breaking, the pressure rise can be quite dramatic. Mechanical damage is avoided by relieving the pressure via a special overpressure valve. This valve was designed in conjunction with ABB Corporate Research as part of an experimental program to measure the pressure rise in the heating volume, in the flowback passages and in the plasmajet itself.

The relatively low arc energy at low currents is unable to create enough pressure for a significant self-blast effect. This is where the concentrically mounted blast pistons come in; by



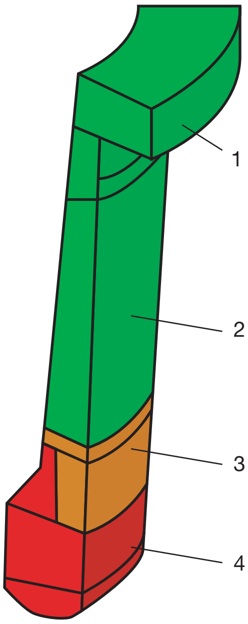
5 Geometry (top), photo (center) and flow simulation (bottom) of a plasma jet with shock zones. The plasma jet originates in the arcing zone (left-hand edge) and strikes the overpressure valve (right-hand edge).

supporting the pressure build-up in the heating volume it helps to ensure successful blasting, and extinction, of the arc.

Passage through zero

Shortly before the alternating current passes through zero, the arc cross-section, the pressure in the arc zone and local heating effects all significantly decrease.

If the contact separates just before the current passes through zero then the pressure build-up in the heating volume may be too weak to extinguish the arc. In this case, the breaker waits a half cycle until the next passage through zero, by which time sufficient pressure has built up.



6 **A finger of the segmented arcing contact system**

1 *Flange*
2 *Contact finger*
3 *Connecting part*
4 *Arc-resistant tip*

Touch and go

The arcing contact system is, quite literally, where the action is. With peak currents of up to 600 kA to handle, the design of this system has to fulfill a quite extraordinary set of criteria:

- A reserve of material sufficient to allow for ablation over the lifetime of the apparatus, bearing in mind the extreme plasma conditions that have to be endured.
- Lowest possible metal ablation rate to minimize contamination and consequent degradation of the insulating gas.
- Mechanical stability in the face of powerful switching and electrodynamic forces.
- Optimal contact force over the entire current range by careful balancing of antiparallel (repulsive) and parallel (attractive) current paths.
- Guarantee of low electrical resistance and high thermal conductivity.

The contact itself consists of a central rod grasped by segmented 'fingers'. 6 shows the construction of an individual finger. The material used for the base (1, 2) is a springy copper alloy (CuCrZr), while for the arc-resistant tip (4) a wolfram-copper composite (5) is used.

Technical data of ABB's SF_6 generator circuit-breakers

Type	HGC 3	HEC 3/4	HEC 5/6	HEC 7/8
Rated maximum voltage	21 kV	25 kV	25 kV	30/25 kV
Rated frequency	50/60 Hz	50/60 Hz	50/60 Hz	50/60 Hz
Rated continuous current:				
■ *with natural cooling*	Up to 7700 A	Up to 13,000 A	Up to 13,000 A	Up to 24,000 A
■ *with forced-air cooling*	Not applicable	Up to 24,000 A	Up to 24,000 A	Up to 38,000 A
Rated short-circuit breaking current	63 kA	100 kA	120 kA	160/200 kA
Standard	IEEE C37.013	IEEE C37.013	IEEE C37.013	IEEE C37.013

The bond between the base and the tip is also made of copper (3).

Thermal considerations

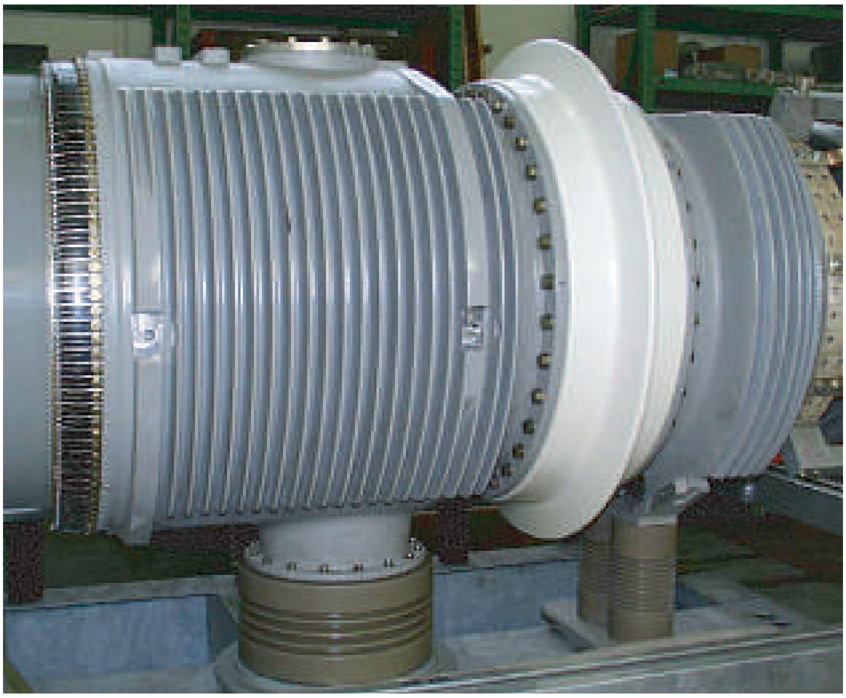
The thermal design of the breaker system is based on the assumption that a constant current flows at the rated values in a 40 °C environment. The maximum temperature allowed of any hot spots on the silver-plated contacts is 105 °C. Outer parts that can be touched may not exceed 70 °C (in some cases 80 °C).

The encapsulated design has the advantage that it includes both the inner conductor current and the outer return current flow path. As these are 180° out of phase, the external field strength, and thus external heat generation, is considerably reduced.

Two-dimensional finite element analysis of current distribution in certain components was used to reveal areas of high current and high loss as well as the degree to which the skin effect impedes current flow at different frequencies.

Physical verification was used in an iterative process to improve model accuracy, and led to an optimal conductor cross-section and an ideal thermal layout of the system.

Specially designed fins around the housing of the interrupter 7 increase its surface area to maximize heat dissipation. Forced-air cooling, by improving the convective heat transfer, allows the 24-kA nominal current with natural cooling to be raised to 38 kA.



7 Interrupter housing

Insulation material

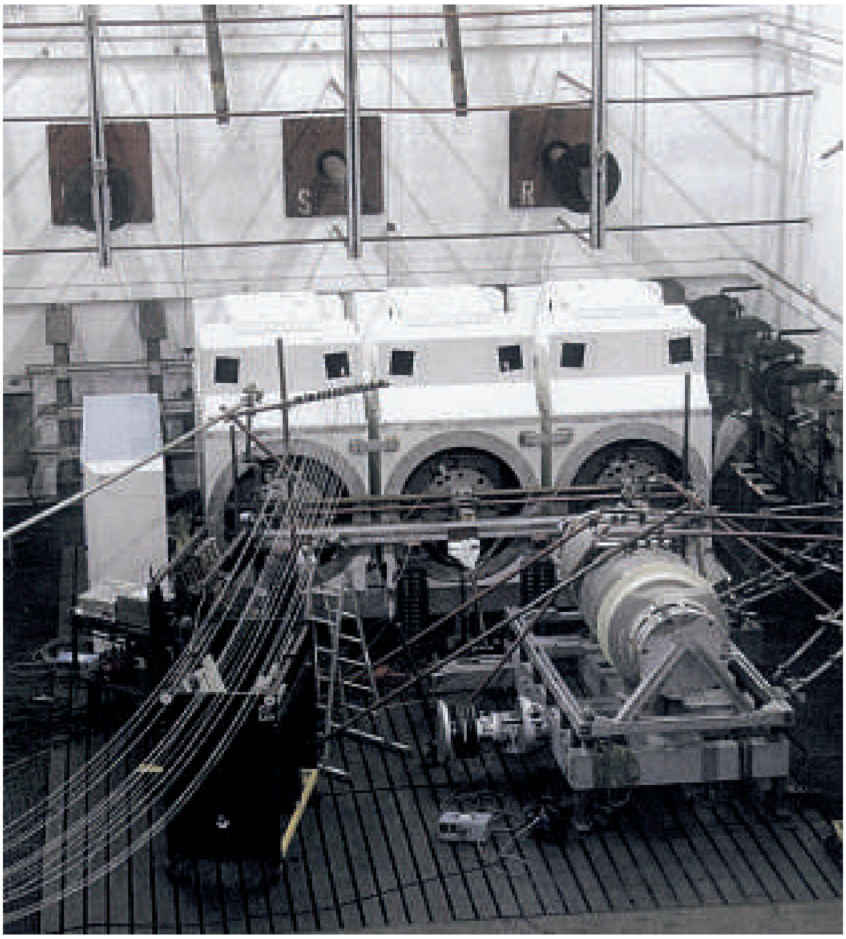
A cooperative venture between ABB Corporate Research and a Swiss company, Vantico, succeeded in developing an epoxy resin capable of withstanding 105 °C for 30 years [2]. With a diameter of 1 meter, the physical dimensions of this insulator are noteworthy 7.

Testing

Producing a breaker to handle hundreds of kiloamperes is one thing, but how do you test it? Fortunately, ABB has its own laboratories in Switzerland where short-circuit test currents of up to 450 kA can be generated. As the HEC 7/8 is specified up to a peak value of 600 kA, further tests were carried out in the KEMA high-power test laboratory 8 in Arnhem, The Netherlands. The facilities here offer the highest test powers anywhere in the world.

The scale of the tests at KEMA can be appreciated by the fact that they involved an eight-strong ABB team going to Arnhem for over three months, taking with them no less than five lorry loads of equipment.

These tests were for 160 kA and 30 kV and were completed in May 2000. Interest in higher current ratings led to an intensive analysis and simulation, culminating in autumn 2001 with a further test series at KEMA, this time at 190 kA for 27.5 kV and 200 kA for 25 kV. These ratings just about match those of the DR air-pressure generator breaker that has until now dominated



8 Type testing in the KEMA high-power test lab

this application area, and which is no longer produced.

Based on these tests, the HEC can quite justifiably claim to be not only the world's largest SF_6 breaker, but also the best and most thoroughly tested.

Reliability

Reliability obviously rates a top priority at the high end of the generator market. To take account of this, a failure analysis methodology refined in the 1960s for aerospace projects was employed to define measures that would ensure the highest reliability standards possible. ABB subsequently implemented these measures in its breaker production facilities.

World's finest

The design of breakers for the world's biggest generators needs to be world-class. Successful cooperation between many different research and development units, including external partners, fostered the key breakthoughs and innovative climate essential to ensure this.

The HEC 7/8 meets, and exceeds, the performance expected by this high-end market, and in so doing has proved itself to be not just the world's biggest SF_6 breaker and the most rigorously tested, but also the best. At the same time, it sets new economic standards – standards that will guarantee its competitiveness in the marketplace.

Authors

Dr. Lukas Zehnder
Dr. Jochen Kiefer
Dieter Braun
Dr. Thomas Schoenemann
ABB Switzerland Ltd.
High Current Systems PTHG
CH-8050 Zurich
Switzerland
thomas.schoenemann@ch.abb.com

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