Integration breakthrough

Creating a flexible and compact DC breaker: the ABB SACE Emax DC

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Wiring is the Achilles heel of many an installation. It costs time and money to wire a new item into the setup, and more time and money to test and verify it. In addition, the assorted connected items all occupy space – a scarce asset in many plants – and each require a power supply. The answer lies in integration; combining as much functionality as possible into a single piece of off-the-shelf equipment. In the field of DC breakers, ABB has achieved a hitherto unseen level of integration.

With its ABB SACE Emax DC breaker, the company has succeeded in integrating a broad range of advanced monitoring, protection and control functions in an application that was previously reliant on external devices. The result is the most innovative and complete air-insulated DC circuit breaker range on the market – a breaker that can stand as a reference product for any kind of DC application.

In this article, ABB Review looks at some of the challenges that were faced in creating this project, and takes a more detailed and technical look at some of the technologies applied.

Examples of applications for DC current breakers include so called "critical power" applications, ie, situations in which the continuity of the power supply is of fundamental importance. Examples are hospitals, continuous process industries, emergency and safety plants, telecommunications and data-processing centers. These are applications in which an immediately available back-up energy source is essential. In this domain, battery packs represent a highly reliable and quickly deployable option.

Further examples of DC applications are electrical traction and drilling, chemical and electrolytic process industries and naval applications (speed control and battery or fuel cell propulsion).

Breakers in these applications must protect and disconnect both supplies and loads while assuring the integrity of the power supply. ABB SACE Emax DC, which is presented in this article, is not only perfectly suited to such applications, providing a complete and fully-integrated solution for high-level DC applications, but is also unique: No other product on the market offers such characteristics Factbox.

Applications

Present applications of DC breakers can be divided into two types, according to the source of the trigger signal for the interruption of the current:

- Automatic breakers triggered by an internal electromechanical mechanism
- Externally triggered switch-disconnectors

Automatic breakers with integrated electromechanical releases offer a solution for low-end applications working in self-supply mode. Such breakers provide only instantaneous short-circuit protection. No other standard or advanced protection, measurement, communication, automation, diagnostic or HMI functions are included.

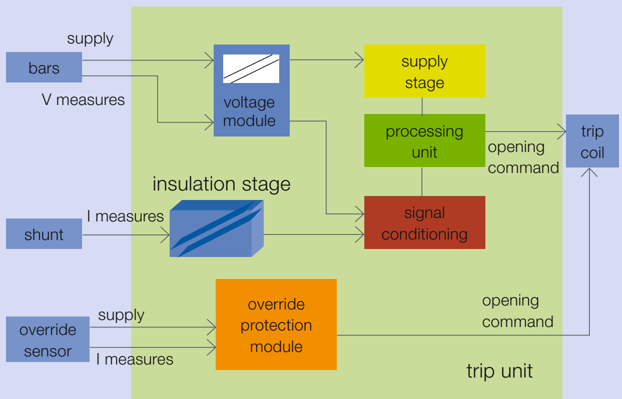
> Breakers in DC applications must protect and disconnect both supplies and loads while assuring the integrity of the power supply.

Switch-disconnectors used in combination with external electronic releases can offer a broad range of standard protection functions (mainly overload and selective/instantaneous short-circuit) but they cannot meet other very important requirements. As they are not an integrated solution, the customer must install the trip unit and current sensors in the switchboard. This means that the switchboard's dimensions cannot be as compact as they are in the case of an automatic breaker.

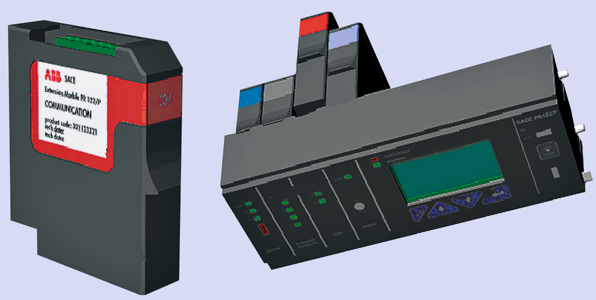
Furthermore, the need to connect, wire and test the external release system implies additional engineering and installation costs (such system testing and certification is the responsibility of the panel builder/system integrator). In addition to this, an auxiliary power supply must be provided for the trip unit and the actuator.

1 Control panel of the ABB SACE Emax DC circuit breaker

2 Product architecture of the circuit breaker



3 Trip unit



A further disadvantage of the externally triggered variant is that the maximum breaking capacity of such a breaker is defined by the short-time current-withstand value of the switch-disconnector. This figure is typically lower than the short-circuit breaking capacity of an automatic breaker, due to the lower reaction delay of the integrated unit.

The ABB SACE Emax DC 1 series offers an innovative solution that includes all the advantages of the integrated solution, while adding several interesting and important features.

This makes it a market reference product for any kind of DC application. This success was achieved through innovatively re-interpreting conventional products to provide new solutions.

Product architecture

Integrated AC breakers have been on the market for many years. The approaches adopted, however, could not directly be transferred to the DC version. A whole range of aspects had to be fundamentally redesigned.

Product innovations

The system architecture of the new DC breaker 2 comprises:

- A shunt for current measurement and protection
- An override sensor for instantaneous back-up protection
- An electronic trip unit
- An actuator to open the breaker (trip coil).

The trip unit uses the same architecture as the present Emax AC series. The hardware has been enhanced to meet the DC unit's higher insulation and lower signal processing requirements. The software has been modified to measure direct current (mean value instead of RMS) and to adapt the protection algorithms to the new measuring method.

The trip unit 3 itself is equipped with optional modules to add functionalities. Examples of these are:

- A communication module providing a galvanically insulated interface to a supervisor system.
- A signalling module equipped with contacts that can be used to drive external devices. It can also be configured as an input.

The electronic trip unit is powered from the breaker's main terminals via an integrated "voltage module," the integrated override sensor (override protection module) or an external insulated power supply (24 Vdc). The voltage module also provides the voltage measurements that the trip unit requires for further signal analysis, such as power measurements, and to perform overvoltage, undervoltage and reverse power protection functions.

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The integration of all these components makes this breaker one of the most significant electronic embedded systems in the field of Air Circuit Breaker (ACBs). Its capabilities border on those of the concept of a "mechatronic system."

Shunt

The shunt is the current sensor[1]. It provides a voltage signal proportional to the current. The output signal of this unit must range between 2.56 mV and 240 mV.

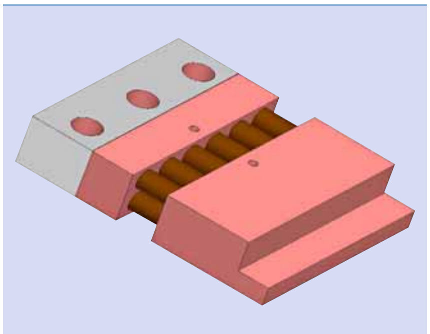
The challenge in designing the shunt 4 was to define a device compact enough to be installed inside the breaker. Furthermore, it should have a resistance high enough to drive the electronics of the TU (Trip Unit) but low enough to permit a power dissipation compatible with the breaker's plastic support – and this both at rated current and under short-circuit conditions (100 kA for 0.5 sec).

The minimum resistance that, at rated current, gives an output with a signal/noise ratio consistent with the specifications of the TU is 8 μΩ at 1600 A. To obtain the required functionality at rated current, the shunt temperature was kept as low as possible by increasing the thermal conductance Equation 1. For this purpose, a detailed thermal flux assessment was performed using FEM (Finite Element Method) analysis 5, permitting the resulting temperature rise on the plastic shunt support to be limited to the required value.

Equation 1 $$\theta_s = \frac{P_P}{G}$$

where:
Pp: power loss
G: thermal conductance
θ_s: steady temperature rise

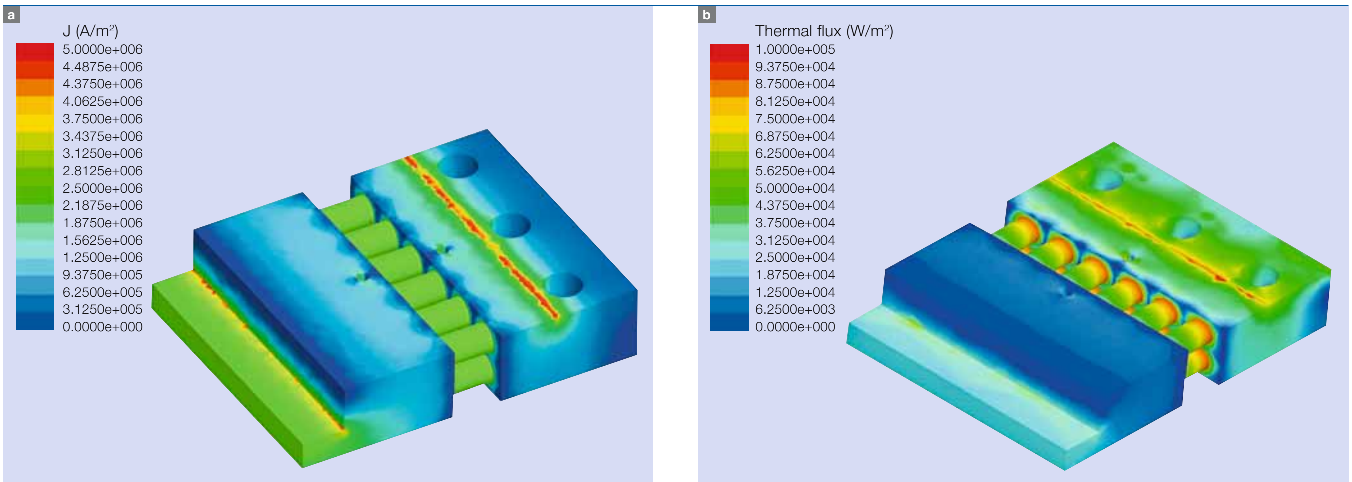
4 The shunt used by the circuit breaker to measure current



Footnote

[1] In AC breakers, a current transformer is normally used. The DC version requires a different approach.

5 Current density a and thermal flux b in the shunt at rated current



To permit the shunt to perform correctly under short-circuit conditions (100 kA for 0.5 sec), the only way to control the temperature is to increase the thermal capacity – because the phenomenon can be seen as adiabatic Equation 2.

Equation 2 $$\theta_{ad} = \frac{R \cdot I^2 t}{C}$$

where:
I^2t: let-through energy
θ_{ad}: adiabatic temperature rise
R: shunt resistance
C: thermal capacity

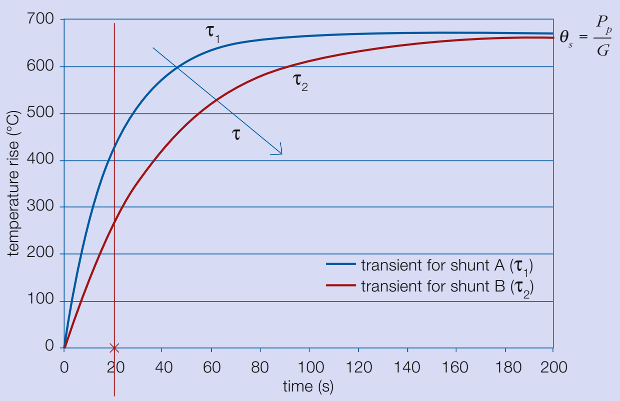
Equation 3 $$C = m \cdot c$$

where
m: mass
c: specific heat

To ensure functionality under overload conditions, the designers maximized the thermal time-constant of the shunts in order to increase their overload performance (ie, to reduce the temperature rise of the shunt during overloading). This was accomplished by optimizing the shape of the shunt-terminal assembly - that is, by increasing the mass without reducing the thermal conductivity Equations 4-5.

The thermal transients for two different solutions are shown in 6: For the same resistance, the red curve (higher time constant) coincides with a 30 percent lower temperature increase before the breaker is tripped after a 20-second overload.

6 Transient shunt temperature rise with different thermal time constants at an overload six times the rated current, $6 I_n$ ($\tau_2 > \tau_1$)



PR123 DC
temperature-rise at maximum time delay for different shunt design.

Equation 4 $$\tau = \frac{C}{G}$$

Equation 5 $$\theta(t) = \theta_s \cdot \left\{1-e^{-\frac{t}{\tau}}\right\}$$

where:
τ: thermal time constant
θ: temperature rise

Insulation

Because shunts are used, the electronic trip unit is not galvanically separated from the main live bars. A major challenge encountered concerned how to guarantee the adequate insulation level. According to the IEC 60947-1 product standard, a rated impulse withstand voltage of 14.4 kV is required without the electronic trip unit having to be withdrawn from the CB frame as a result. This is made more tricky by the fact that the electronic trip unit is connected directly to the power bars, without any type of insulation or segregation (as in the situation when current transformers are used as in the AC breaker): This problem was solved by introducing insulated operational amplifiers (one for each shunt sensor).

Signal conditioning

To guarantee the maximum measurement accuracy over a wide range of currents by exploiting the maximum dynamics of the AD converter, the signals coming from different shunt sensors are scaled using an analog circuit.

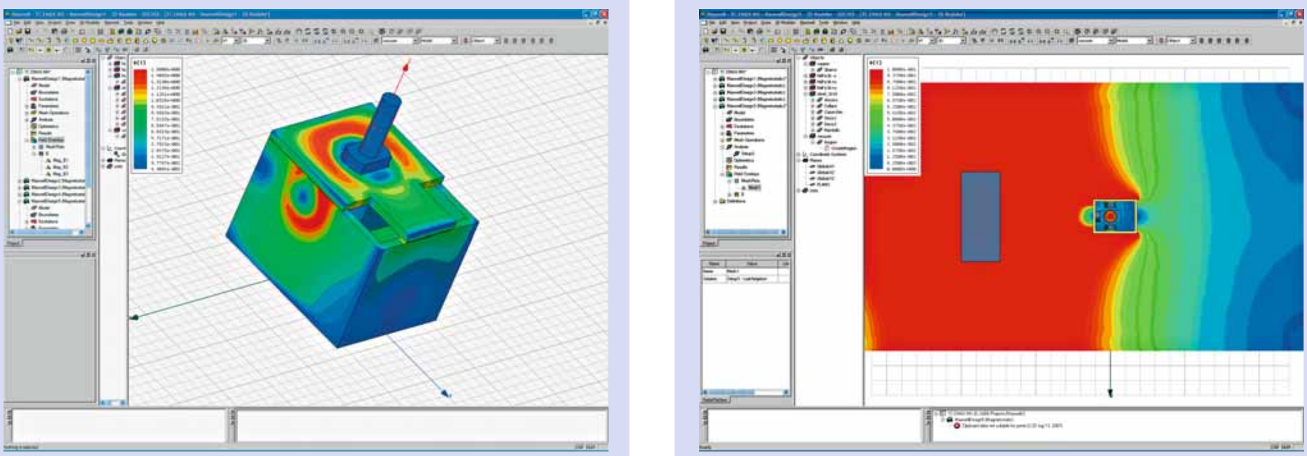
Voltage module

The voltage module provides the energy for supplying the trip unit and also supplies a voltage signal that is proportional to the primary voltage. This is used for its measurement (with high-impedance insulation).

Supply stage

The supply stage handles the supply coming from the two possible sources

7 Mesh calculation with FEM (Finite Element Method) and output simulations



Product innovations

(an insulated power supply from an optional external source or the bar voltage) and delivers the energy to each part of the electronic system at the required voltage levels.

Processing unit

The processing uses a parallel architecture with three processors: a low-power processor for handling start-up and very fast protection functions, a DSP (Digital Signal Processor) for all other functionalities, and another low-power processor containing information about the current breaker (CB) in which the electronic unit is installed. Due to the very low resistance of the shunt's sensors, the source signal is very weak. Consequently, the means of measurement must be adapted to such a signal. The signal is amplified and scaled to make it proportional to the CB's rated current (I_n). To guarantee better measurements, two scales are provided, one from 0 to 4 I_n and the other from 4 to 12 I_n. The signal dynamic is quite significant: about 50 dB.

The electronic system could be made highly sensitive to low signals, while at the same time remaining immune to high external disturbances and short-circuit currents through the choice of high-performance components and a very accurate PCB layout.

The software was created using the UML method and written in C language. It is fully modular and developed according to best software engineering practices and internal software quality procedures.

Factbox A unique solution

ABB SACE Emax DC is the only breaker of its type on the market. It is set apart by a unique mix of features and characteristics:

- Wide range of protection functions and relevant settings taking full advantage of an electronic trip unit with standard features (overload, selective and instantaneous short-circuit) and advanced features under- and over-voltage, polarity unbalance, reverse power flow, zone selectivity and thermal memory). Both polarities are protected so as to detect and extinguish all possible types of fault whatever the type of distribution system.
- No need for an auxiliary power supply: all protection and measurement functions are performed in self-supply mode by means of the voltage module.
- Full integration: The trip unit, current and voltage sensors and connections are completely integrated in the breaker. The breaker is officially certified and compliant with the main shipping registers and every unit tested at production facilities.
- High electrical performance: rated currents from 800 A up to 5000 A, operating voltages up to 1000 V, rated short-circuit levels up to 100 kA and rated short-time withstand current up to 100 kA.
- A complete set of measurements: currents, voltages, power, energy counter.
- A wide range of communication and automation functions: communication module with the Modbus RTU protocol and, thanks to the FieldBusPlug*) system, Profibus and Devicenet, Bluetooth connectivity for local configuration, programmable contacts for warning and alarm indications and load control function.
- Advanced HMI and diagnostic information: graphic display, trip indicators, continuous checking of wiring integrity, hand-portable test unit, data recording for the most recent 20 trips and 80 events, and a data logger function (recording all measurements at a sampling frequency of up to 4800 Hz for 27 seconds and with a configurable trigger).

These features combine to make ABB's SACE Emax DC the reference ACB for DC applications: No other product currently on the market achieves such a performance.

Footnote

*) FieldBusPlug is an ABB technology permitting the same devices to be connected to different field-bus types by integrating the connectivity in the plug.

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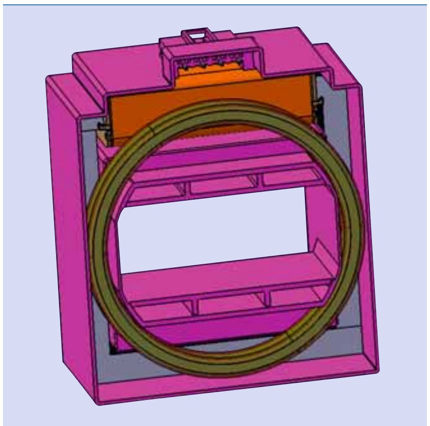
Trip coil

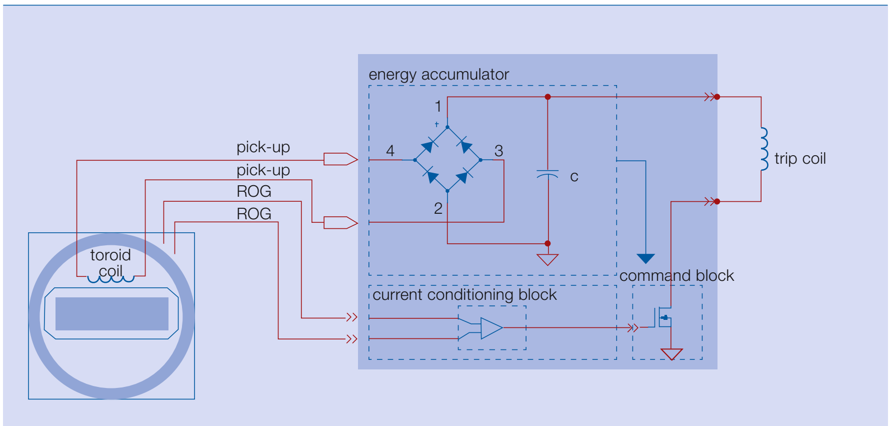
The current breaker is opened by an electromagnetic actuator. It is controlled by the electronic trip unit and the self-supply override protection unit with two independent and parallel channels.

A typical contradiction in CB design lies in designing an actuator that is small, cost-effective, energy-efficient

8 Internal view of override current sensor



9 Self-supply override protection module



and high performance, while is at the same time being able to avoiding any spurious tripping by shielding against the very high electromagnetic fields generated by the short-circuit currents flowing in the power bar. The correct dimensioning of the actuator was achieved by means of a magnetic field FEM analysis 7.

Override current sensors

The purpose of override current sensors is to provide an output signal in the event of a transient short-circuit. Such a condition arises when a breaker that was previously closed on a short-circuited line is energized by an upstream circuit breaker.

> With this solution, customers can avoid having to combine different components.

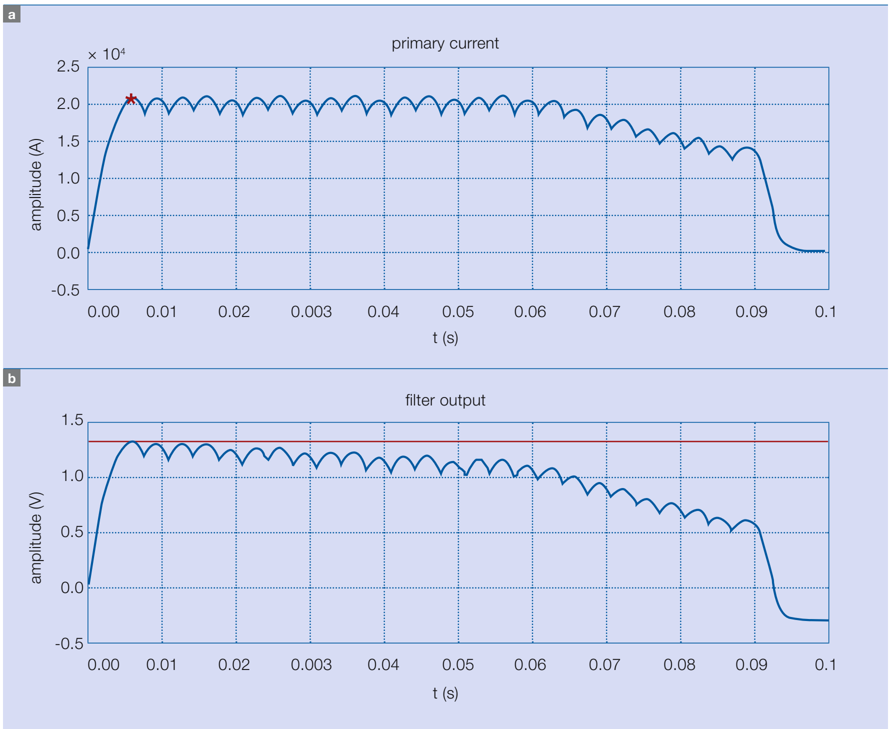
The sensor is made in two parts: a current transformer for supplying the electronic module and the trip coil and a Rogowski coil for providing the signal to be measured. The sensors can guarantee the required level of accuracy over the whole range of currents. They also guarantee the right insulation level between primary bars and the secondary system 8.

Self-supply override protection module

This is an analog electronic module designed to guarantee instantaneous protection whatever the supply conditions. The challenge was to assure protection even in the absence of an external power supply and bar voltage. A dedicated module 9 (the override protection module) was developed to go into action whenever the electronic trip unit is off.

The unit is powered by a current transformer energized by a DC current gradient during a short-circuit. The current is measured by a Rogowski coil. This provides an output proportional to the derivative of the current. The conditioning block receives the signal from the coil and processes it through an analog filter (or integrator) to reconstruct the primary signal. This output is compared with a threshold set by means of dip switches and if this threshold is exceeded, an opening command is sent to the trip coil.

10 Simulation using a primary current with a 2 ms time constant coming from a rectifier bridge a, recorded during a test and the filter output after integration b



A simulation using a primary current is shown in 10a. This example, recorded during a test, features a 2 ms time constant coming from a rectifier bridge. The corresponding filter output after integration is shown in 10b.

A highly successful development

The success with which all the challenges of the project were met led to the development of an innovative, compact product that provides the solution to all possible protection and control needs in DC systems.

> A vast range of protection, measurement and interfacing functions provides better control.

With this solution, customers can avoid having to combine different components and can rely on an integrated product that has been tested and certified by the manufacturer. There are also significant advantages in terms of a reduced overall size of the installation by comparison with the solutions with outside sensors and relays, and a reduction in engineering requirements for the customer.

The availability of a vast range of protection, measurement and interfacing functions provides customers with the means to better control and protect their electric systems.

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