

Performing at a higher level

Advanced heat pipe cooling increases circuit breaker performance by over 25 percent

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A generator circuit breaker (GCB) is a core component of a power plant, protecting both the generator and the power transformer. ABB's current breaker portfolio includes breakers with rated nominal currents ranging from 6300 A to over 50,000 A. HECS breakers are designed for nominal currents up to 18,000 A. However, a side effect of these large currents is heat dissipation in the device, which must be limited if other system components are to remain within their rated temperature tolerances. Natural cooling limits the rated nominal current and therefore many of today's GCBs employ forced cooling methods to increase nominal current levels. However, these "forced" coolers also limit nominal current capability.

To increase GCB nominal currents, an innovative cooling method was required to meet the ever-increasing demand for lighter, cheaper and more powerful devices. Using so-called heat pipes to achieve efficient heat transfer, not only have they developed two products that are lighter and more robust than previous versions, but GCB performance has increased by over 25 percent!

Powering the economy

Power devices are following the trend of most other electrical products by becoming smaller and lighter while at the same time incorporating greater functionality. Cost efficiency is for the most part the main driving force behind this because a lighter device results in lower material, transportation and installation costs. One part of ABB's Generator Circuit Breaker (GCB) family **Factbox 1**, the HECS breaker, has gone through this process with impressive results: by replacing a so-called "forced" cooling system (ie, one that needs pumps, fans or motors to operate) with a "passive" cooling apparatus (one that operates without the need for pumps, fans or motors), nominal HECS breaker current has been increased from today's 18,000 A to 23,000 A! Using an innovative approach based on a heat pipe cooling concept, ABB engineers have transformed members of this family of devices into silent, slimmer and lighter versions of their former selves with extremely low-maintenance requirements **Factbox 2**.

Efficient heat transfer in ABB's HECS circuit breakers demanded a purely passive and low-maintenance device if nominal current values were to be increased.

Knowing what to do

Nominal and short-circuit currents generate a tremendous amount of heat. Even tiny electrical resistances (resulting from the material or sliding electrical contacts) lead to ohmic losses, which can generate many kilowatts of heat. However, the steady-state temperature at the hot spot has to be limited to 105 °C¹⁾ during normal (closed) operation, thereby thermally limiting the maximum allowable nominal current. Hence, the operating temperature of the generator circuit breaker is determined by both the nominal current and the cooling of the device. To successfully increase the rated nominal current of its GCBs, engineers had to focus on the thermal management of the GCB.

Factbox 1 ABB's Generator Circuit Breaker (GCB) portfolio

ABB's GCBs are widely used in all kinds of power stations, such as gas turbine, combined cycle and thermal power plants, as well as geothermal, hydro and pumped storage power stations. Currently the company has a market share of some 70 percent. The breaker portfolio covers devices with electrical power ratings from 100 MVA to over 1500 MVA. Included are breakers with rated nominal currents ranging from 6300 A (and a maximum short-circuit current of 63 kA) to over 50,000 A (with a short circuit current rating of 210 kA). Introduced in 2003 and available for both indoor and outdoor application, HECS-type breakers are rated for the power range up to 800 MVA. They can switch short-circuit currents up to 130 kA and are suited for nominal currents of up to 13,000 A using naturally cooled



systems and 18,000 A with forced cooled systems.

The power density is very high considering their small size and weight – typically 6000 kg. They are therefore ideal for retrofitting in existing power plants, and allow substantial savings in transportation and installation costs.

Factbox 2 Overview of the new products resulting from heat pipe implementation

New product name	Maximum operating current	
	Today's HECS-based product	New product with heat pipe (passive cooling)
HECS-100/130XLp	18,000 A (with forced cooling)	18,000 A
HECPS-5Sp (pump storage solution)	13,500 A	18,000 A
HECS-130XXLp	Not available	23,000 A

Within ABB's HECS breaker family, nominal currents of up to 13,000 A are possible using natural cooling methods. However, a forced air-to-air cooling device – itself a heat generator as well as a source of extra weight – is required to increase this value to a maximum of 18,000 A. Increasing the nominal current of a given breaker to 23,000 A can therefore be achieved only by improving the heat transfer from the HECS conductor to the environment while at the same time ensuring that the temperature of sensitive components stays within a tolerable range. This challenge was made even more taxing given that the heat source (the conductor) is on a high electrical potential of 25.3 kV while the heat sink (the HECS enclosure) is ground-

ed, and any form of forced cooling has undesirable side effects. If efficient heat transfer across this large electrically isolated gap was to be achieved, a purely passive and low-maintenance device was needed. And such a device was realized using heat pipes²⁾ **Factbox 3**.

Product development

Even though it has been around for several decades, the heat pipe con-

Footnote

¹⁾ The IEEE standard allows a temperature increase of 65 K for silver-coated contacts above an ambient temperature of 40 °C.

²⁾ The principle of the heat pipe has been around for several decades, and cooling systems in the consumer electronics industry use the idea.

1 A single pole of a heat pipe cooled HECS breaker. From the outside, only the condenser fins are visible on the upper section of the encapsulation



cept was never applied to GCB cooling because of the challenge of using electrically insulated heat pipes where a large potential difference exists between the heat source (the evaporator) and sink (the condenser). This in turn ruled out a design composed entirely of metallic components, requiring instead a solution that provides mechanical robustness and material compatibility between the heat pipe materials and the working fluid. Overall, the following requirements for a successful solution needed to be met:

Thermal management

The maximum total heat load to be transferred is determined by the current and the resistances in the circuit breaker. The number of heat pipe systems therefore determines the maximum allowable thermal resistance for the individual components.

Heat pipe dielectric design

This refers in particular to the dielectric insulation between the conductor and the enclosure for normal operating conditions (namely around 25 kV) and for other voltages the system needs to be protected against, for example those generated by lightning impulses. The solid insulators of the heat pipes as well as the working fluid must also comply with this requirement.

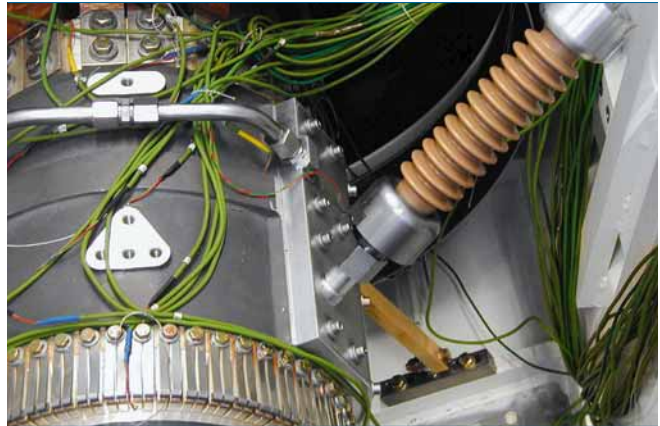
Heat pipe mechanical design

The system must be able to tolerate a high number of switching operations (20,000 cycles), transport and earthquakes.

Long term stability and environmental considerations

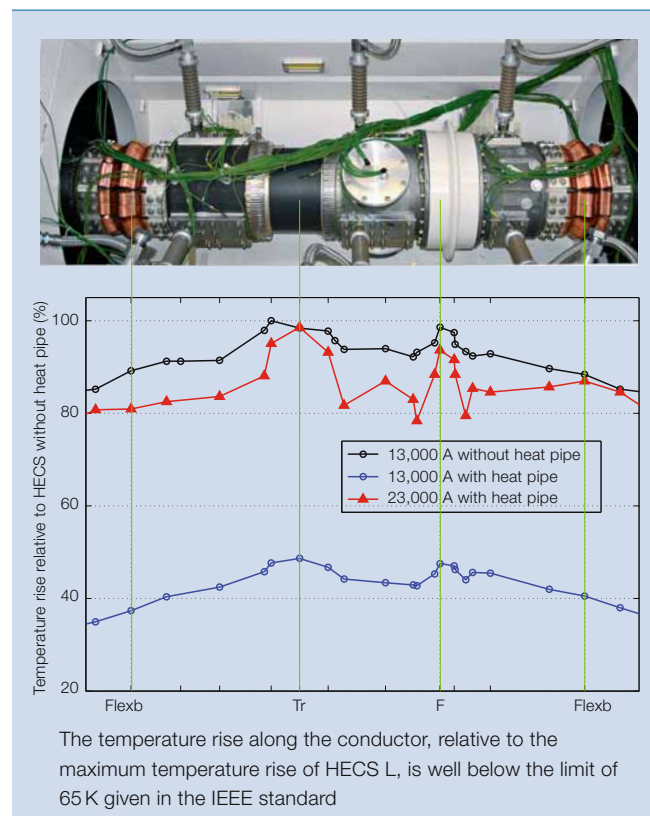
The system needs to be maintenance-free for over 20 years. In addition, the

2 Evaporator and isolating section attached to the connection chamber. The vapor flows through the waved insulating tube to the condenser (see **3**)



working fluid needs to be environmentally friendly for at least 20 years. Environmental protection requires low global warming and ozone-depletion potential. The LCA (Life Cycle Assessment), which compares the novel cooling device to the current forced air-to-air cooler, needs to show that the heat pipe solution is indeed more environmentally friendly.

3 Heat pipes attached to the HECS GCB. The transport sections are connected to the condensers that are incorporated into the enclosure



Using an innovative approach based on a heat pipe cooling concept, ABB's HECS breakers have been transformed into silent, slimmer and lighter versions of their former selves.

Technical realization

A standard GCB consists of three parallel phases. Each GCB conductor is housed in an individual enclosure which is insulated from the pole frame **1**. In the ABB design, each phase has six heat pipes, and the heat generated by a nominal current has to be transferred to the ambient through these heat pipes. To do this as uniformly as possible, the conductor area

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covered by the evaporator was maximized³⁾ 2. Homogeneous heat dissipation to the six evaporators is needed to ensure that no hot spots occur inside the conductor material due to the non-vanishing thermal resistance of the material itself. The isolating section actually proved quite challenging in that its dielectric stability had to be ensured, as well as its mechanical integrity against breaker operation, not to mention air and working fluid diffusion⁴⁾. Results taken during the testing phase are shown in 3. Not only has the nominal current been increased by 27.8 percent, from 18,000 A to 23,000 A, but the measured thermal resistance using the heat pipe solution was 58 mK/W. In other words, the temperature increase for a heat dissipation of 1000 W is only 58 K.

Looking to the future

ABB's portfolio is the widest available on the GCB market. Upgrading the existing HECS-XL breaker with the

passive heat pipe cooling system, as well as the creation of two new products, HECS-100/130XXLp and HECPS-5Sp, for standard and pump storage applications, will extend this portfolio even further Factbox 2.

ABB's new heat pipe solution needs no electricity to operate, requires little maintenance and has helped increase circuit breaker performance by over 25 percent!

The HECS-100/130XL breaker currently uses a forced cooling system. ABB's aim is to keep the market leadership with a substitute for HECS XL. This version would be feasible either with small attached evaporators and smaller number of full-size heat pipe systems. Of the proposed new products, the

HECS-100/130XXLp breaker product is aimed at the market segment between 18,000 A and 23,000 A. The maximum possible evaporator surface has been chosen for this version, guaranteeing a very low thermal resistance and a homogeneous temperature distribution along the disconnecter profile. Another important parameter in this design is the condenser surface area mainly because it influences the thermal resistance along the heat pipe system. Equipping the HECPS-5S breaker – a pump storage solution – with a heat pipe cooling system would extend its nominal current to 18,000 A.

ABB's new heat pipe solution needs no electricity to operate, requires little maintenance and is impressively silent. Its main benefit, however, is the extension of the HECS generator breaker nominal current to 23,000 A. Not only will this new passive cooling solution contribute to further complete the company's circuit breaker portfolio, but it will also allow for a very cost-efficient product for each kind of application. These products will make their market debut in 2008.

Factbox 3 Heat pipes as an alternative cooling concept

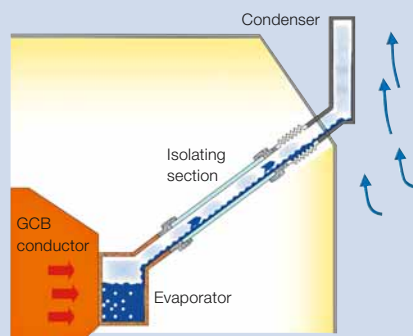
A heat pipe is a device that makes use of the effect that a liquid absorbs heat when it is evaporated (latent heat of vaporization) and that this heat can subsequently be released somewhere else during the condensation process.

The system is composed of three major components: an evaporator section which is attached to the GCB conductor (heat source); a transfer section; and a condenser section located in the cooler environment outside the enclosure.

It operates like a closed-loop system that is partly filled with a working fluid. Inside the evaporator, the heat flux causes the working liquid to boil.

A small pressure imbalance then carries the vapor to the condenser section where the heat is dissipated by natural convection cooling to the outside of the GCB enclosure.

Following the condensation process, the liquid returns to the evaporator via a gravity heat pipe. An outstanding characteristic of



this pipe is that it is driven only by the heat that is being transferred and by the gravity that returns the condensed liquid, making it a purely passive device.

Because the fluid boils and condenses at roughly the same temperature, the temperature gradient along the pipe is small, leading to efficient heat transfer and a heat flux value that may be several thousand times higher than that in good metallic thermal conductors.

The heat flux from the evaporator to the condenser is limited only by the vapor flow properties inside the transport section.

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Footnotes

³⁾ Doing this also reduces the thermal resistance of the evaporator.

⁴⁾ At the beginning of the project, it was thought that the insertion of an electrically insulating tube, carrying liquid and vapor, between the evaporator and the condenser would be straightforward. However, challenges arose because official type tests needed to be carried out for voltages up to 88 kV AC and 165 kV (lightning impulse voltage). Additionally, the tube has to be mechanically very strong (metal cannot be used), and finally the connection at both ends of the tube to the rest of the pipe must be very tight.