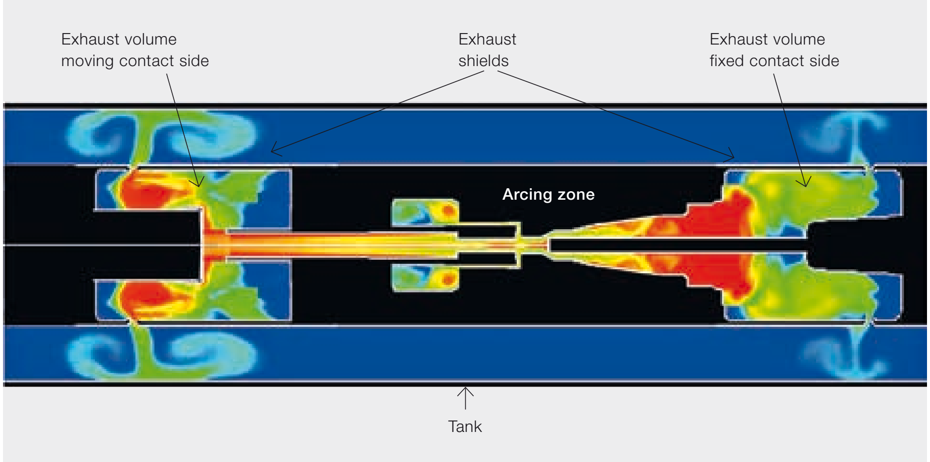
Breaking new ground

A circuit breaker with the capacity to switch 15 large power plants

HELMUT HEIERMEIER, RETO KARRER – The power networks that span the landscape and bring electrical energy to cities and towns are constantly evolving. In particular, operating voltages are being increased, mostly to minimize transportation losses. This places higher demands on the critical elements that control and protect these networks – the circuit breakers. At the heart of the circuit breaker lies the interrupter – the chamber where the switching physically takes place. The changing technical and market conditions, as well as new international standards, have brought about the need to develop a new generation of interrupter.

1 Example of a computational fluid dynamics simulation of a metal-enclosed circuit breaker



The networks that keep crucial electrical power flowing to society are being run at ever-higher voltages to minimize transportation losses and reduce environmental impact. This higher voltage, and other demands, means that a key element for the protection and control of power networks, the circuit breaker, also has to evolve. Of critical importance is the availability of the circuit breaker, as this directly impacts the reliability of the electrical network itself.

Reduced breaker component count and low operating energy lead to lower risk of unexpected outages. Additionally, if the size of the breaker can be reduced, cost and space requirements will also fall.

With this in mind, ABB began development of a new, single-chamber breaker for 420 kV networks. This new interrupter should fulfill the latest IEC and ANSI/IEEE international standards as well as known special requirements from different markets worldwide. Since both the nominal and the short-circuit currents that are to be handled are expected to increase in the future, a rated nominal current of 5 kA and a rated short-circuit current of 63 kA based on 50 Hz and 60 Hz were targeted.

Additional requirements were:
- Small bay size (it should be possible to put a complete bay into a standard container)
- Full-short line fault switching capability without needing a line-to-ground capacitor
- Reduction in SF_6 gas volume
- Lowest possible reaction forces (impact on buildings and foundations)
- Small, standard drive
- Two-cycle interrupt time

Circuit breakers

A circuit breaker is a remarkable piece of equipment. It has to cope with a range of currents from 1 A up to several tens of kA; it has to withstand a large range of voltage scenarios, eg, very fast voltage rises and long-term AC stresses; it must perform mundane daily switching operations as well as emergency interruption of short-circuit currents; it may be inactive for a long period but must then be capable of emergency interruption of faults within a few milliseconds.

> Reduced breaker component count and low operating energy lead to the lowest risk of unexpected outages. Additionally, smaller breakers reduce cost and real-estate requirements.

Designing a new breaker

Many very different factors need to be considered when designing a new switching device and deciding on a new technology.

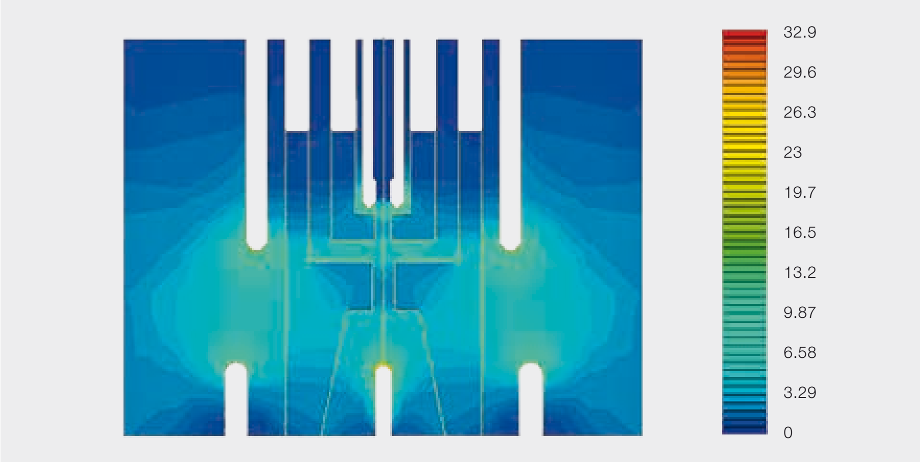
Capacitive switching capability

This duty is characterized by relatively small currents but high voltages across circuit breaker contacts, so a high dynamic voltage withstand capability is required. The voltage withstand capability needs to be greater than the rising network voltage during the opening operation of the circuit breaker. This is best characterized as a race between the opening contacts and the transient voltage buildup. It is vital that the breaker wins this race since no voltage breakdowns can occur as these can lead to a voltage escalation that stresses substation components and overhead lines. In other words, this new breaker has to have a high contact speed so that a high dielectric withstand capability is reached in a very short time.

Title picture
Power lines at ever-higher voltages are driving new developments in high-voltage technology. How do the latest circuit breakers deal with the new challenges?

A single-chamber breaker for 420 kV networks with 5 kA rated nominal current, a rated short-circuit current of 63 kA at 60 Hz and no line-to-ground capacitor requirement was targeted.

2 Example of an electric field simulation of the arcing zone



In international standards, this aspect is covered by a very detailed test procedure and an extensive test program.

Full-short line fault interrupting capability

This requires a high gas pressure in the volume between the breaker contacts in order to provide enough cooling power to quench the arc so interruption will be successful. This pressure buildup is one key value for fast fault-clearing capability. A single-chamber interrupter designed for high short-circuit interrupting capability requires a high clearing pressure.

New materials and production techniques were evaluated to help identify a product with costs comparable to conventional offerings.

Terminal fault interrupting capability

Since one of the requirements is to stay within a two-cycle interrupting time, a short opening time is required, which leads to higher asymmetrical requirements than for earlier breakers. Interrupting at high asymmetry levels leads to high-pressure buildups that must be handled by the drive as well as the exhaust and nozzle system. For this new breaker, this means that high energy inputs into the arcing zone as well as the exhaust system need to be safely handled.

Transformer-limited fault requirements

This special requirement, which has to be met at some locations, comes up when a fraction (7 to 30 percent) of the rated short-circuit current is present together with a very high rate of rise of the recovery voltage (the voltage that appears across the terminals after current interruption.) In order to withstand such severe stress, it is necessary to build up a high dynamic voltage withstand capability very quickly after current interruption. This means the hot gas between the arcing contacts needs to be replaced by cold gas as swiftly as possible.

Deciding on a switching technology

Circuit breakers currently come in several varieties, all of which have their own merits:

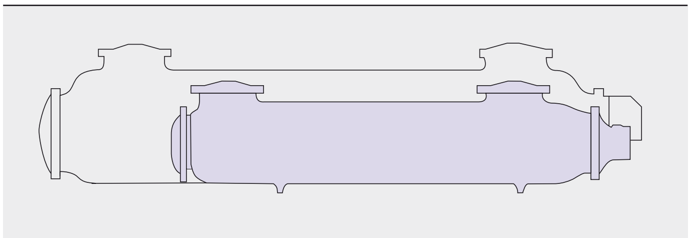
- Puffer breakers
- Advanced puffer breakers
- Puffer-assisted self-blast breakers
- Pure self-blast breakers
- Self-blast breakers with linear double moving system
- Self-blast breakers with nonlinear double moving system

The virtues of several of these concepts were combined when developing the new breaker, which has been designated as an advanced puffer breaker with a nonlinear double moving system. Such an approach has advantages:

- High and adjustable contact speed.
- Low moving masses, leading to low reaction forces.

3 Full laboratory evaluation of test designs were carried out.

4 The volume of the circuit breaker was significantly reduced.



5 First installation in Switzerland: old (right) versus new (left).

- Fast opening times (using a standard, low-energy hydraulic spring mechanism.)
- Low ratio between no-load pressure buildup and maximum pressure buildup (leading to low temperatures of the extinguishing gas during power interruption.)
- Low mechanical stress on moving parts due to reduced speed of certain parts.
- Even for higher asymmetry levels, maximum pressure buildup does not overstress the arcing unit parts

Reaction forces are lower than any other solution, so physical infrastructure will be less expensive.

mechanically since it is possible to limit the maximum pressure generated.

The development relied heavily on simulation software to mimic different physical effects, like flow, pressure buildup and electric fields, during current interruption → 1 – 2. Finite element method (FEM) tools assisted mechanical analysis. Test objects were equipped with various measurement sensors to obtain data with which to improve and crosscheck the simulation tools. Furthermore, tests have been carried out to determine the limits of the test device. In parallel to the development, new materials and advanced production techniques were evaluated to help identify a product with costs comparable to conventional offerings → 3.

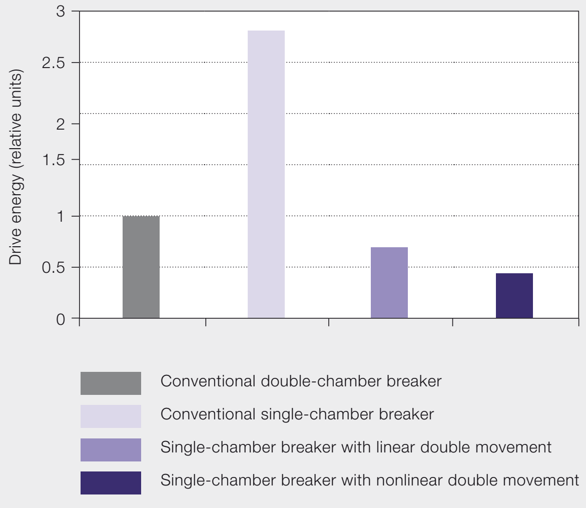
Project results

The development achieved or surpassed targets when compared with the previous breaker generation:

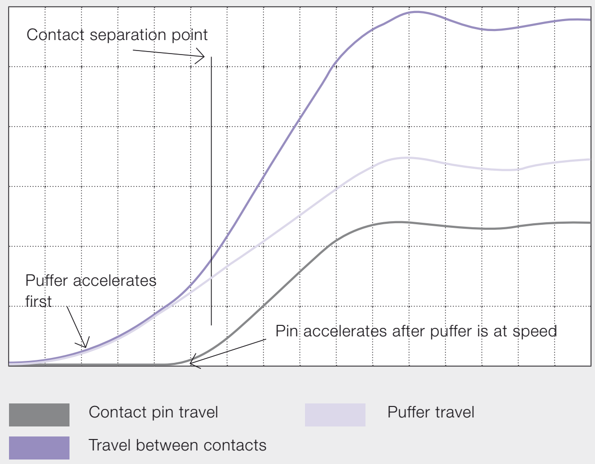
- 50 percent drive energy reduction.
- 30 percent SF_6 volume reduction → 4.
- 50 percent gas-insulated switchgear (GIS) bay size volume reduction (301 ELK 3-2, 147 ELK 3-1) → 5. Further bay size reduction will be achieved with adapted GIS parts. This improved bay will fit into a standard container for transportation as well as

50 percent drive energy reduction, 50 percent bay size volume and 30 percent SF_6 volume reduction were achieved.

6 A comparison of the drive energy needed (relative units)



7 The switching scheme (axes in relative units). The switching characteristics are in line with newest IEC and IEEE standards.



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for emergency use as a container switchyard (as shown at the 2012 Hanover Fair.)

A conventional two-chamber solution uses twice the drive energy of the new nonlinear double movement system (a single chamber, with one side driven, nearly five times) ➔ 6. The moving mass per chamber is about the same (single or double chamber) though there is a slight increase of moving mass for the double movement system (pin and levers).

The reaction forces are lower than any other solution, so physical infrastructure will be less expensive. In addition, the acceleration of the moving mass can be staggered and the pin movement can be reduced, further reducing energy requirements ➔ 7.

The new breaker, which can be used in dead tank breaker and Plug and Switch System (PASS) applications as well as GIS, met all the major targets that were set. This new product is a modern, competitive breaker that fulfills the newest international standards. In terms of sheer capability, it is interesting to note that the short-circuit power that a single chamber is able to switch is nearly 23 GW, corresponding to the nominal power of approximately 15 nuclear power stations.

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