review

Innovation

01|2017 en

The LLT100 non-contact laser level transmitter

50 years of flatness control

Dry insulation for condenser bushings

Saving sunlight for later

Designing reliable generators

Retrofitting unlocks potential

Like years past, 2017 has begun with a challenge to businesses, politicians, and citizens alike to innovate solutions to the world's most pressing problems, so it only seems fitting that the year's first issue of ABB Review focuses on innovation, and that the publication itself has been completely redesigned with a user-friendly layout, engaging graphics, and more expository editorial.

Your feedback is welcome.
abb.com/abbreview

EDITORIAL

Innovation

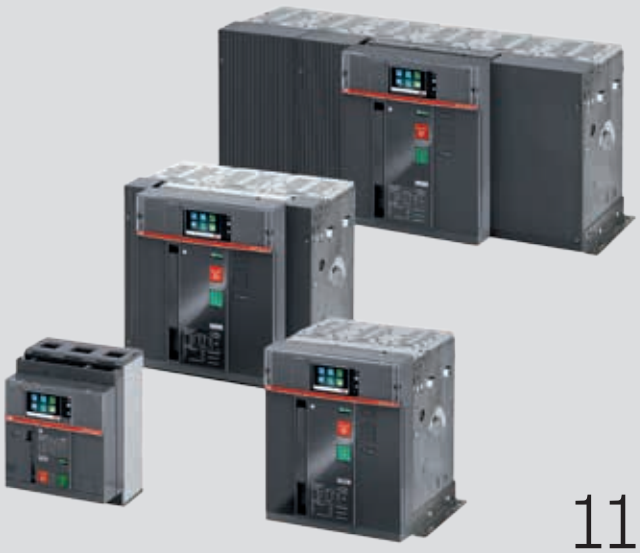
Dear Reader,
Welcome to the first edition of ABB Review to be published in the new format. Besides the complete visual makeover, we hope that you will discover structural changes that render the journal more accessible and easier to navigate.

The redesign of ABB Review is occurring within the context of broad and far-reaching transformation in the company. ABB has dedicated itself to helping customers improve three important metrics: uptime, speed and yield. One of the most significant tools in realizing this is digitalization. Whereas past breakthroughs in productivity were typically achieved on the level of devices and individual technologies, the new revolution will center on collaboration between devices and systems and across value chains. Real-time information is shared and processed digitally.

This and upcoming issues of ABB Review will show you ways in which the digital future is becoming reality. Enjoy your reading.

Bazmi Husain
Chief Technology Officer

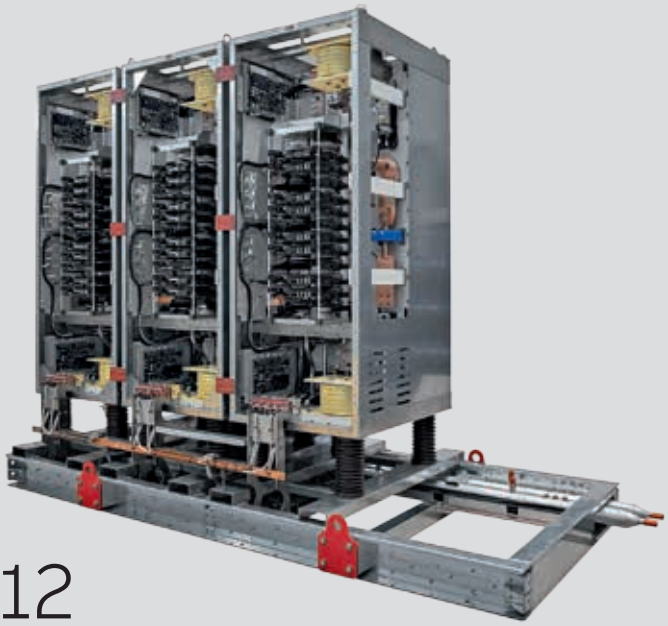
Innovation highlights 2017



11

n

s

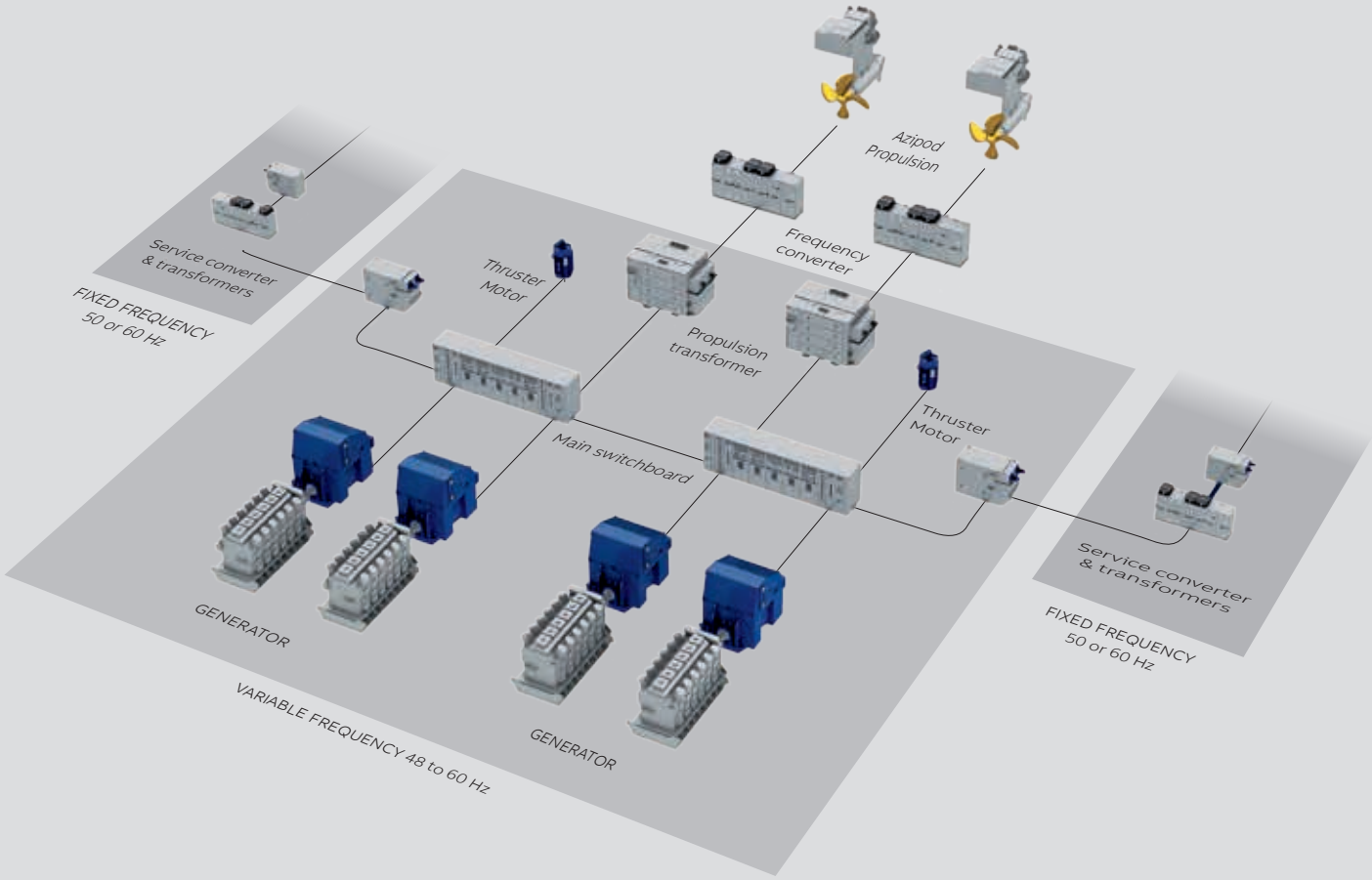


12

“Innovation” is a popular term these days, and for many it serves as a synonym for “new.” At ABB, it means things like using challenging methods involving advanced, patented tools and maths to locate gas distribution leaks; meeting high expectations with a level transmitter that can literally “see” through any condition, or making energy storage easier and safer, and establishing new performance benchmarks for electrical transmission, or record-setting transformers. Innovation at ABB means technical leadership, market relevance, and client success.

13

Dynamic AC achieves high performance at power ratings ≥ 20 MW



Dynamic AC (DAC) is a power plant solution for large ships operating with electric propulsion. DAC allows the main engine running speed to vary according to load changes without a loss of performance. In this way fuel consumption can be optimized, resulting in a fuel savings of between four and six percent. DAC is particularly effective for marine vessels that travel routes of varying lengths and at varying speeds during the year or over their entire lifetime. ABB's DAC provides ship designers and builders with the added flexibility to meet a changing world market.

Conventional diesel-electric propulsion systems separate power production from the propulsion and rely on generating sets to balance power production with fuel consumption. DAC goes one step further by controlling the rotational speed of the generating sets. The electrical system is engineered to operate at variable system frequency – usually ranging between 48 and 60 Hz. Adjustments in engine speed result in optimal fuel consumption under each operating condition.

Power distribution for auxiliary shipboard consumers and hotel loads are provided by frequency converters operating at constant frequency, except for certain loads that can be supplied directly from the variable-frequency system. All DAC components can be fully integrated into ABB's intelligent automation and advisory systems.

DAC is a new concept that complements the ABB Onboard DC Grid solution for energy-efficient marine vessel power generation. DAC achieves superior functionality for large vessels operating with high-voltage power systems and power ratings at or above 20 MW. This contrasts with the Onboard DC Grid system designed by ABB with smaller vessels in mind. ●

The LLT100 non-contact laser level transmitter

ABB is pleased to introduce the LLT100 high performance laser level transmitter. It accurately measures level, distance and position over short and long ranges. It is designed for all industrial applications and harsh environments and replaces open-path radar and other level transmitters.

The LLT100 measures the level of any material, solid or liquid, including clear liquids, independently of their properties or conditions. With its narrow laser beam, the LLT100 can avoid obstructions and can be installed near vessel walls, or in tanks with mixing blades, grids or obstructions. The LLT100 measures continuously and provides rapid surface change tracking. In addition, the advanced signal processing delivers reliable measurements in the presence of mixers and in dusty, foggy and narrow environments. Easy configuration, fast installation and loop-power make it convenient to use. It has a rugged IP 67 / NEMA 4X enclosure and is approved for use in hazardous areas: explosion proof class 1 / division 1 (zone 1). It is suitable for use in applications in challenging industrial environments such as mining, aggregates, oil and gas, chemicals, food and beverages, power, pulp and paper, pharma, water and waste water.

LLT100 embodies ABB's "Measurement made easy" design philosophy: fast startup, flexible installation, and no need to recalibrate over time or when the environment changes. ●

Rapid gas-pipe-line leak detection with MobileGuard™

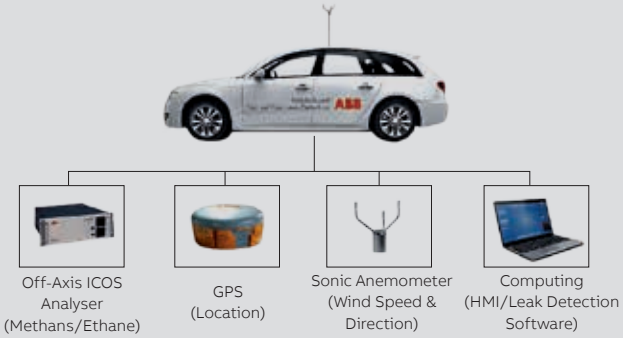
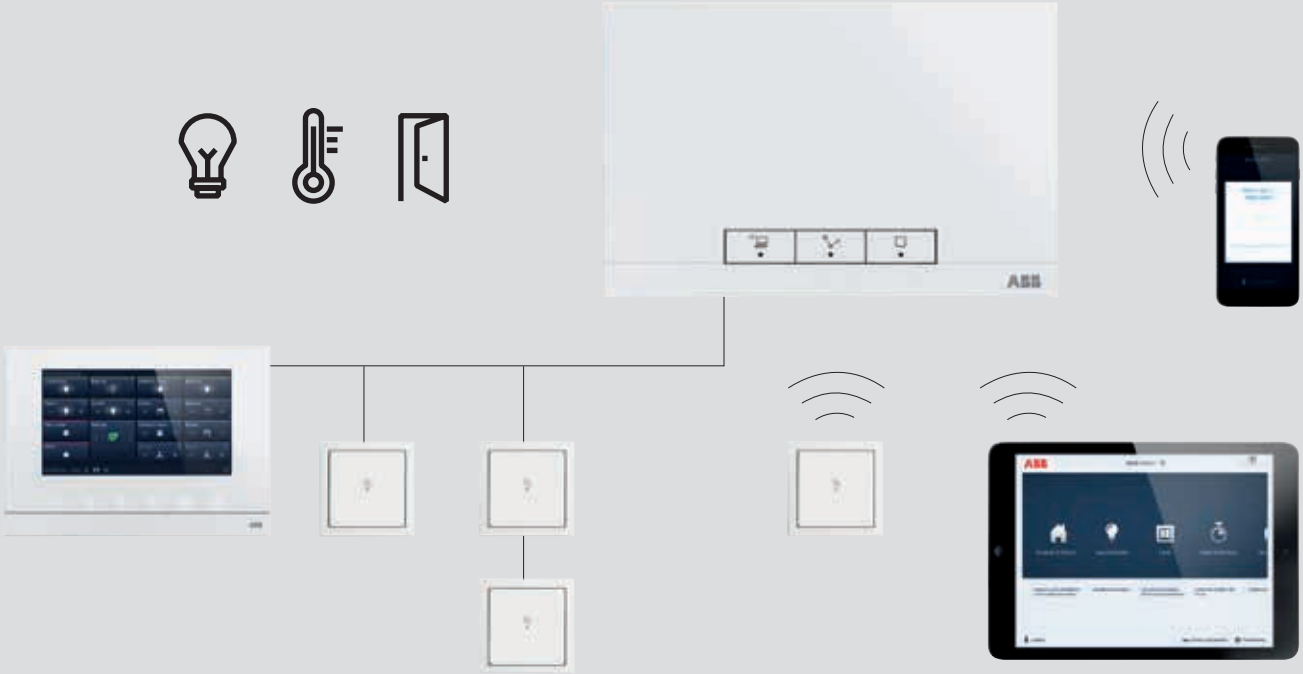


ABB has developed the MobileGuard system for the rapid and cost effective detection of dangerous and environmentally harmful leaks in the natural gas pipeline distribution network. The heart of the system is an analyzer that simultaneously measures methane and ethane using ABB's patented, laser-based, OA-ICOS™ technology. The analyzer is capable of detecting single parts-per-billions of methane, which allows the system to sense methane leaks from hundreds of feet away rather than the few feet of conventional survey equipment. With the analyzer integrated into a vehicle, users can rapidly survey pipeline networks. The analyzer measures up to 5 Hz, allowing users to survey at speeds of up to 88 kph (55 mph). Furthermore, the ability to measure ethane allows the system to distinguish between pipeline gas and other methane sources such as landfills, swamps and livestock, thus reducing the incidence of false positives.

Sophisticated, proprietary, analysis algorithms turn the measured gas concentrations, local wind and GPS data into precise estimates of where leaks are occurring on the distribution network. Customers receive analysis reports in real-time through cloud-based sharing, which can be viewed in GIS systems. The novel MobileGuard system provides natural gas utilities with important new capabilities to ensure routine public safety, odor investigation and fast post-disaster support, while reducing unwanted greenhouse gas emissions and saving money. ●

Home automation easier than ever with ABB-free@home® wireless

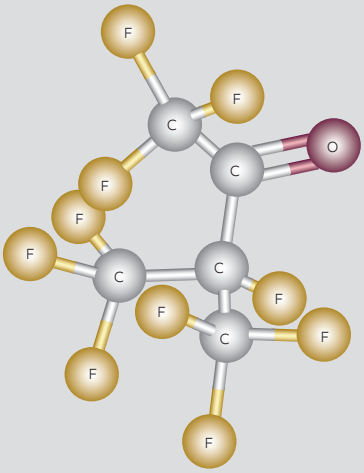


Smart home solutions are dependent on an infrastructure of sensors, actuators and intelligent control. ABB-free@home wireless now allows these elements to be connected into a flexible system in a very simple way.

ABB-free@home wireless is a wireless-based smart home integration system, making it ideal for converting old buildings into smart homes as well as for outfitting newbuilds with the very latest in home automation technology.

Thanks to its meshed network, which provides the very best radio connection, ABB-free@home wireless opens up new possibilities for carrying out smart home projects in a simple and economic fashion. With wireless, the fabric of the building can remain unchanged, which means that lighting, blinds, door entry and heating systems can all easily be upgraded to the latest smart home standard. If required, wired components can also be integrated into the system.

For the electrical fitter, the installation of ABB-free@home wireless is very simple and fast. The System Access Point allows access from a PC, tablet or smartphone and even features voice control. ABB-free@home wireless can be combined with an existing bus-based ABB-free@home system and supports direct integration with ABB's door entry systems and cloud-based remote access. ●



SF_6-free GIS now for medium-voltage applications

For decades, gas-insulated switchgear (GIS) technology with sulfur hexafluoride (SF_6) gas has been the choice of users seeking the most compact dimensions, highest reliability and maximum safety. However, despite its outstanding properties, SF_6 is a potent greenhouse gas. ABB is the first company to offer medium-voltage (MV) GIS with a climate-friendly insulation gas based on a new molecule.

Together with partner 3M, ABB has developed a promising alternative to SF_6: ABB's AirPlus™ insulation gas. While coming close to the technical performance of SF_6, the new gas has virtually no global warming effect: After an average of 16 days (compared to over 3,000 years for SF_6) exposed to radiation in the atmosphere, AirPlus's new molecule decomposes.

AirPlus is a gas mixture: For MV applications, over 80 percent by volume is dry air and the remainder is NOVEC 5110 dielectric fluid, a C5 fluoroketone molecule provided by 3M.

AirPlus is not subject to regulations, as SF_6 is, making handling simpler and reducing administrative efforts.

ABB has launched two AirPlus switchgear products for medium-voltage: ZX2 AirPlus and SafeRing AirPlus, for primary and secondary distribution respectively. These products are the first step toward a broader AirPlus portfolio and the opening of a new era for GIS technology in the MV market. ●

Emax 2 goes digital

In 2013, ABB launched Emax 2, a best-in-class low-voltage circuit breaker with a unique integrated energy management function. Emax 2 was a real breakthrough innovation that elevated the circuit breaker product concept from mere current interrupter to comprehensive power manager. However, the world of electrical power distribution changes quickly and major new trends such as renewables, energy storage and microgrids are now crowding onto the stage. These trends lead to new customer and application demands. To meet these demands, ABB has now unveiled the innovative Emax 2 all-in-one – the evolution of the Emax 2 into a multifunctional platform that is able to manage the next generation of electrical installations: microgrids.

At the core of the Emax 2 all-in-one's power are its unique digital features in:

- Control: optimal management of microgrid power resources
- Connectivity: full integration into the digital era
- Ease of use: making the complex simple

Emax 2 all-in-one is the first circuit breaker that matches new grid requirements and – unique for its class – harnesses the power of data, enabling a direct communication to the new energy management cloud-computing platform – the ABB Ability™ Electrical Distribution Control System. Smart and plug-and-play architecture makes Emax 2 all-in-one easy to use. Once again, Emax 2 sets a new circuit breaker benchmark for the needs of today and tomorrow. ●

Improved GCB simplifies power plant protection

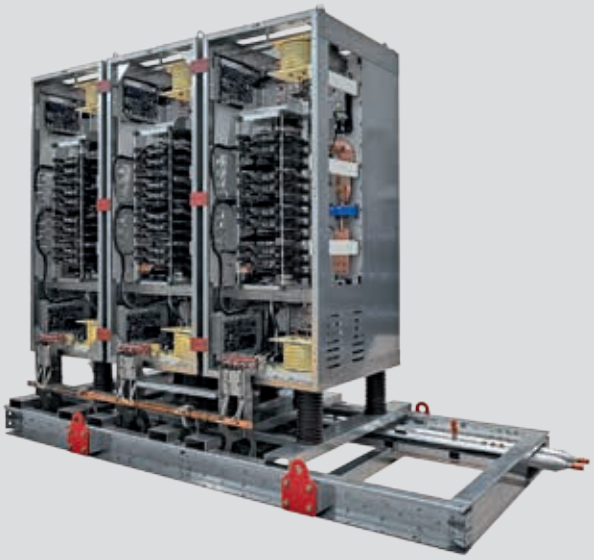
ABB's generator circuit breakers (GCBs) have been protecting power plants and simplifying operations since the 1950s. Continually striving to improve performance, ABB has developed the HEC 10-170 GCB for power plants up to 1,600 MW.

The HEC 10-170 is the successor of the HEC 7/8A series, which is in operation in hundreds of power plants around the world. The HEC 10-170 is rated at 170 kA / 31.5 kV and offers a compact yet flexible design.

With simplification being the primary design philosophy, ABB collaborated with its suppliers to develop this streamlined GCB. The HEC 10-170 boasts a series of innovative solutions such as a new short-stroke disconnector, radically simplified linkage and a hybrid cooling concept based on heat pipes. Factory assembly has also been substantially simplified.

The robust new GCB will be on the market in the first quarter of 2017. ●

New SVC Light for medium power



As part of the static var compensation (SVC) Light portfolio, ABB has developed a new modular multilevel converter (MMC) using a chain-link topology for static compensator (STATCOM) applications.

The new converter, which targets the medium power range up to approximately 100 MVA, uses a new technology platform for reverse-conducting integrated gate-commutated thyristor (RC-IGCT) semiconductors, with ratings of 4.5 kV / 3 kA and 6.5 kV / 2.15 kA. By optimizing the IGCT devices for low-frequency applications – such as grid-connected MMC converters – the lowest losses in the industry are achieved. Other advantageous features of press-pack devices such as the IGCT – compared to eg, wire-bonded industrial modules – are the superior load cycling performance and the inherently stable short-circuit failure mode. These advantages give a natural robustness to the cell design, where a failure of the press-pack device does not lead to explosion or rupture. A single thyristor switch protects the cell against catastrophic damage in all relevant failure modes and allows continued operation of the chain-link converter after a single cell failure. Further, the converter design is made for easy maintenance and replacement of components in the field.

In the new SVC Light for medium power, this rugged converter cell design is combined with ABB's well-proven control algorithms for applications such as flicker compensation in arc furnaces, voltage support in renewables, and utility and rail compensation, among others. To maximize performance, the application control software of the SVC Light is implemented on the new modular advanced control system platform MACH™3, also used for HVDC applications. ●

SCARA: Choosing the best arm for the job

ABB has introduced its first-ever line of Selective Compliance Articulated Robot Arm (SCARA) robots, the IRB 910SC, to extend its industrial robot portfolio. This new addition adds more speed, accuracy and cost-effectiveness to its line of small robots.

SCARA refers to a class of robots with four moving axes: the first two provide positioning in a horizontal place, the third offers vertical motion, and the fourth provides rotation around the vertical axes. These types of robots are often used when robot tasks are limited to manipulation on a horizontal surface, typically for customers requiring rapid cycle times, high precision and high reliability for a range of applications, such as electronic assembly, inspection, packaging, drug testing or other material handling applications.

ABB's new series of SCARA robots has a nominal payload of 3 kg and maximum payload of 6 kg with three variable reach options of 450, 550 and 650 mm, allowing customers to choose the best arm for the job. SCARA robots are faster and, due to smaller number of axes, often more cost-efficient than six axis robots in the same market.

Following ABB's strategy, the same controllers are used for SCARA as for all of its other robots. Having the same base hardware and software architecture means partners and customers avoid unnecessary ownership costs while benefitting from a homogeneous robotic automation system that is programmed, used and maintained in the same way for all types and sizes of robots. RobotStudio, Integrated Vision and PickMaster are just some of the products that are available for use together with SCARA robots. ●

REACT saves sunlight for rainy days

This year ABB launched a game changer in photovoltaics (PV) and residential energy storage called REACT. Home owners and landlords can now set aside any excess energy produced by their PV installation to be used later. Sourcing the complete system (PV inverter plus storage) from ABB means the end customer now has a single point of contact to the supplier. REACT is available in two power ratings: 3.6 and 4.6 kW for single-phase applications. The 2 kWh lithium-ion battery guarantees a residual capacity of at least 60 percent after a cumulative energy delivery of 9 MWh with daily charge/discharge cycles. This translates into a battery life of at least ten years.

A unique feature that differentiates the product from any competitor offering is that the battery capacity can be upgraded from the basic 2 kWh configuration to 6 kWh by adding two further battery compartments. The optimization of energy consumption is executed by the on-board energy management software which also interfaces with the power meter (provided as part of REACT) at the point of connection to the grid. REACT is equipped with embedded communication capabilities (Ethernet, wifi, etc.) that allow local or remote data monitoring through the cloud without requiring additional interfaces. The mobile app MyREACT, that monitors and controls the product, completes the offering. ●

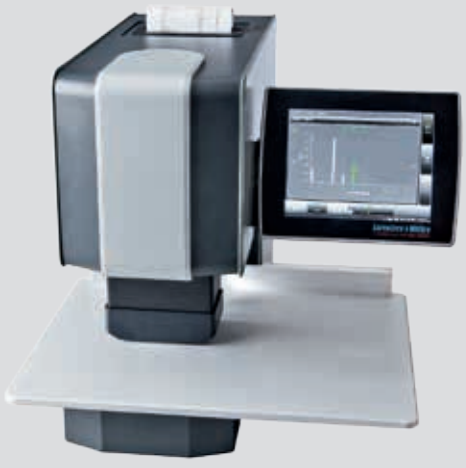
Stepping transformer voltages up to new records

When ABB put the Xiangjiaba-Shanghai UHVDC (ultra-high voltage DC) link into operation in 2008, its commercial 800 kV, 6400 MW rating was unprecedented in the HVDC industry. Now, ABB is breaking its own record. The company has been contracted to supply converters for the 1,100 kV, 12,000 MW transmission between Changji and Guquan (China).

Raising the voltage level represents a huge challenge for the dielectric design of the converter transformers. Achieving higher voltages is not merely about extrapolating learnings from previous voltage hikes. In fact the electric field stress that governs the performance of insulation is non-linear in its behavior. The insulation designs related to the valve-side of the transformers, including the bushings, have had to be completely reworked.

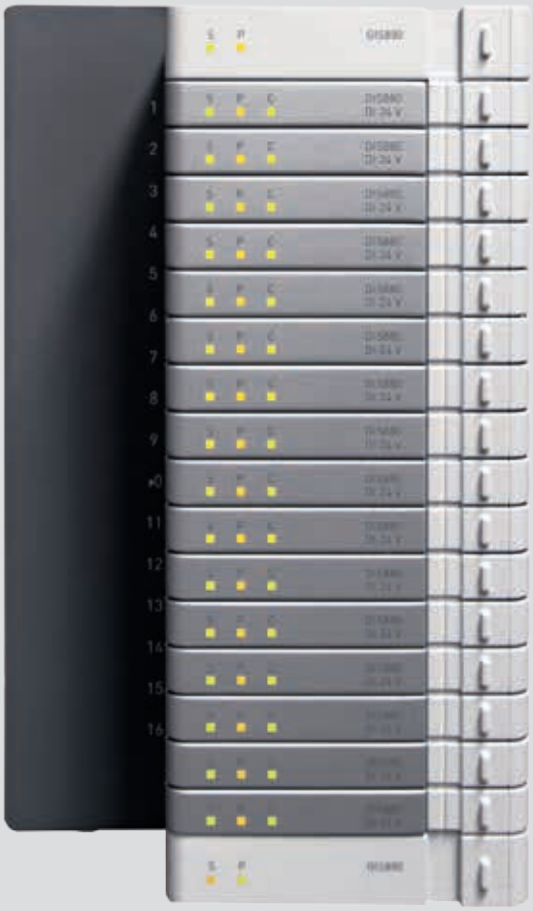
The very high voltage and power ratings also make this transformer the world's physically largest. This also affected the design of the bushings, which have to handle both extreme voltage levels and very high currents.
The technology ABB is using for the first 1,100 kVdc converter transformers has been verified through an ambitious research and development program completed in 2012. The solutions applied in the commercial project presently underway are thus already proven. ●

Faster and more accurate assessment of printability with optical topography



A new instrument that quickly and accurately assesses the printability of paper and cardboard by analyzing the surface topography helps paper manufacturers to produce paper that meets customer needs for quality printing. Many years of research and printing studies by Innventia – a Swedish institute that is a world leader in pulp and paper research – have shown that optical topography, ie, measuring small variations and craters on the surface of paper, performs better than traditional methods in predicting how ink will cover paper or board surface in flexographic, gravure, offset or hybrid printing.

Optical topography is a measurement technique in which light is projected onto a sample at an acute angle from two opposite directions, resulting in a stereoscopic image. By creating shadows, the technique reveals variations in the paper surface. These variations can then be used as the basis for a mathematical description of the paper surface topography. This measurement principle is the basis of the L&W OptiTopo. Based on an invention by Innventia, the L&W OptiTopo was developed by ABB. The L&W OptiTopo measures surface variations and crater properties with such high precision that it can accurately predict printability – for example, the risk of areas remaining uncovered by ink. ●



System 800xA's Select I/O fundamentally changes automation project execution

For decades, automation projects have used controller-centric distributed control system (DCS) architectures. Such architectures create a significant number of interdependencies between project tasks that can easily lead to considerable cost overruns and delays should any change orders be implemented. ABB has developed a new I/O family – complete with engineering tools and methodologies – that eliminates this scenario and takes project efficiency to the next level, making over-budget or late automation projects a thing of the past.

One example of project interdependency is when a "design freeze" is declared before hardware purchase, which, in turn, has to precede application engineering, and so on. Any changes to the design, like changing I/O types, adding I/O, moving I/O to a different controller, etc., require potentially costly change orders due to the amount of work needed to make changes after design freeze.

In response, ABB has developed an extension to the System 800xA family of I/O solutions called Select I/O. Select I/O is a single channel I/O solution for both process and safety applications that communicates with the system via a redundant industrial Ethernet I/O network.

The Select I/O terminations can be installed and wired in the field early in the project phase, obviating the need for space-consuming marshalling cabinets. The signal types can be defined much later by adding individual signal conditioning modules, which reduces the financial impact of any late changes.

With the multiple clusters of Select I/O communicating on a redundant Ethernet network, the I/O can be automatically scanned, configured, and checked in the field in parallel with the application engineering being done in the ABB project factory. This paralleling is called "xStream" engineering and includes soft marshalling capabilities that automatically converge the two workstream deliverables – ie, the application engineering project and field I/O configuration – just before final commissioning.

The result is that automation is removed from the overall project critical path. Fewer surprises, fewer change orders, earlier commissioning of projects and happier owner-operators is the result. ●

INTERVIEW

A finger on the pulse of the digital revolution

Guido Jouret

ABB's Chief Digital Officer, Guido Jouret, discusses the digital future in an interview with ABB Review and explains how the digital revolution will transform the businesses of ABB and its customers.

AR **ABB Review (AR):** What do we mean when we speak of a digital revolution? Hasn't digitalization been around for a long time?

GJ **Guido Jouret (GJ):** There is nothing genuinely new about being able to communicate remotely with a sensor in a factory, for example. But the cost of connecting that device – including not just the connectivity component of the device itself but also the network, servers, software, etc. – has become much more affordable thanks to developments in areas such as mobile communications.

There are already numerous digital devices in factories. They are all producing data, but much of this data is marooned. If it could be collected, stored and analyzed, factory owners could optimize their operations. It could also be used by ABB to provide service and improve the reliability and operation of equipment. Rather than perform this storage and analysis on a local server, it is advantageous to run it in the cloud.

AR Doesn't placing data on the cloud mean the customer is losing control over it?

GJ No online storage can be absolutely secure. But data on the cloud is typically more secure than that on a proprietary server. Companies providing cloud services are aware that their reputation is at stake if any customer data is compromised.

Furthermore, most companies have already accepted cloud storage in other areas. For example, they are probably using Microsoft Office 365. If sensitive business documents can be entrusted to the cloud, why not process data?

AR What sort of data analysis are we talking about?

GJ With the help of libraries provided by companies such as Microsoft and Google we can, for example, perform image recognition or analyze data streams based on past experience.

AR Isn't relying on the algorithms of external suppliers eroding ABB's leading edge? After all, competitors can use the same libraries.

GJ Indeed they can and they will. But look at it this way: Companies such as Microsoft and Intel provide our operating systems and processors. We would not dream of developing such components ourselves. Machine learning and cloud storage are, similarly, just tools. Our competitive edge lies in what we do with them.

Using isolated customized solutions to encapsulate ourselves is not a wise strategy in the long term. The market is moving towards more choice. Standards such as IEC 61850 for substation automation mean that customers can freely mix and match devices from different suppliers. Choice is good for the customer and is good for ABB. Rather than seeking to grow our share of a cake, it means we are getting a share of a bigger cake.

AR What about the digitalization of the devices themselves?

GJ Devices are becoming more and more digital. For example, the cockpit of a Tesla car has only two buttons that do not act via software. They are the button for the emergency warning lights and the button on the glove compartment.

By installing new software, a manufacturer can add functionality or improve performance even after the product has been delivered. To come back to Tesla, an incident recently occurred while a car was on autopilot. The algorithm was modified to prevent a recurrence and the new software was remotely installed on all Tesla cars. All customers thus benefitted. This is a radical deviation from the present situation in which a product remains unchanged throughout its working life.

AR Can you give us some insight into technologies that will open new opportunities?

GJ Just as an example, let us consider blockchain technology, which gave birth to the Bitcoin. Essentially, a blockchain creates, in the public domain, a decentralized record of past transactions. The blockchain can be added to but not easily erased. Transparency and compliance are important for conducting business. If a quote or goods have been delivered, it is important that this is acknowledged, thus providing certainty for both parties.

Automation and digitalization are moving up the value chain. For example, electrical grids are already digital at the operating level: Opening a breaker is a digital action but on a higher level, scheduling may still involve somebody picking up a telephone. The digital revolution will move entire businesses into the digital world.

AR Thank you for this interview. ●

Protectio and safet

n

y

Electricity is the energy source of choice for homes, industry, and transportation, as well as for the infrastructure that keeps them running and handles the ever-increasing and vital exchange of data. The next decade will see a massive increase in the demand for electricity around the world, which will require upgrading the capacity of existing systems, and installing new equipment where none existed before. Greater uses entail greater risks, however, which is why safety and protection remain at the core of ABB's innovative leadership in electrical generation, transmission, services, and use.

PROTECTION AND SAFETY

Emax 2 and Arc Guard System™ TVOC-2 mitigate electric arc flash

An electric arc flash is an extremely dangerous and undesirable event in an electrical enclosure. ABB's Arc Guard System TVOC-2 teamed up with ABB Emax 2 circuit breakers creates the foundation for a very effective arc flash damage mitigation strategy for electrical installations.

Marco Carminati
ABB Electrification Products, Protection and Connection

Bergamo, Italy
marco.carminati@it.abb.com

Andreas von-Lako
ABB Electrification Products, Protection and Connection

Västerås, Sweden
andreas.von-lako@se.abb.com

With temperatures of up to 20,000 °C and violent overpressure waves, an electric arc flash is an extremely dangerous and undesirable event in an electrical enclosure. Arc flashes are usually caused by human error, a defective connection or failure to put measures in place to exclude the entry of small animals into the electrical enclosure. Much work has been conducted over the years to mitigate the effects of arc flash and ABB has had effective countermeasure products on the market for some decades. The Arc Guard System TVOC-2 is ABB's latest generation of such a product. By combining TVOC-2 with ABB's Emax 2 circuit breakers, electrical designers can create a system that greatly diminishes the effects of arc flash. The TVOC-2/Emax 2 combination can be deployed in various ways so that not only are arc flash events contained, but facility downtime is minimized.

Most arcing accidents in electrical equipment are caused by human error (65 percent occur with an operator working on the equipment), faulty connections or the intrusion of animals. Most often, the accident occurs when personnel are performing switchgear maintenance or installation and the cabinet door is open. With the door open, the frontline defense of arc-proofed switchgear design – strong doors – is neutralized.

Fortunately, accidents are relatively rare but when they occur, injuries can be serious or even fatal and damage to equipment extensive. Replacing and repairing the equipment can lead to long down-times, so an arc flash event can be expensive as well as tragic.

For this reason, it is essential to avoid arc flashes at all costs. If they cannot be avoided, their effects must be minimized. An arc guard system is, therefore, a necessary part of a modern switchgear design. ABB's Arc Guard TVOC-2 – the new version of a well-established arc guard system that has been protecting people and electrical equipment

Most often, arcing accidents occur when personnel are performing switchgear maintenance or installation and the cabinet door is open.

from dangerous electrical arcs for over 35 years – is a device that uses a configuration of optical sensors to detect an electric arc. The TVOC-2 interfaces perfectly with ABB Emax 2 circuit breakers to provide a fast-response active protection system that limits the effects of internal arcing.

01

—
01 ABB's Arc Guard System TVOC-2 teamed up with ABB Emax 2 circuit breakers (shown) creates the foundation for a very effective arc flash damage mitigation strategy for electrical installations.

—
02 Example positioning of detectors in the horizontal and vertical busbars system, and in the circuit breaker cubicle.

Electric arc phenomena

An electric arc is a phenomenon that takes place as a consequence of a discharge. A discharge occurs when the voltage between two points exceeds the insulation strength of the interposed gas. Gases, which are good insulators under normal conditions, may become current conductors as a consequence of a change in their chemical-physical properties. Under suitable conditions, a plasma can be generated that carries the electric current until the opening of the protective device on the supply side.

02 a Horizontal and vertical bus bars system b Circuit breaker cuicle

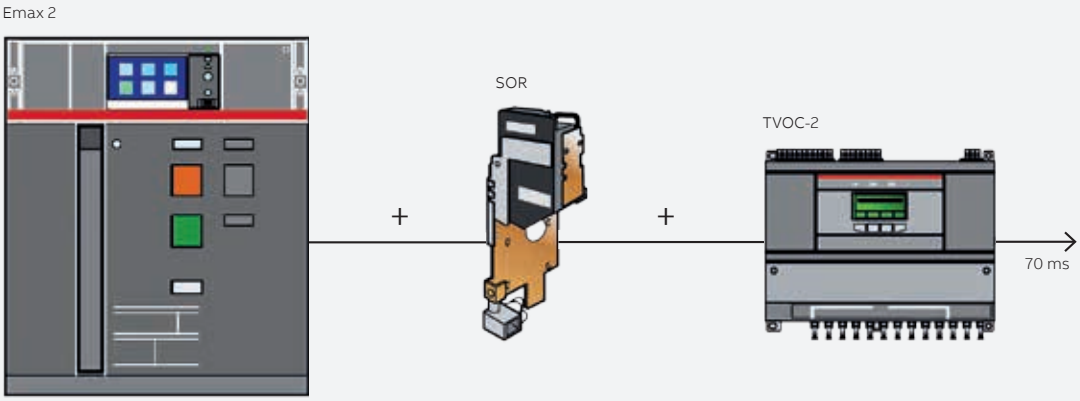
Besides thermal ionization, there is also electron emission from the cathodic pole of the arc due to a thermionic effect: Ions, formed in the gas by collisions caused by the very high temperature, are accelerated by the electric field. They strike the cathode and release energy, thus causing a localized heating that generates electron emission.

The high fault current that arises during an arcing event causes overheating in the cables or circuit busbars, up to their melting point. As soon as a conductor melts, conditions arise that are similar to those present during a circuit opening: An electric

—

An electric arc can easily reach 7,000 to 8,000 °C; 20,000 °C can be reached in some cases.

arc is created that lasts either until the protection devices intervene or until the conditions necessary for its stability subside. The arc results in an intense ionization of the ambient gas, a drop of the anodic and cathodic voltage and very high current density in the middle of the column (of the order of 100 A/cm^2). There are also very high temperatures (thousands of degrees centigrade) in the middle of the current column and – in low-voltage situations – across a distance of some microns to some centimeters.



03

Effects of the electric arc inside electrical assemblies

The first instants of arc formation inside a cubicle can be divided into four phases:

- Compression phase: In this phase, the air volume occupied by the arc is overheated due to the continuous supply of energy delivered into it by the power supply. Due to convection and radiation, the remaining volume of air inside the cubicle warms up. Initially, temperature and pressure are nonhomogeneous.
- Expansion phase: From the first instants of internal pressure increase, a hole will most likely be formed in the enclosure through which the overheated air begins to flow out. In this phase, the pressure reaches its maximum value and then starts to decrease as hot air egresses the cabinet.
- Emission phase: In this phase, due to the continuous contribution of energy by the arc, nearly all the air is forced out of the enclosure.
- Thermal phase: After the expulsion of the air, the temperature inside the switchgear almost reaches that of the electric arc. In this final phase, which lasts until the arc is quenched, materials that come into contact with the arc undergo erosion, with the associated production of gases, fumes and molten material particles.

Should the electric arc occur in an open configuration, some of these phases will not occur or will have less effect. However, there will still be a pressure wave and a rise in the temperature in the arc zone.

—

The TVOC-2 interfaces perfectly with ABB Emax 2 circuit breakers to provide a fast-response active protection system that limits the effects of internal arcing.

Effects of the electric arc on humans

The effects manifested in the vicinity of an electric arc make it a dangerous place:

- Pressure: It has been estimated that at a distance of 60 cm from an electric arc associated with a 20 kA arcing fault, a person is subject to a force of 225 kg over their body area. The pressure wave may cause permanent injuries to the eardrum.
- Temperature: An electric arc can easily reach 7,000 to 8,000 °C; 20,000 °C can be reached in some cases.
- Sound: Sound levels can reach 160 dB (a shotgun blast is only 130 dB) and can damage hearing.
- Ejecta: High-velocity shrapnel poses an obvious danger, especially to the eyes.
- Radiation: Ultraviolet and infrared radiation can injure the cornea and the retina.
- Toxic gases: The fumes produced by burnt insulating materials and by molten or vaporized metals can be toxic.

In other words, the effects of an arc blast are similar to those of an explosion.

Passive and active protection

There are three assembly design philosophies that ensure operator and installation safety in the event of arcing inside low-voltage (LV) switchgear:

- Assemblies mechanically capable of withstanding the electric arc (passive protection)
- Assemblies equipped with devices limiting the effects of internal arcing (active protection)
- Assemblies equipped with current-limiting circuit breakers

These three solutions (and combinations thereof) have been successfully applied by the main manufacturers of LV switchgear and controlgear assemblies. ABB's TVOC-2/Emax 2 combination is an active protection approach. There are two main approaches to using active protection to limit the destructive effects of the arc:

—
03 Emax 2 circuit breaker in series with an SOR and TVOC-2

—
04 Ekip Touch/Hi-Touch trip units for the Emax 2 along with an Ekip signaling 2K module deliver shorter trip times.

Pressure sensors that detect the overpressure wave
Sensors can be used to signal the pressure peak associated with the arc ignition. This signal operates on the supply circuit breaker without waiting for the trip time of the selectivity protection to elapse, which is, necessarily, longer. Delay time is about 10 to 15 ms.

Such a system does not need any electronic processing device since it acts directly on the shunt opening release (SOR) of the supply circuit breaker. Obviously, it is essential that the device is set at a fixed trip threshold. However, it is not easy to define in advance what this threshold should be as the value of overpressure generated by an arc fault inside a switchboard is nondeterministic.

Light detectors
The second possibility is to install detectors that sense the light flux associated with the electric arc phenomenon and that send a tripping signal to the circuit breaker. In this case, the reaction time of the detection is about 1 ms. This principle

—
ABB's Arc Guard TVOC-2 is a device that uses a configuration of optical sensors to detect an electric arc.

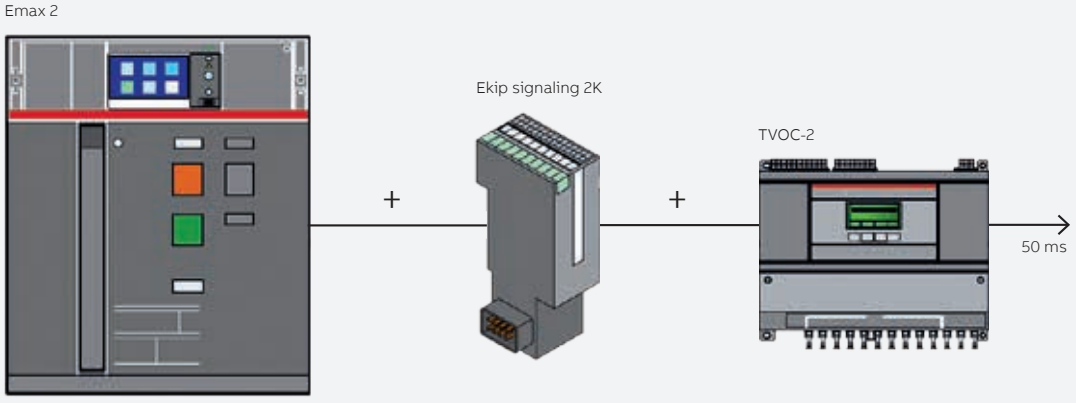
is the basis of the Arc Guard System TVOC-2 →1–2 shows example detector locations. An ideal solution would have at least one detector per column and strategic detector positioning will eliminate interference between zones of detection. Sensors are calibrated to have equal light sensitivity and their orientation is not critical as their fish-eye lens design can observe a large angle.

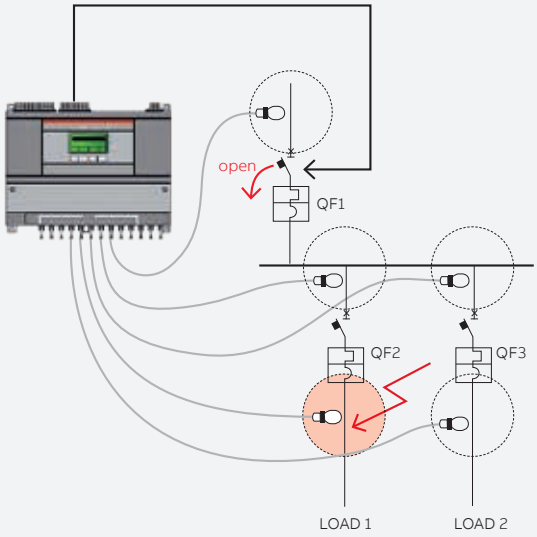
To avoid false tripping due to camera flashes or sunlight, the arc monitor can be combined with a current sensor and set to activate only when an overcurrent is also registered. Further interference immunity is conferred by the use of fiber-optic cables, which are not only fast but impervious to the electromagnetic interference that will certainly accompany an arc fault.

—
A TVOC-2 can individually command three different output contacts, each of which can be associated with a particular set of light sensor inputs.

Complementing the TVOC-2 is the Emax 2 circuit breaker. The Emax 2 is rated up to 6,300 A and contains a protection trip relay with an integrated power controller that measures and evaluates energy consumption, managing the loads to maintain or reduce the peak power usage. The circuit breaker is easy to use and its advanced connectivity abilities mean it is simple to integrate into smart grids, buildings and industrial plants. These characteristics mean it is easy to connect it to the TVOC-2 to create a fast-acting arc mitigation partnership.

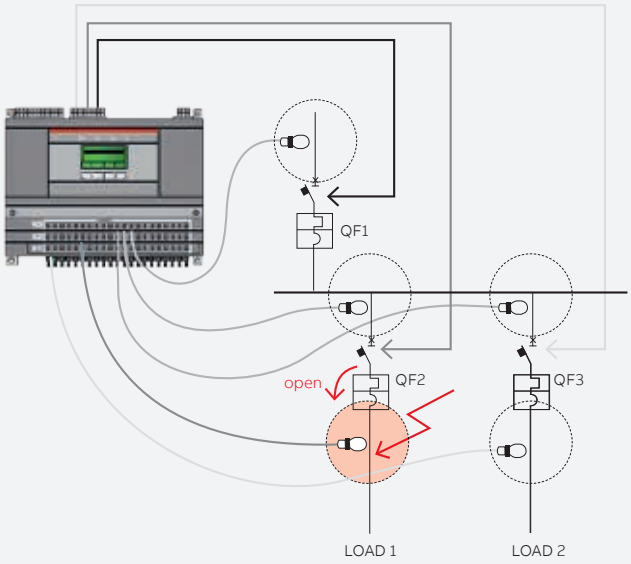
Working with the circuit breaker
One possible configuration is an Arc Guard System formed by TVOC-2 and Emax 2 with an SOR →3. However, a much shorter breaking time can be achieved using the capabilities of Ekip Touch/Hi-Touch trip units for the Emax 2 along with an Ekip signaling 2K module →4.





QF1 open: LOAD 1 and LOAD 2 not supplied

05



QF1 and QF3 closed: LOAD 2 supplied
QF2 open: LOAD 1 isolated

06

— 05 Nonselective configuration can shut the entire plant in the event of a trip.

— 06 Subsets of light sensors can be associated with particular TVOC-2 outputs to allow selective circuit-breaker tripping.

Ekip Touch/Hi-Touch are a new generation of protection trip units that are easy to program and read. The module can be programmed via its MMI (man-machine interface) or using Ekip Connect software running on a laptop. The Ekip Touch/Hi-Touch trip units measure power and energy with precision and save the most recent alarms, events and measurements in order to prevent faults to the installation and trip effectively when necessary. This arrangement allows the total breaking times to be significantly reduced since they no longer depend on the SOR, but on the opening directly commanded by the electronic unit.

Examples of manageable operation logic

A TVOC-2 can individually command three different output contacts (each can have multiple breakers connected). Each of the three contacts can be associated with a particular set of light sensor inputs. This selectivity allows discernment as far

— A much shorter breaking time can be achieved using the capabilities of Ekip Touch/Hi-Touch trip units for the Emax 2 along with an Ekip signaling 2K module.

as circuit breaker tripping is concerned: Instead of shutting down the entire plant in the event of an arc →5, only sections adversely impacted by the arc are isolated. For simplification, only five of the 30 possible light sensors are shown in the figures.

Essential arc protection

Arc protection systems have become an essential element of electrical cabinet design. Indeed, because they reduce downtime cost and damage,

— Combined with the Emax 2 circuit breaker, the TVOC-2 ensures the safety of personnel even when the cabinet door is open and provides all-round, comprehensive arc protection.

some insurance companies will reduce premiums when they are used. Also, protection against arcing accidents is increasingly becoming enshrined in legislation. For example, the Low Voltage Directive of the European Union stipulates that measures to prevent damage by excessive heat, caused by arc flashes, for example, are to be taken.

Combined with the Emax 2 circuit breaker, the TVOC-2 ensures the safety of personnel even when the cabinet door is open and provides all-around, comprehensive arc protection. With the ability to communicate between the Emax2 Ekip and the TVOC-2 using Modbus RTU, the customer will be able to get information regarding trip locations and faults quickly and accurately. The TVOC-2/Emax 2 combination is one of the most reliable arc mitigation products available on the market. ●

PROTECTION AND SAFETY

IEC 61850 unites low-and medium-voltage

IEC 61850 can be used with ABB's low-voltage (LV) intelligent electronic devices (IEDs) such as REF medium-voltage (MV) protection relays and Emax 2 LV circuit breakers to design and operate a fully integrated protection and supervision system that spans the LV and MV worlds.

Enrico Ragaini
ABB Electrification Products, Protection and Connection

Bergamo, Italy
enrico.ragaini@it.abb.com

Damiano Benedetti
ABB Electrification Products, Distribution Automation

Dalmine, Italy
damiano.benedetti@it.abb.com

Already a well-established standard in high-voltage (HV) and medium-voltage (MV) protection, IEC 61850 is now being increasingly used in low-voltage (LV) applications, thus greatly extending its reach →1. Equipment now benefitting from IEC 61850 functionality includes ABB's intelligent electronic devices (IEDs) such as REF MV protection relays as well as Emax 2 LV circuit breakers. Together, these two devices make it possible to design and operate a fully integrated protection and supervision system that spans the LV and MV worlds. This comprehensive approach is made possible by exploiting IEC 61850 to create features such as advanced logic selectivity based on device-to-device communication, real-time diagnostics and integrated engineering. A significant deployment of this innovative technology recently took place in Italy, where ABB installed an IEC 61850-based LV and MV protection system in an ice-cream factory.

01

—
01 Adoption of IEC 68150 for LV equipment has greatly enhanced protection and supervision systems. Shown is LV and MV switchgear ABB recently provided to a customer site.

—
02 Simplified single-line diagram of GOOSE communication.

—
03 GOOSE-based LV/MV diagnostics.

IEC 61850 is a well-established communications standard for substation automation. However, rather than merely embodying a set of dry rules, IEC 61850 can also form the bedrock of a complete electrical design concept that includes the entire protection, control and supervision system. In contrast to other industrial automation protocols, IEC 61850 was specifically designed to meet the needs of substation automation, which are relentless in their increasing complexity. Also, interoperability is considered at a very basic level to enable equipment from different vendors to be integrated into the same system without custom-designed gateways or other engineering-intensive complications.

While designed for substation automation, IEC 61850 is potentially applicable to protection systems in all electrical installations, including those in industrial and commercial arenas. In fact, its increased reliability, finer selectivity, shorter fault reaction times and the possibility to implement fault tolerance and integrated diagnostics make IEC 61850 the protocol of choice for many critical process control systems in chemical plants, oil installations, data centers and marine applications, etc.

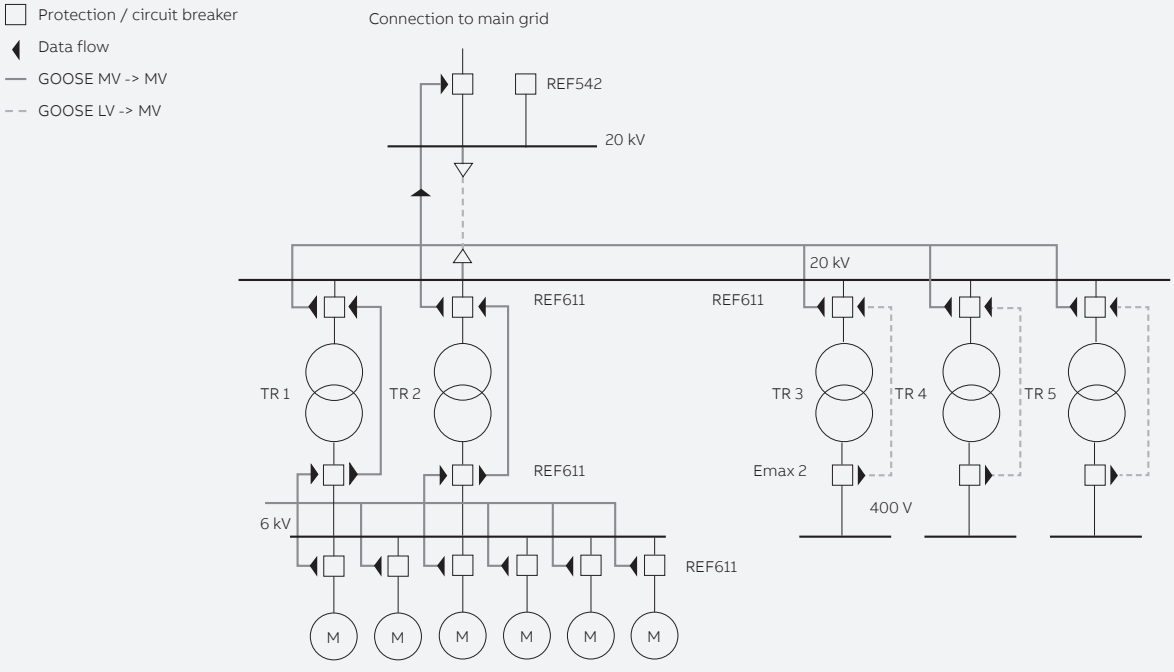
GOOSE

From the data communication point of view, IEC 61850 has been designed to fulfill the needs of electrical protection systems. However, there are some basic differences between these systems

—

IEC 61850 can form the bedrock of a complete electrical design concept that includes the entire protection, control and supervision system.

and process control systems that influence how communications should be implemented.
Process control is typically designed for the implementation of control loops: Measured samples from sensors need to be transferred to a controller that runs control algorithms and produces output to be sent to actuators. These actions are repeated cyclically, with adherence to sampling frequency and cycle time a paramount requirement.
When a network or field bus is used to connect controllers, sensors and actuators, many interlaced control loops share the available bandwidth in a round-robin fashion. Designing this kind of system often involves scheduling as many cyclic data packets as possible into the available bandwidth.



In each cycle, sensors are read and actuators are operated only at fixed times, with the step interval determined by the cycle duration. This cycle time, determined in the system design phase, introduces a delay between a change in the measured quantity and the operation of the relevant actuator. Such a delay is of no concern as long as it is compatible with the time constants of the process under control.

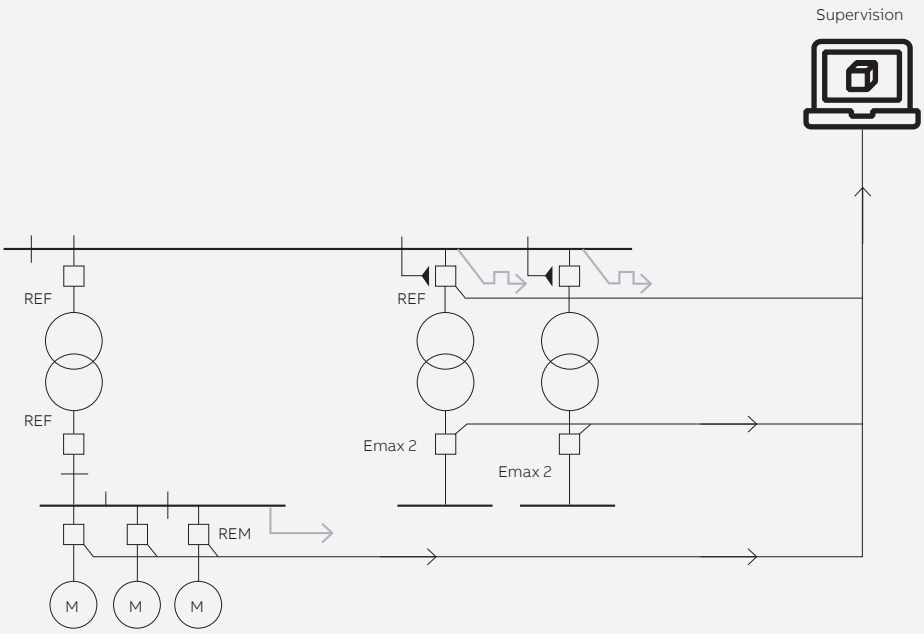
Protection systems, as well as the supervision of electrical installations, follow a different concept: Electrical quantities are measured by the supervision system in cycles that are relatively slow and the measured quantities are typically not used in control loops. When a fault occurs, however, the protection devices that detected it suddenly need to transmit fault information as quickly as possible because other devices must receive the information and decide which breaker should trip. Arranging such transmissions in a round-robin or other cyclical fashion, which requires the device to wait its turn for access to the communication media, would introduce unacceptable delays. The effective handling of such unscheduled, on-event communication is one of the differentiating features of IEC 61850 and it is implemented using special data packets named GOOSE (generic object oriented substation event) messages. Instead of cycle time, with GOOSE messages the key engineering characteristic is latency, ie, the delay between an event and the transmission of relevant information on the network →2.

The effective handling of unscheduled, on-event communication is one of the differentiating features of IEC 61850 and it is implemented using special data packets named GOOSE messages.

A key feature of GOOSE messages is that they can be used for horizontal (ie, peer-to-peer) communication between devices in addition to the usual vertical communication from devices to a supervision system.

So, a logic selectivity or an interlock between two circuit breakers can be implemented by direct message exchange between the relevant devices without relying on a central processing unit to manage the process. Horizontal communication improves both performance (shorter overall reaction time and more efficient use of the communication channel) and reliability (as a failure of the central processing unit would impair the whole protection scheme).

Normal status



— 04 Installation work at a customer site.

— 05 General view of the LV and MV switchgear ABB provided to a customer site.

In addition to fault signaling, GOOSE messages can be used to implement a built-in diagnostic mechanism in the protection system. Each device can be configured to send a GOOSE message to others on a regular basis (eg, every second) to report that its status is normal. If the relevant devices fail to receive the appropriate message they may send alarm messages, switch to a predefined safe mode or take other actions as required →3. Diagnostic messages use the same communication medium as other data packets, so no additional hardware is required.

— Interoperability is considered at a very basic level to enable equipment from different vendors to be integrated into the same system without custom-designed gateways or other engineering-intensive complications.

Engineering and configuration

Additional advantages of IEC 61850 are related to engineering and configuration processes. Because of the complexity and number of the devices involved, designing a protection system without a structured, computer-assisted process would be impossible. The sheer number of configuration and working details would overwhelm the engineer and cause critical errors. To prevent this, IEC 61850 relies on standardization of objects and data types, and on formal electronic descriptions.

IEDs used for protection can be very complex. Their complexity is managed in IEC 61850 by describing each device as a set of logical objects, which can be published to the final application. Such objects are abstract enough to be applicable to devices of different types or from different vendors, yet realistic enough to be applicable to the engineering job in hand. Examples of such objects are overcurrent protection, current and voltage measurement, control of a switch, etc.

04

05

At the cornerstone of the IEC 61850 data model is a catalog of standardized logical objects with well-defined meanings, and applicable parameters and data items. All devices compliant with IEC 61850 use the same objects to implement the same function, making it possible to combine objects in a common way in a final application.

Such standardization goes down to object names (eg, PTOC always represents an overcurrent protection), which makes them easy to recognize and use by the design engineer. Data types are also set by IEC 61850, so that, for example, the result of a measurement is defined together with its name, measurement units, quality indications and so on, thus reducing the probability of errors.

06

—
06 Transformer panel in a customer site.

—
07 GOOSE-based circuit-breaker trip selectivity.

To complement such standardization, IEC 61850 describes a common electronic format in which devices and systems are described.

All devices – ie, all IEDs in this case – are each described by a file, written in SCL (Substation Configuration description Language), that lists all its properties and logical objects.

—

A key feature of GOOSE messages is that they can be used for peer-to-peer) communication between devices, thus improving performance.

SCL files can be read and manipulated by IEC 61850 software engineering tools, allowing a smooth process and a reduced number of errors.

Such a formalized electronic description language has the important side effect of easing interoperability between devices from different vendors: As long as the objects they implement are described by the SCL file, the user need not be concerned with their inner workings.

IEC 61850 joining the LV and MV worlds

Most existing IEDs are protection relays used in MV installations. However, significant advantages are achieved when IEC 61850 is applied in the LV world. This is now possible by using ABB Emax 2 circuit breakers – the first air circuit breakers to implement a native IEC 61850 interface.

Further, ABB's Ekip digital protection unit, which can be installed on Emax 2 breakers ranging from 800 A to 6,300 A and fitted with a choice of communication protocols, also comes with IEC 61850. Full integration between LV and MV protection and supervision systems can finally be attained, with significant improvement in reliability and a smoother, unified interface to supervision systems.

IEC 61850 for an ice-cream factory
A particularly significant example of such integration is the LV and MV switchgear ABB recently

ABB's Emax 2 circuit breakers are the first air circuit breakers to implement a native 61850 interface.

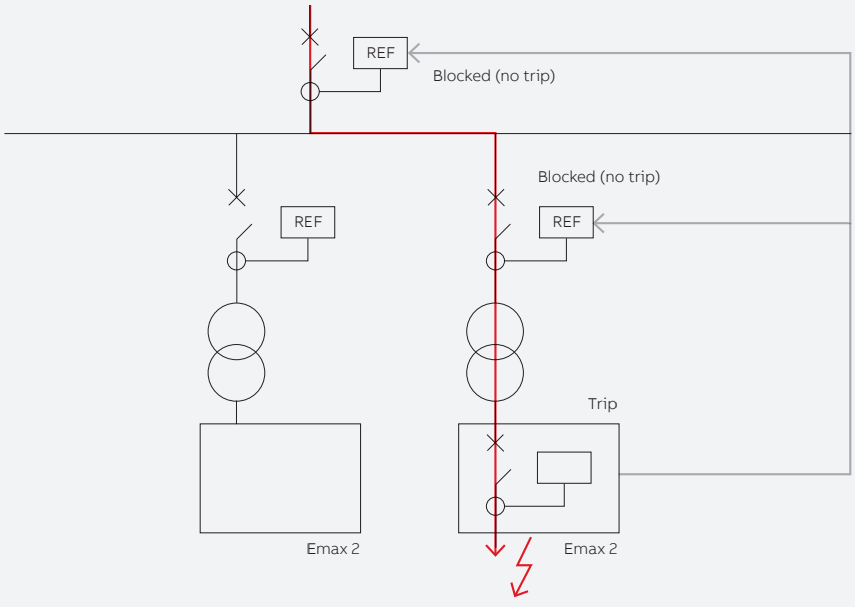
provided to a customer site in Ferentino, Italy. The plant, one of the largest of its kind, is an ice-cream factory producing some of the best-known brands in Italy.

The installation includes a main 20 kV panel with UniSec switchgear for connection to the main grid and a second panel feeding several 4 MVA and 3 MVA transformers. The transformers, in turn, power a 6 kV panel that supplies process motors and the main LV switchboards. The LV switchboards are supplied by a third-party panel builder and use ABB Emax 2 circuit breakers. All the MV relays (REF611, REF542+ and RIO600) and REM motor protection devices are connected by an IEC 61850 bus, which also connects the three main Emax 2 circuit breakers serving as main incomers for the LV part →4–6.

Using IEC 61850 across the LV and MV protection systems allows implementation of a number of advanced features, the most important of which is logic selectivity when a short circuit occurs. Should a short circuit occur on one of the MV motor feeders, its protection relay immediately sends a GOOSE message to the upstream protective devices (REFs used for transformer protection and interface protection), so that they refrain from tripping; only the circuit breaker installed closest to the fault is instructed to open →7. Unnecessary loss of power on other parts of the plant is thus avoided and process availability is maximized.

Similarly, in the case of a short circuit on the LV side, the affected Emax 2, while clearing the fault, sends a GOOSE message to the REFs, so that no MV breaker trips unnecessarily.

In addition to improved logic selectivity and a higher overall reliability, use of a single protocol offers a common interface for plant supervision and monitoring, providing more and better quality data to operators so they can run the plant in an optimum way. ●



07 — Fault current — Goose signal (trip block)

PROTECTION AND SAFETY

Leading the way with ABB emergency lighting

Increased safety is delivered with ABB's Guideway emergency lighting in the world's most sustainable building. Guideway also delivers a 57 percent saving in terms of energy and maintenance over a 12 year period.

02

Barbara Brokken
ABB Electrification Products,
Installation Products
Emergency Lighting

Barendrecht, Netherlands
barbara.brokken@tnb.com

How do you combine increased safety with low energy consumption in the ultimate design setting? The Edge – the world's most sustainable building, located in Amsterdam, the Netherlands – sets a contemporary standard in emergency lighting with Guideway from ABB's solutions for emergency lighting. The lighting's green pictogram plates are highly visible in daylight, whilst their powerful LED lights save 57 percent on energy compared to standard fluorescent tubes. Although the pictogram plate may be striking, its design keeps things low key. The frameless Guideway blends with the environment →1.

01

The use of large glass walls in contemporary architecture is setting new requirements in terms of escape route signalisation. In daylight, the legend plate has to be clearly visible so building users see the fastest way out in case of an emergency →2. ABB's Guideway escape route signalisation illuminates the pictogram plate with a light of 500 cd/m². To put that in context, an average desktop LCD has a luminance of 200 to 300 cd/m² →3–4.

The lighting's green pictogram plates are highly visible in daylight, whilst their powerful LED lights save 57 percent on energy

Focus on design

In December 2014, The Edge received the highest ever score from BREEAM-NL (Building Research Establishment Environmental Assessment Methodology). The building got an outstanding rating with the highest-ever score of 98.4 percent [1]. Such highly rated environmental credentials naturally required an emergency lighting solution to match and that is where Guideway came in.

—
01 ABB's wall-mounted version of the Guideway emergency lighting.

—
02 The Edge features large glass walls and lots of daylight, which makes Guideway's 500 cd/m² luminance essential.

—
03 QR code for (English) Guideway product video.

—
04 QR code for (English) Guideway installation video.

—
Reference
[1] BREEAM-NL (accessed 2016, April 6). The Edge Amsterdam [Online]. Available: https://www.breeam.nl/projecten/edge-amsterdam-0

Increased safety
Deloitte's project manager for The Edge, Tim Sluiter, said "This building is very transparent, built with clean lines and sophisticated materials,

The long lifespan of 100,000 hours reduces by 10 times the need to replace the light source over a 12-year period

which means there was no place to hide a thick bumpy luminaire. We needed nice, well-designed luminaires that suited our vision for the building. We have the large atrium and open skywalks – big open spaces that are also very light, with ambient daylight or reflections hampering the visibility of the escape route. We eventually decided on the Guideway luminaire, with its very flat, thin plate and thin steel frame. But Guideway's distinctive quality is that it is very easy to see. If you're on one side of the skywalk, then you can look all the way over to the other side, where the sign can be clearly seen. It goes without saying that this luminaire meets all the regulatory requirements and can clearly be seen from 32 metres away.

At Deloitte, health and safety are naturally an important starting point, since our people are our capital. So we must treat them with care. Emergency lighting is obviously a big part of that."

Cost reductions
The pictogram plate emits an even and strong illumination across the entire surface thanks to powerful LED technology. This results in a 57 percent saving in terms of energy and maintenance over a 12-year period in comparison with a fluorescent tube. The long lifespan of 100,000 hours reduces by 10 times the need to replace the light source over a 12-year period.

That's the power of ABB emergency lighting.
It only draws attention when it needs to. ●

03 04

PROTECTION AND SAFETY

Dry insulation for condenser bushings

High-voltage (HV) condenser bushings are critical components of all electrical networks. Because they are subject to high levels of electrical stress, failures in HV condenser bushings tend can be catastrophic. Producing bushings for use at 800 kV and above requires careful design and manufacture.

Lars Jonsson
Roger Hedlund
ABB Insulation and Components, Bushings

Ludvika, Sweden
lars.y.jonsson@se.abb.com
roger.hedlund@se.abb.com

High-voltage (HV) condenser bushings are critical components found in all electrical networks. Because they are subject to high levels of electrical stress, failures in HV condenser bushings tend to result in sudden and catastrophic events of an explosive nature. There is much to gain if the consequences of failures can be reduced, and this is probably why a growing number of utilities now specify dry insulation technology with an outer insulation made of non-brittle materials. However, producing bushings for use at 800 kV and above requires careful design and manufacture, and is not just a matter of upgrading existing, lower-voltage technology as the technical steps that need to be taken to ensure trouble-free operation are often nonlinear →1.

Condenser bushings are a familiar sight to anyone working in the world of HV. Though presenting an outward impression of simplicity, these essential components of the power grid have emerged from a design and manufacture process that is highly sophisticated.

Condenser bushings consist of three primary components: an outer insulation for minimizing creepage currents and preventing external flashover; an inner capacitance-graded insulation “condenser” for distributing and stabilizing the electrical field (thus “condenser”); and a conductor system for carrying the current.

In the inner insulation there are a number of very precisely positioned, coaxial layers of conducting material in a paper web →2. To increase the dielectric strength of this insulation, it is impregnated with either transformer oil or a curable epoxy resin. These approaches are called oil-impregnated paper (OIP) and resin-impregnated paper (RIP), respectively. Use of OIP bushings began in the 1950s and is still the dominant concept for the highest voltage levels, ie, those from 735 kV. RIP bushings have been gradually developed for higher voltages too and are becoming increasingly common, but the step up to the highest voltage levels has taken time due to the technical challenges involved as well as general conservatism in the power industry.

Since the 1980s, silicone rubber has gradually been developed as a perfectly good alternative to ceramic material.

For the outer insulator, ceramics have dominated for quite some time. Various forms of polymeric materials have been tested over the years, but the effects of sunlight have limited service life. Since the 1980s however, silicone rubber has gradually

—
01 Producing condenser bushings with dry insulation for voltage levels of 800 kV and above requires much skill and care in design and manufacture. Shown is routine electrical testing of the first commercial delivery.

been developed as a perfectly good alternative to ceramic material. Silicone rubber attains maximum energy absorption at wavelengths lower than those present in sunlight and consequently provides significantly better service life than other polymeric materials.

Advantages of RIP

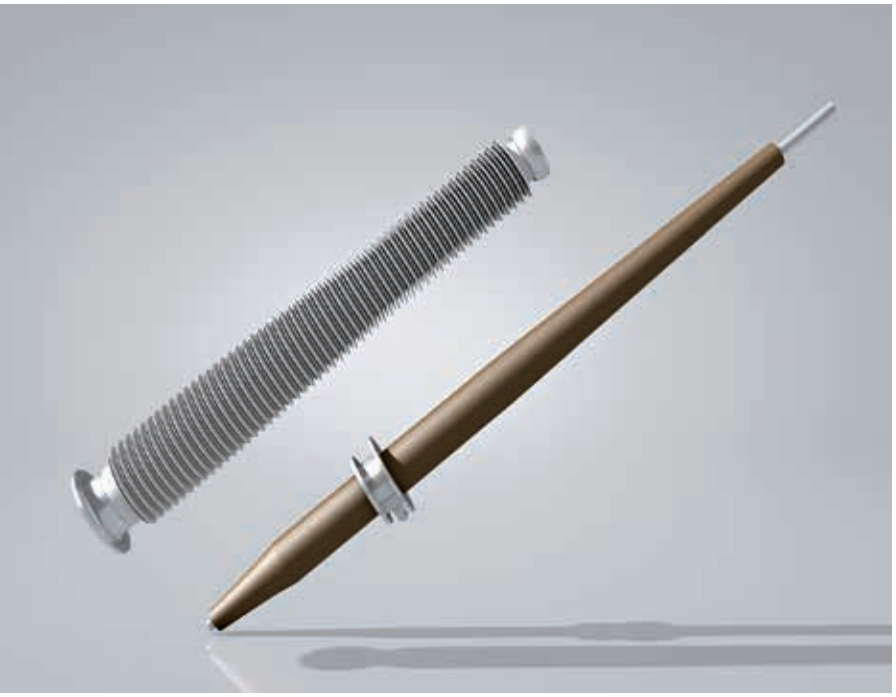
The biggest advantage of the RIP concept for utilities is the dramatically decreased consequences in the event of bushing failure. Although phase-to-ground flashover can have many causes – for example, failure of the bushing itself or electrical, mechanical or thermal stresses from the grid system – flashover in an OIP bushing nearly always produces an explosion that results in shattered insulators and oil spills. The consequences are especially serious when transformers catch fire [1]. Because RIP bushings do not contain highly flammable and energy-rich oil, the risk of fire is largely eliminated. There are a number of other factors that also support the benefits of RIP technology when it comes to reducing the consequences of failures [2], [3]. Besides not shattering in the event of failures, composite insulators consisting of silicone rubber that is extruded on a filament-wound tube have a multitude of other positive properties as outer insulation:

—

The mechanical engineering effort for the dry-insulated 800 kV bushing has been extensive, especially concerning seismic requirements.

- Thanks to the chemical structure of the silicone, the insulator's surface is hydrophobic, so water forms droplets – instead of a water path – on the surface. This reduces creepage currents (and, consequently, erosion), and flashover risks in extreme weather conditions.
- The continuous nature of the manufacturing process produces a chemical bond between the tube and insulator. Because both the silicone rubber and filament-wound tube are entirely free of joints, the electrical field distribution is smooth and continuous, and there is minimal risk of moisture penetration. There are also no parting lines where salt and pollutants could collect →3.
- Extrusion also provides the opportunity to optimize the insulator's shed profile for different applications. This results in a further reduced electrical field, which in turn lessens the risk for tracking and erosion [2].
- The chosen polymeric insulation material is a high-temperature vulcanized (HTV) rubber that has a carefully balanced mixture of pure silicone and an aluminum trihydrate (ATH) filler as the basic material. Besides mechanical strength, the ATH filler is also temperature- and fire-resistant, and recovery of hydrophobic properties after heavy rain, for example, is rapid if the amount of ATH used is optimized. Experience from the field has also shown that HTV rubber is highly resistant to erosion and that it retains its hydrophobicity for extended periods [4].

01



02

— 02 Primary bushing components: Outer insulation (left); inner insulation with mounting flange and conductor (right).

— 03 Manufacture of outer insulation.

— 04 Details from the FEM analysis for the mounting flange.

— 05 FEM calculation of silicone sheds.

- This type of insulator is significantly lighter and mechanically stronger than corresponding ceramic insulators. This is very important in withstanding the effects of earthquakes and short circuits, as well as in limiting damage during handling.

Important considerations when developing bushings for 800 kV

A few examples of important considerations to be kept in mind when developing dry-insulated bushings for 800 kV are:

- A major cost driver is the required wet switching impulse withstand since this, to a large extent, determines the bushing's length. This is of special significance for RIP bushings since length is closely related to the complex casting and hardening process, process vessel dimensions, machining equipment specifications, etc.
- Seismic requirements apply in some parts of the world. During the engineering process, extensive dialog is necessary between transformer manufacturers and utilities to assess, for example, installation angles and structural reinforcement factors where the bushing will be installed.
- Regard for requirements that reflect local conditions, such as ambient temperatures.
- A flexible design that permits dimensional adaptation to previously installed equipment, regardless of manufacturer.

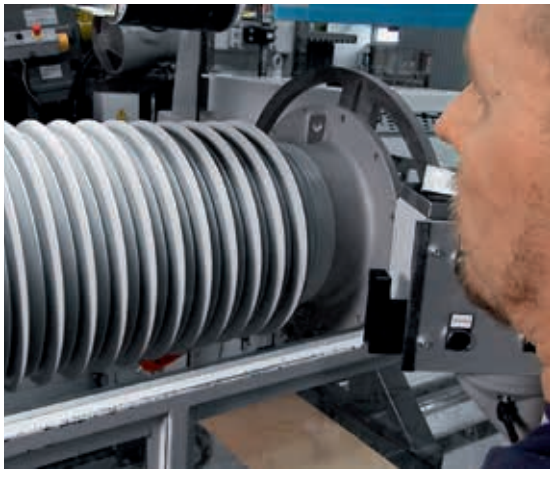
Mechanical engineering aspects

The mechanical engineering effort for the dry-insulated 800 kV bushing has been extensive, especially concerning seismic requirements.

A solid base of experience from previous seismically tested bushings from the GSB series has been of great benefit, particularly with regard to modelling and analysis of dampening and natural frequency. Nonetheless, several finite element (FEM) analyses have been conducted – linear as well as nonlinear – with subsequent verification tests of critical components. The dynamic analyses have been performed both with required response spectra (RRS) and test response spectra (TRS). The calculated results have been verified with full-scale shake table testing and are in compliance with the seismic requirements as stipulated in IEEE 693-2005 and other, even more demanding local specifications →4.

The draw-rod solution, used by ABB since the 1970s to simplify installation and replacement of bushings in the field presented mechanical challenges that resulted in a partially new technical solution. Compared to oil-insulated bushings with ceramic insulators for corresponding voltages, the higher temperature expansion in RIP bushings made it impossible to retain the contact force between different current-conducting components without a major redesign. In-depth mechanical analyses, such as for buckling cases, short-circuit force, contact forces, etc., have been performed with the support of FEM analyses and associated testing.

Due to the dry bushings' general difficulty in dissipating heat, new low-resistive material combinations have sometimes been necessary to reduce losses. This has led to challenges when it comes to corrosion protection in harsh industrial and coastal environments. New materials have also entailed the introduction of newly developed sealing systems. All design solutions, including those related to corrosion, have been verified by testing.



03

—
This article is based on the following CIGRE paper: L. Jonsson, R. Hedlund, "Development of dry-insulated 800 kV transformer bushings," 2016 CIGRE-IEC Colloquium, © 2016 IEEE, Montreal, Canada.

—
References
[1] S. Tenbohlen et al., "Development and results of a worldwide transformer reliability Survey," CIGRÉ Study Committee A2 Colloquium, 2015.

[2] L. Jonsson, et al., "Dry transformer bushings with composite insulators – the obvious combination for increased reliability," TechCon Asia-Pacific, 2013.

[3] L. Jonsson; "Fire and safety aspects on high-voltage bushings," World Congress on Insulators, Arresters and Bushings, 2009.

[4] I. Gutman, et al., "Long-term service experience and inspection results of HV equipment made of silicone rubber insulators," Ref. 412, CIGRÉ session, Auckland, 2013.

Thermal engineering aspects

Dielectric heating of inner insulation can be of major significance. Oil-insulated bushings have effective convective cooling for handling dielectric and resistive losses; RIP bushings do not. This necessitates an extensive theoretical analysis of designs to ensure thermal stability under all testing and operational conditions, as well as to comply with overload requirements.

During the temperature cycling tests, the ambient temperature was varied between -50 and +40 °C, with carefully specified up and down ramp times. The main challenge is to cope with the substantial temperature gradients and associated mechanical stress set up by the condenser core's cool mass and elevated ambient temperatures.

In-depth analyses using, for example, differential scanning calorimetry (DSC) and dynamic mechanical thermal analysis (DMTA) have been necessary to gain a detailed understanding of crystallization at various cooling temperatures and of how stresses in the materials occur. Extensive FEM analyses of the cooling and crystallization process in different sections of the insulation, followed by verifying component testing, were conducted prior to the final, full-scale tests that were performed on a complete bushing. These analyses led to, among other things, optimization of certain steps in the manufacture of the outer insulation →5.

—

An entirely new production facility was necessary to make the new bushing series.

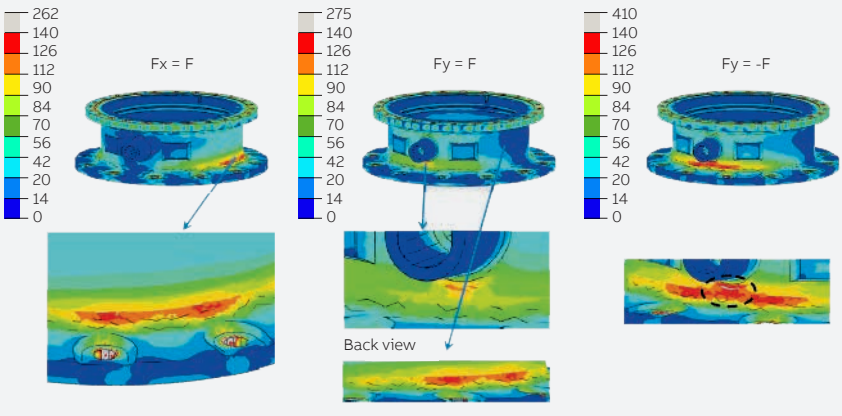
Manufacturing

Because high-voltage bushings generally require very low levels of partial discharge, one of the greatest challenges in RIP bushing manufacture is the impregnation and hardening of the inner insulation. The ability to manage sophisticated manufacturing processes with minimal process deviation is thus entirely decisive. With such complex manufacture processes, it has also been difficult to directly utilize experience from existing products for lower voltages because many critical parameters are not linearly scalable, but are quadric or even cubic in nature. This can place requirements on production equipment many times greater than what may be initially perceived: The weight of a dry 800 kV bushing is, for example, more than twice that of a corresponding product for 500 kV systems, and the length of the air side is over 40 percent longer.

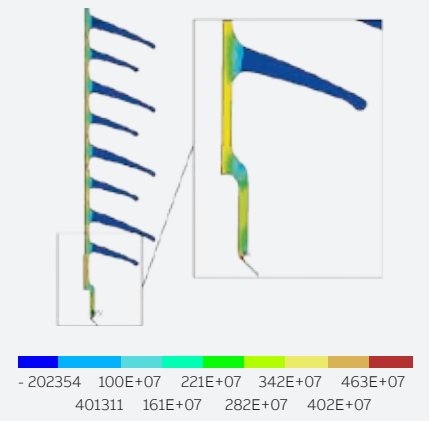
The challenges involved in winding condenser cores for these voltage levels are largely related to placement control of the condenser core's conducting layers. The dimensional change that occurs when drying alters the layers' axial dimensions more than the radial dimensions. Temperature effects have also entailed that process tools must be dimensioned to handle substantial changes in length during casting.

During the actual casting process, nearly 2,000 kg of epoxy must be injected into the cellulose core and hardened without the formation of air cavities. Air cavities would otherwise cause electrical discharges during the final routine test and necessitate scrapping of the bushing. To avoid this, hardening of the epoxy must be closely monitored throughout the process.

An entirely new production facility – with a winding machine, process equipment and updated control equipment, as well as entirely new equipment for machining – was necessary to make the new bushing series. The first commercial deliveries were made during 2015. ●



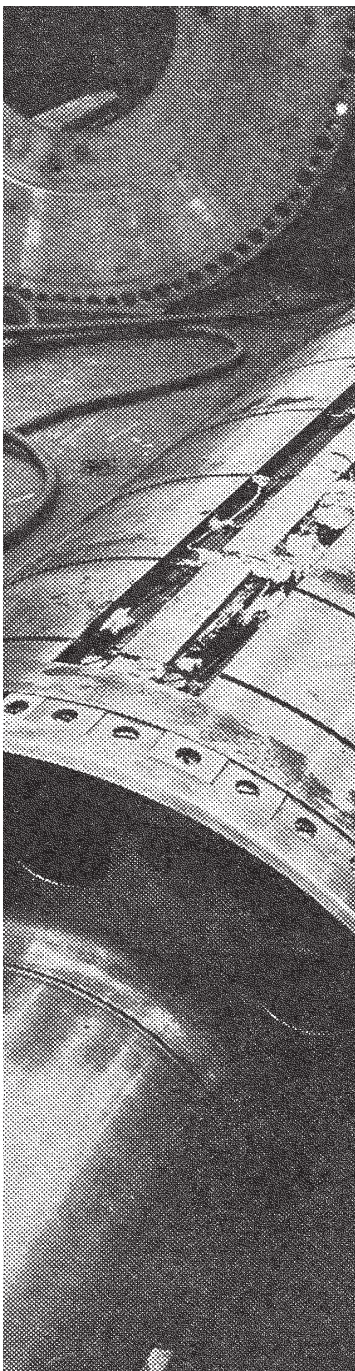
04



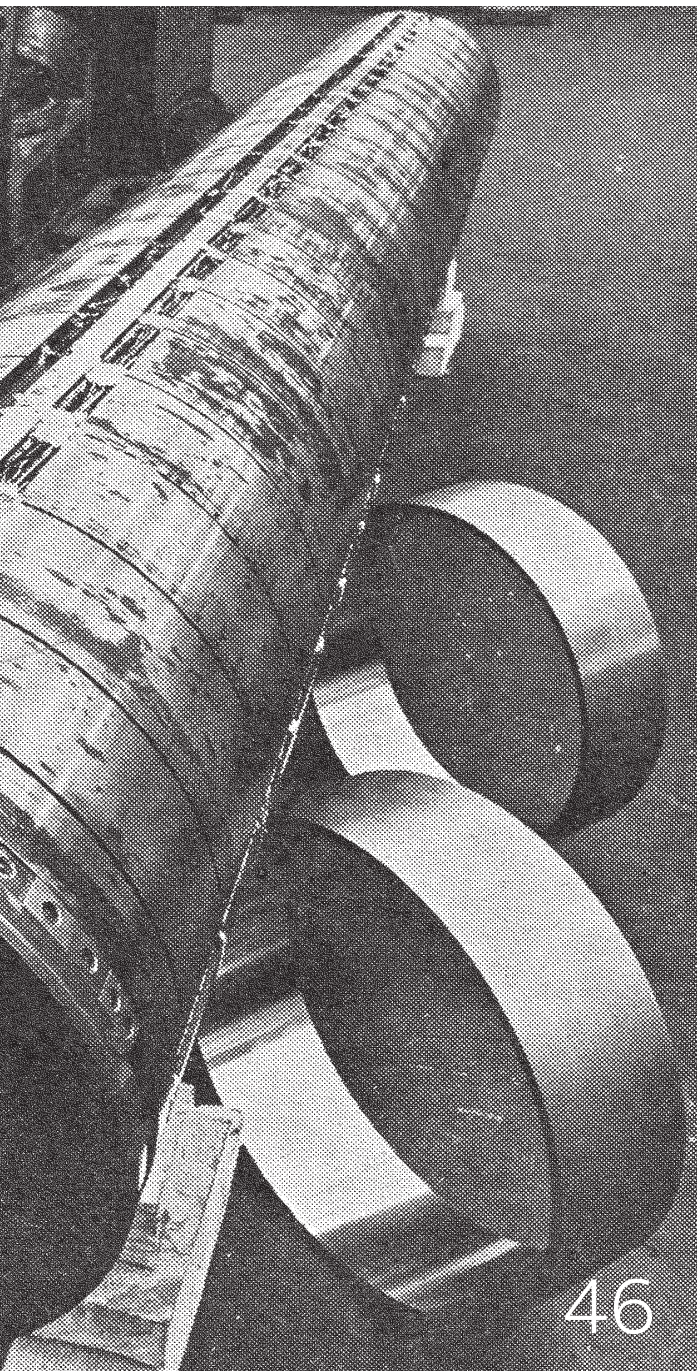
05

Measurem

40



nent



Collecting data from a metal rolling mill while it's operating involves far more challenges than aggregating smartphone user data. It illustrates the yawning gap between the performance requirements of industrial versus consumer technologies.
Operationalizing it is as complicated as it's important, because it gives clients a lever to better quality, yield and higher productivity in safer environments.
ABB kicked-off the modern era of innovation in measurement for flatness a half century ago, and has iterated it ever since. Its state-of-the-art thickness gauge is based on the latest technology.
Both measurement tools are accessible by smartphone.

MEASUREMENT

Non-ferrous metal thickness gauges

ABB's Millmate thickness gapless gauges (MTG) based on pulsed eddy current technology ensure reliable and efficient thickness control under harsh mill conditions while eliminating health, safety and environmental concerns.

Lennart Thegel
Eva Wadman
ABB Industrial Automation
Measurement & Analytics

Västerås, Sweden
lennart.thegel@se.abb.com
eva.k.wadmann@se.abb.com

ABB's Millmate thickness gauge (MTG) systems in combination with pulsed eddy current (PEC) technology provides customers with a choice of products tailor-made for non-ferrous strip production needs. Both the gapless MTG box gauge system and the MTG C-frame gauge system depend solely on strip thickness and are the ultimate sensors to ensure thickness control under harsh mill conditions while eliminating health, safety and environmental concerns associated with radiometric gauges. The MTG gapless gauge provides the ability to measure at the heart of the rolling process, where it is impossible for other gauges to operate. By developing state-of-the-art measurement sensors, ABB addresses the customer need to increase the reliability, efficiency and cost-effective production of non-ferrous metal strip products such as aluminum can stock and car body stock →1.

Low weight, recyclability and attractive material properties make aluminum ideal for many consumer and industrial processes. Currently, there is a worldwide market demand for and investment in aluminum production capacity. This demand has translated into an increased use of rolled aluminum products during the last decade. A greater production of aluminum is evident for both the canned drinks and automotive industries. This expansion is partly due to consumption of aluminum for car structural components and exterior panels for both high-end and high-volume vehicles →2.

Aluminum, due to its low density and relatively high strength, is particularly suited to replace steel in the car body. The resulting lightweight vehicle produces lower CO_2 emissions and consumes less fuel than conventional cars. To accommodate the increase in production of aluminum strip for these industries, improved production facilities

> Currently, there is a worldwide market demand for and investment in aluminum production capacity.

and state-of-the-art measurement sensors are required. ABB has more than 15 years of experience in sensor development to ensure the accurate measurement of aluminum thickness and optimized production process costs.

Sensor significance

The use of sensors for accurate measurement has been indispensable for the control of industrial processes since the industrial revolution. Yet the facility constraints and environmentally harsh conditions within industrial environments, such as rolling mills, can affect sensors negatively, leading to production process delays and downtime,

—
01 Operation of MTG Box gauge in an industrial setting.

which translates to increased production costs. ABB invests in the research and development of sensors that operate under a variety of mill spatial constraints and that are insensitive to production environmental conditions and variations in material composition, with a view to improving aluminum strip production and reducing cost.

—

In the aluminum industry, thickness is one of the most important properties to measure and control.

Traditional measurement technology concept

In the aluminum industry, thickness is one of the most important properties to measure and control. Meeting tight strip tolerances is crucial for both the production process and the product itself. Radiometric gauges, ie, isotope and X-ray gauges, have been available for many decades and are commonly employed. X-ray gauges exploit the attenuation of radiation passing through the metal strip. A detector measures the intensity of radiation emitted from a source on the other side of the strip. The thickness is calculated from the knowledge that the intensity is affected by density changes in the measuring gap.

There are advantages to this method, such as tolerance of large air gaps, but disadvantages exist too. In addition to health, safety and environmental issues, radiometric gauges are problematic for aluminum measurement accuracy. Aluminum has low density and therefore a low absorption coefficient. Consequently, environmental factors such as dirt, steam and air temperature impact thickness measurements and result in deviations, which must be corrected. Aluminum is also typically alloyed with other metals to create desired properties such as strength. The presence of other metals, such as copper, affects the absorption of aluminum thereby making thickness measurement using X-ray gauges challenging. The alloy dependency of X-ray gauge results necessitates thickness corrections of up to 50 percent, which can easily mean a thickness deviation of one percent, clearly a strong disadvantage for aluminum strip producers.

01

Innovations in measuring technology
In response to the problem of accurate measurement of aluminum strip using radiometric sensors, ABB has pursued the development of the perfect gauge for aluminum strip producers. In 2001, ABB introduced the MTG C-frame gauge for strip thickness measurement in non-ferrous cold rolling mills. This sensor addresses the needs of customers

—

In 2001, ABB introduced the MTG C-frame gauge for strip thickness measurement in non-ferrous cold rolling mills.

who wish to achieve accurate thickness measurements for aluminum, as well as copper, independent of rolling mill environment and alloy properties. The MTG C-frame gauge is based on patented PEC technology, as opposed to the radiometric gauges common in the past.

PEC technology uses electrical coils to create pulse-formed electromagnetic fields that result in a pulse response from the strip. A voltage pulse induced in the coil when the current is suddenly interrupted is measured. After the abrupt interruption of the constant excitation current fed to the coil, the magnetic field produced by the eddy current in the metal sheet is measured as a transient voltage →3.

Customers can now measure distance, resistivity and thickness for non-ferrous strip with exceptional accuracies without the need for information about alloy properties or environmental conditions at the mill. Superior thickness accuracy is achieved.

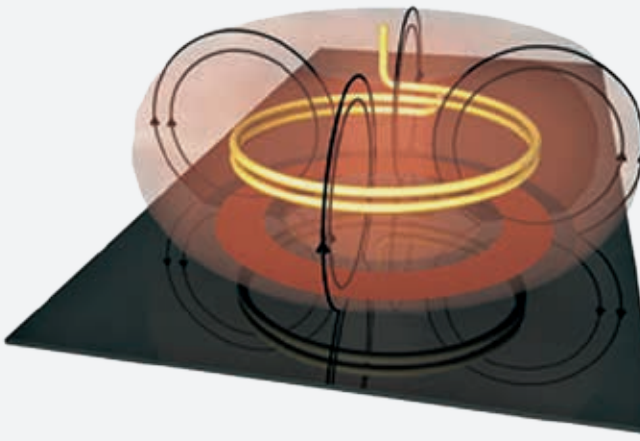
The use of MTG gauges instead of radiometric gauges also results in a safer work environment and eliminates the need to train or certify employees or dispose of radioactive waste material.

02

—
02 Growth of aluminum bodied automotive vehicles is anticipated.

—
03 The patented pulsed eddy current technology relies on weak magnetic fields for measurement.

—
04 Accuracy levels attained in aluminum strip production.

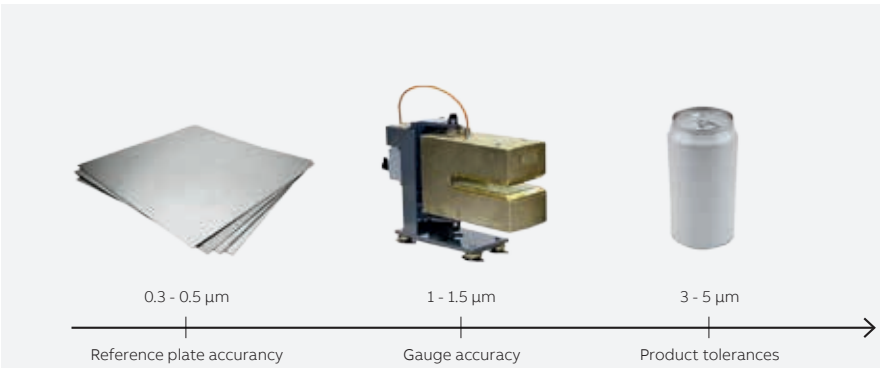


03

Calibration requirements and process
In an ideal world, manufacturers would like sensors to be ten times more accurate than the product process tolerances. Commonly used sensor accuracy is three to four times greater than product process tolerances. Reference material measurements must be at least three to four times more accurate than the sensor being utilized. Accordingly, calibration reference material measurements must be at least ten times more accurate than the product tolerances in can stock products as well as other types of aluminum strip →4. To achieve accurate sensor measurements ABB has invested in technology to perfect calibration by simplifying the related procedures.

MTG systems calibration processes
ABB provides aluminum producers with efficient, reliable and accurate sensors to compensate for the presence of various alloys and remove the need for extensive calibration materials and procedures, especially when using X-ray gauges. A variety of challenges are resolved by installing MTG systems based on PEC technology. The application of a weak magnetic field results in a contact-free thickness measurement and eliminates the disadvantage associated with aluminum's low absorption coefficient. Because the thickness measurements are independent of environmental factors and material properties, there is no need for customer-specific calibration plates – making downtime due to calibration negligible. The MTG systems developed at ABB are delivered calibrated and ready to use. Calibration is conducted at intervals of six months and takes 20 minutes to perform. ABB delivers the system with the 12 site calibration plates that are required for traceability and accuracy of the gauge by calibration on-site.

—
Customers can measure distance, resistivity and thickness with exceptional accuracies without the need for information about alloy properties or environmental conditions.



04

The calibration process is a two-step process →5: The first step is the calibration of reference plates maintained at ABB. The second step is the calibration of the site calibration plates that are included with the MTG system delivered to the customer.

Reference plates are calibrated at ABB by comparison with gauge blocks calibrated with traceability to national standard labs including NIST, PTG and NMIJ. ABB has developed and designed an accurate mechanical measuring machine for this purpose. Reference measurements are performed using a laser Hologage probe with a measuring resolution of 0.01 µm.

In the second step, the site calibration plates are calibrated by direct comparison with the calibration reference plates of similar thickness and equal material properties, using an MTG gauge that is both calibrated and temperature stabilized. Calibration accuracy of 0.3 to 0.5 µm is reached for site calibration plates. There is no need for customer specific plates or frequent calibration procedures to achieve the desired thickness tolerances so crucial for aluminum strip producers.

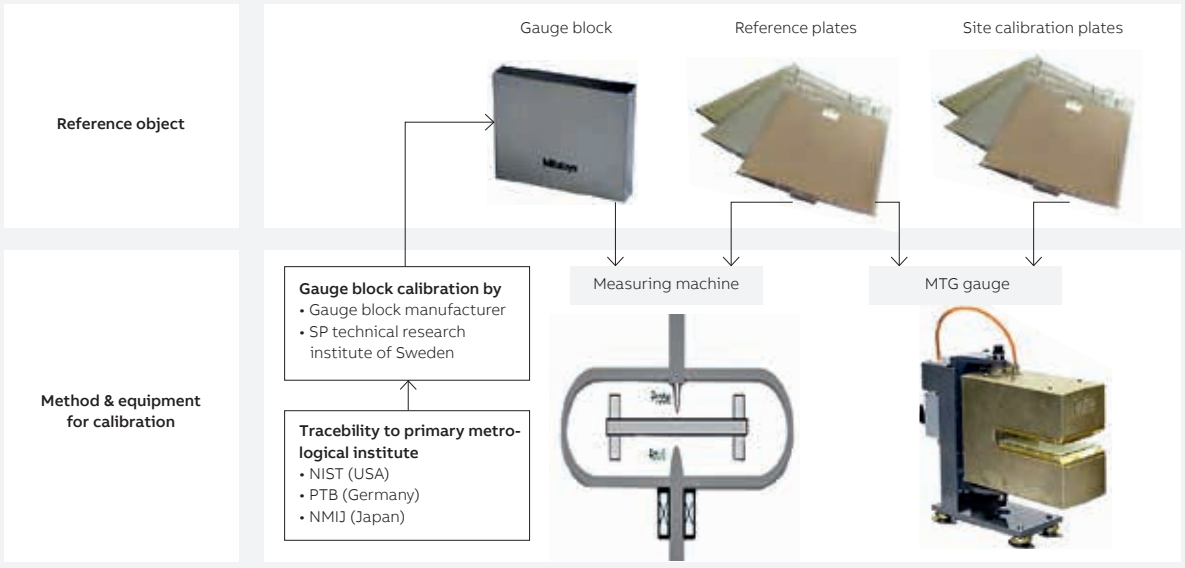
The MTG box gauge, invented and patented by ABB, is compact, robust and uses weak magnetic fields for measurement based on PEC technology.

Unique gapless measurement solution

In 2016, ABB added the singular gapless gauge sensor to its palette of MTG gauge systems that measure aluminum strip in aluminum rolling mills and continuous casters →6. The MTG box gauge, invented and patented by ABB, is compact, robust and uses weak magnetic fields for measurement based on PEC technology. The gauge is safe and survives mechanical impact. Most significantly, the new gauge sensor is gapless with nothing above the pass line that could obstruct the passage of the strip being measured. This unique invention can be placed in the center of the production process.

This unique invention can be placed in the center of the production process.

The MTG box gauge is usually installed below the mill table, which provides protection during threading, tail out and strip break. Like the MTG C-frame system, this new sensor is insensitive to anything located within the measuring area except for the metal strip. True aluminum strip thickness is measured from below with accuracy of 0.05 percent. The compact gauge can be placed close to the roll gap, or interstand, because it is independent of all environmental conditions. Considering the sensor is immune to material variations, the need to compensate for alloy content is eliminated and extensive calibration is unnecessary.



06

—
05 MTG Site plate calibration process.

—
06 MTG Box gauge system including gauge head, hydraulics, air regulator, control and operator units and monitors.

A mere 20 minutes is required every six months for onsite calibration. The use of the MTG box gauge results in increased levels of aluminum strip thickness control and fast feedback for the strip producers.

The MTG box gauge system consists of the PMGG201-H gauge head with an aluminum-bronze housing mounted on a vertically mobile frame. This robust sensor automatically adjusts its position

—

The presence of a hydraulic positioning system allows the gauge to measure instantly as soon as the strip tension comes on.

to optimize thickness measurements. The presence of a hydraulic positioning system allows the gauge to measure instantly as soon as the strip tension comes on. The control unit – the PMGA201 – is available either as a wall or floor cabinet and communicates with the gauge, thereby handling measurement data, error and status control. System interfaces using network communication with VIP (vendor internet protocol), OPC DA, Modbus TCP and a Profibus-DP fieldbus communication are possible, thereby integrating the gauge with other control mill systems. Operators can observe and control functions including operation diagnostics, service and settings.

The ease of use of the control system combined with the benefits of the gapless MTG box gauge using the PEC technology for aluminum thickness measurements make this system ideal for use in aluminum rolling mills. The material independence, elimination of environmental influence, safety, fast commissioning and reduced on-site calibration translate to increased production time and higher yields with virtually no maintenance. ●

MEASUREMENT

50 years of flatness control with ABB's Stressometer

For 50 years, ABB's Stressometer system has helped rolling mill operators improve quality and productivity. The technology has evolved greatly over the past half-century and it is worth reviewing the innovation that has been a key ingredient in overcoming the many challenges that arise in rolling mills.

Lars Jonsson
Force Measurement,
Measurement and Analytics

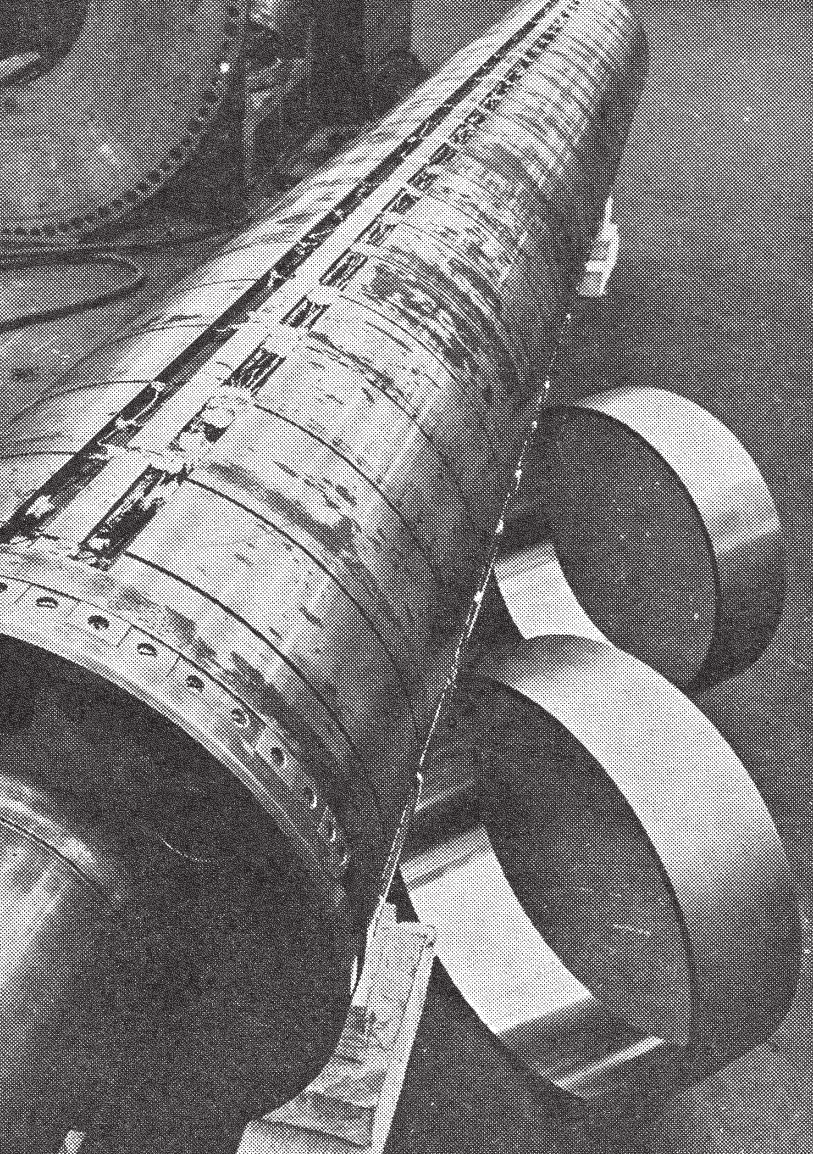
Västerås, Sweden
lars.oi.jonsson@se.abb.com

On April 14th, 1967, Asea, a predecessor of ABB, delivered the world's first strip flatness measurement system for a metal rolling mill. The customer who received this new product – the so-called Stressometer – was the Canadian aluminum company Alcan (now Novelis). Using it, Alcan was immediately able to make huge strides in productivity, profit and quality. After many technical enhancements and breakthroughs since 1967 – and more than 1,200 systems delivered – ABB is now highlighting the 50th anniversary of Stressometer →1.

01

ABB's Stressometer has its roots in Pressductor® technology. Pressductor is a transducer, developed by Asea and patented in 1954, that measures mechanical force using the magnetoelastic effect. This effect exploits the fact that the magnetic properties of some materials are influenced by mechanical forces applied to them. Because Pressductor transducers are not reliant on physical movement or deformation, they combine sensitivity with an extraordinary tolerance to overloads and virtually no built-in limit to the number of load cycles. ABB Pressductor transducers produce high-power, low-impedance AC signals that are very resistant to electrical interference and earth faults.

In the mid-1960s, Alcan of Canada and Asea started a joint development to make a sensor that would measure strip flatness.



02

—
01 For 50 years, ABB's Stressometer system has helped rolling mill operators improve quality and productivity. Shown is the operator room in an aluminium tandem cold mill equipped with two Stressometer systems.

—
02 First Stressometer roll, delivered to Alcan Kingston, Canada in 1967 (from "ASEA Veckobladet" April 14, 1967)

As the demands of metal strip processing increased in the 1960s, interest arose in finding a way to measure flatness during cold rolling to achieve an automatic flatness control (AFC). Up until then, flatness during cold rolling had been manually controlled through visual and audible observations by the operator.

In the mid-1960s, Alcan of Canada and Asea started a joint development to make a sensor that would measure strip flatness. A decision was made early on to base the product on a mill-duty meas-

—

A decision was made early on to base the product on a mill-duty measuring roll equipped with Pressductor sensors.

uring roll equipped with Pressductor sensors. The first system was installed in 1967 in Alcan's cold rolling mill in Kingston, Canada, where it underwent comprehensive tests →2.

The idea was to control the transversal stress distribution in the strip, thus improving strip flatness. The assumption was that a controlled strip stress distribution, ie, strip flatness, would lead to improvements in strip quality and mill productivity. The hypothesis turned out to be correct: By using the Stressometer equipment and a flatness control system, Alcan substantially improved the flatness of the rolled strip, achieved higher yield, reduced the number of strip breaks, and raised productivity through higher mill speed and shorter pass times. In other words, the new product was a resounding success.

50 years of customer collaboration
In the 50 years since that first installation, the demand from strip users, and from other types of rolling mills, for ever more sophisticated flatness control has increased dramatically. ABB has, therefore, in collaboration with customers, continuously developed the Stressometer system →3. The improvements enable mill operators to fully utilize the rolling mill to produce a high-quality strip with maximum yield while keeping maintenance needs to a minimum.

The Stressometer system of today is designed for both hot and cold rolling, and handles thickness and product ranges from 0.005 mm aluminium foil up to 12 mm stainless steel.

What is strip flatness control in a rolling mill?
Flatness control is about controlling the roll gap in the mill so that it exactly matches the thickness profile of the incoming strip. If there is a mismatch, then flatness problems will arise →5.

The Stressometer measures the force distribution (Fi) on the roll →6. Using strip tension (T), width (w), length (L) and thickness (t), the stress distribution in the strip can be calculated. When this value is divided by Young's Modulus, the (un) flatness distribution can be derived. The flatness distribution is measured in I units, which correspond to the relative elongation distribution multiplied by 100,000, ie, one I unit corresponds to an elongation of 1 mm on a 100 m strip.

$$\text{Stress: } \Delta\sigma i = \frac{Fi-\bar{F}}{\bar{F}} x \frac{T}{w x t} \quad [N/mm^2]$$

$$\text{Unflatness: } \frac{\Delta Li}{L} = \frac{-\Delta\sigma i}{E} \quad [x10^5 = I \text{ units}]$$

The I unit was introduced by ABB in the 1960s as a way of quantifying flatness and has since become the de facto, industry-wide flatness measuring unit.

STRESSOMETER DEVELOPMENTS

1967	World's first flatness system delivered to Alcan Kingston, Canada →4
1970	Improved measurement resolution: 52 mm zone width from 84 mm
1976	First microprocessor-based system (Intel 8080)
1977	World's first digital closed-loop flatness control (Kobe Steel, Japan)
1980	World's first flatness control system for a cluster mill (Outokumpu)
1982	Resolution improved further: 26 mm from 52 mm
1989	Digital color-graphic human-machine interface (HMI)
1989	World's first flatness control based on actuator models
1990	New technology for measurement of strip width and edge position – MSS (millmate strip scanner)
1993	Measurement and compensation for strip temperature in steel applications
1994	New transducer and roll for foil applications
1998	World's first HMI based on a Web browser for industrial applications
2001	New generation with future-safe architecture (FSA)
2002	Seamless roll for surface-critical applications
2006	Predictive flatness control
2007	Foil roll with 26 mm resolution
2011	Flatness control with automatic process identification
2013	Optimal coordinated control through ESVD for cluster mills
2014	Digital maintenance-free signal transmission (DTU)
2017	Fully digital system RoHS (restrictions on hazardous substances) compliant

03

How does the Stressometer technology work?
The Stressometer measuring roll is the key to successful flatness measurement and control. It consists of a solid core with four axial grooves that accommodate a large number of Pressductor sensors. Each measurement zone across the width has, therefore, four sensors. This four-sensor approach has been fundamental to the Stressometer design since the very beginning and confers upon the system the advantage of a physical, automatic compensation for both roll deflection and temperature change so no compensation software is needed and very fast measurement response time is achieved.

The roll is divided into 26 or 52 mm measuring zones. A hardened steel ring is shrunk onto each zone to protect the sensors and to present an appropriate surface to the metal strip being rolled. A digital transmission unit (DTU) provides contact-free power and signal transmission with the sensors in the roll →7. Each zone measures independently the local force directed radially from the strip.

Four measurements are obtained for each revolution of the roll, at speeds of 1 to 4,000 rpm. The Stressometer roll measures the entire strip force including the edge stresses. The actual strip flatness is presented in I units.

Stressometer innovations over the years
From the beginning, six main design principles were adhered to in order to secure a reliable, accurate and fast flatness measurement:

- The force measurement must be stiff – ie, the deformation of the strip and of the force sensor should be negligible. Thereby, a direct and reliable force measurement is achieved without any stress filtering due to strip deformation.
- Sensors with the same thermal expansion coefficient as the surrounding material must be used. This minimizes inaccuracy due to thermal effects.
- Sensors must function reliably and accurately for many years in a rolling mill without the need for recalibration.

The improvements enable mill operators to fully utilize the rolling mill to produce a high-quality strip with maximum yield while keeping maintenance needs to a minimum.

- Measurement should be of the whole force distribution across the strip in one instant – ie, no force shunting to the roll body.
- The four-sensor principle. This enables measurement of the whole force distribution four times per roll revolution while keeping the measurement signal unaffected by temperature changes and roll deflection.
- The signal output from a measurement zone must be directly proportional to the strip coverage degree. This will enable accurate measurement of the strip edges.

—
03 The progress of ABB's Stressometer over the past 50 years.

—
04 Flatness measurement HMI from 1967. Nowadays, a computer or cell phone can be used as an operator station.

Necessary requirements on a modern flatness system

If the flatness control system is to make a difference to yield, pass times and number of strip breaks, it must comply with a number of tough requirements:

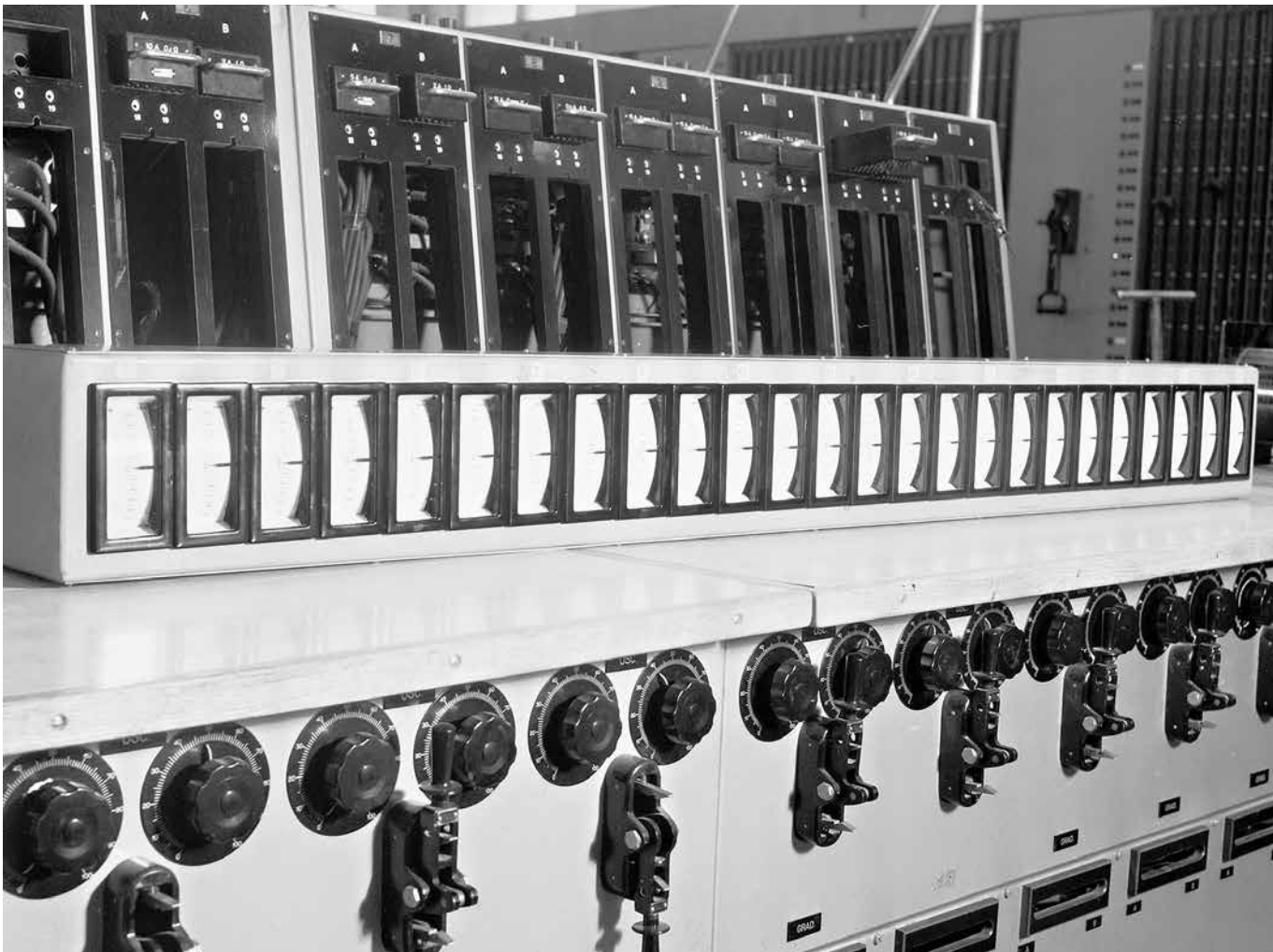
- Reliability is the most important requirement. The system must not cause any unplanned stops in the mill (planned stops are acceptable). In this respect, the Stressometer system has an MTBR (mean time between repair) that exceeds 20 years and utilizes a maintenance-free, contact-free signal transmission from the roll.
- Accurate measurement. Without an accurate measurement of the complete stress distribution, no flatness control can do a good job. (Stressometer system measurement accuracy is typically 0.5 I units.)
- The measurement must be unaffected by mill disturbances such as variable strip tension.
- The measurement must operate equally well at all mill speeds and include edges, and the head end and the tail end of the strip, regardless of the strip thickness.
- The measurement system must, within milliseconds and several times per rolled meter of strip, provide accurate outputs to the flatness control system.
- It is essential to visualize the actual flatness for the operator in an intuitive way.
- The system must, without any adjustments, be able to handle a wide range of products and it should never deteriorate the strip surface.

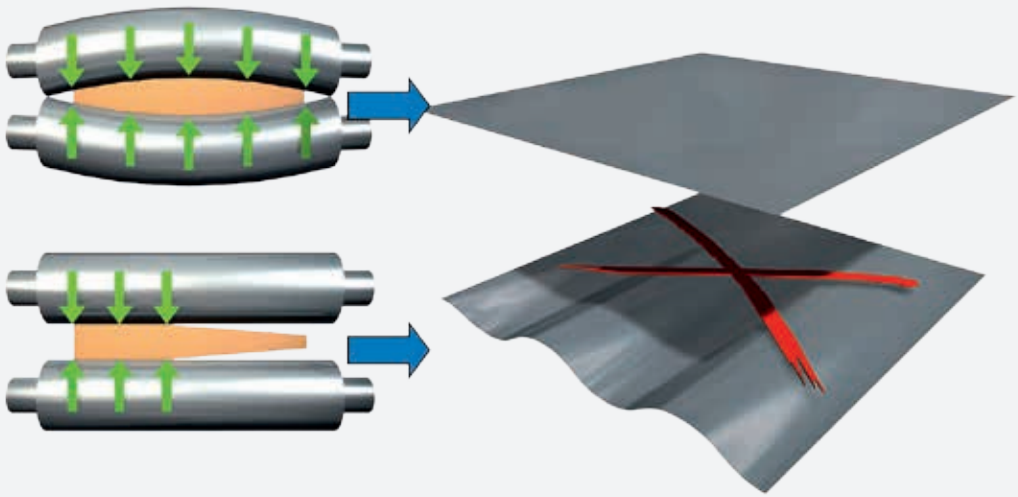
—

The Stressometer system of today is designed for both hot and cold rolling, and handles thickness and product ranges from 0.005 mm aluminium foil up to 12 mm stainless steel.

- The flatness control system must be able to simultaneously and efficiently use all mill actuators on all occasions and for all products. Since several actuator combinations might have the same flatness effect, the system must be capable of selecting the most efficient combination. No manual control should be needed. Here, the Stressometer system has advanced control facilities, including extended singular value decomposition (ESVD) and adaptive/predictive control →8.

04





05

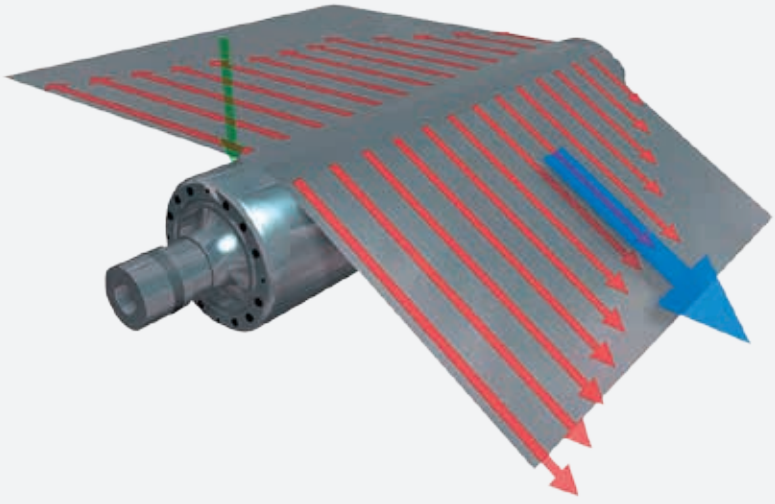
Challenges and potential for flatness control
The rolling industry has faced many challenges over the past 50 years and there are sure to be more in the future. One ongoing challenge is to produce in a sustainable way so that environmental and climate effects are minimized. The Stressometer system improves quality and yield, which means less energy is needed per ton of finished product.

Another challenge is to provide facilities that can produce, within short delivery times, the increasing number of products, alloys and dimensions that the market wants – and short-run, custom requests for these. These demands make it necessary to switch within seconds from one type of product to a completely different one – without deterioration in quality or productivity.

Cost reduction is an area in which the Stressometer provides great potential: Rolling mill productivity is directly affected by yield achieved, pass

The Stressometer system has an MTBR that exceeds 20 years and utilizes a maintenance-free, contact-free signal transmission from the roll.

times and mill downtime due to strip breaks. In an aluminium cold mill, bottom line sensitivity (BLS) to a strip break is typically $10,000. For yield, BLS



06

07a

07b

—
05 A match between the roll gap and the strip gives a flat strip. A mismatch results in non-constant elongation across the strip and, consequently, flatness problems.

—
06 The Stressometer measures the force distribution on the roll.

—
07 Stressometer signal processing hardware.

07a In 1967, three analogue circuit boards were needed to process the signals from one measurement zone.

07b Today, signal processing is completely digital and 80 measurement zones are processed in parallel by the DTU.

—
08 Flatness control with ESVD.

08a Actuators.

08b Flatness effect.

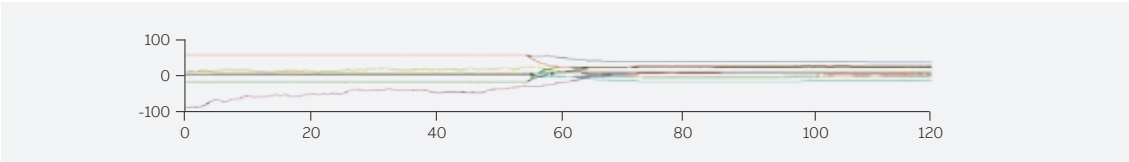
08c Mean flatness and control strategy.

is typically $150,000 per 0.1 percent and for pass time it is $100,000/s. With such substantial sensitivity factors, every improvement, no matter how small, brings with it a significant financial payoff.

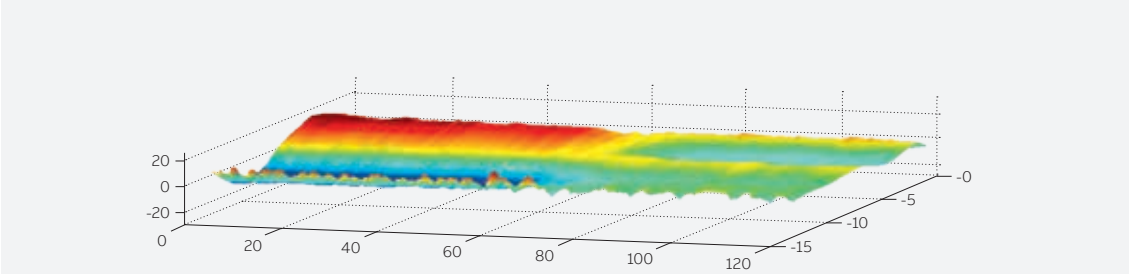
The 50 years of development of the Stressometer system have led to significant enhancements in the product:

- Use in any hot- or cold-rolled product
- Extremely high roll reliability with MTBR of over 20 years
- Improvements in resolution, accuracy, response time and visualization
- Expansion of flatness control to a general concept that includes all existing mill types, with an optimal use of the available actuators

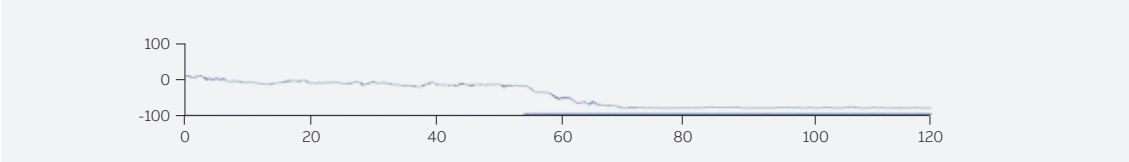
Further customer collaborations will establish how quality and productivity can be taken to the next level – perhaps by extending flatness control to upstream and downstream operations. This then includes control of the strip profile during hot rolling so that consistent and controllable flatness can be achieved downstream. Systems in the future will also be securely connected to the so-called IoPTS – the Internet of People, Things and Services. This connectivity will enable ABB to also remotely assist customers in the pursuit of the optimal long-term operating performance of their rolling process. ●



08a

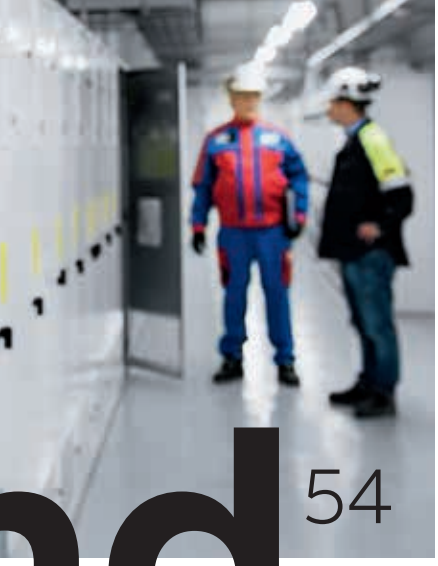


08b



08c

Service ar Reliability



nd 54

“Always on” takes on particular significance when applied to manufacturing and infrastructure. It is an aspirational goal for companies that want to increase performance of existing invested capital, and a performance requirement for critical services, like electricity.

Further, a more interconnected world is more dependent on those connections working reliably. Devices and systems need to quickly get back into service after a disruption or, better yet, avoid problems altogether.

ABB is innovating ways to unlock value from existing devices, and ensure the reliability of old and new ones working together.

60

SERVICE AND RELIABILITY

Retrofitting unlocks potential

A modern approach to life cycle optimization for ABB's drives delivers immediate performance improvement and a more sustainable way to breathe new life into existing installations.

01

Marjukka Virkki
Country Service Manager, Finland

Helsinki, Finland
marjukka.virkki@fi.abb.com

As a company's drives installed base ages, drive life cycle services become an increasingly important part of its operations. Drive services do not only prevent breakdowns, but they also improve the asset productivity and reliability of the drive and the company's overall operational effectiveness. Retrofit service is one of the offerings that can further unlock the potential of aging drives and improve their performance.

Service is key

As companies increasingly focus on their core competencies, the need for services from drive suppliers increases and becomes a more critical part of their operations. Drives are an essential part of many different industrial processes, providing energy efficiency, improved productivity and high performance to electric motors in a variety of applications. Thus, when a drive breaks unexpectedly, it can bring operations to a halt and cause a broad range of problems for the company.

The best strategy is to prevent a breakdown before it happens. During the product's life cycle, this typically means regular preventive maintenance. But for an industrial drive at the end of its life cycle, retrofit or replacement is the best solution for minimizing the risk of breakage and unplanned production shutdowns →1. Simultaneously, these two services will often improve a drive's performance →2.

Building upon life cycle management thinking, ABB has developed a life cycle management model to demonstrate a drive's performance and availability throughout the product's life cycle →3. This model divides a product's life cycle into four phases: active, classic, limited and obsolete. In a product's active and classic phase, ABB has a full range of services and support available. In the limited and obsolete phase, on the other hand, often the only

Retrofit service is one of the offerings that can further unlock the potential of aging drives and improve their performance.

available and thus recommended services are replacement and retrofit, which, in addition to updating the drive, will also return the product's life cycle status back to active.

—
01 A retrofit solution is often tailored according to the customer's specific needs.

Because industrial companies have several different maintenance strategies for their investments, ABB's broad offering allows them to choose the drive services that best support their strategies. As part of the life cycle management model and ABB's service offering, retrofit supports replacement service and other solutions to provide different drives maintenance options for ABB's customers.

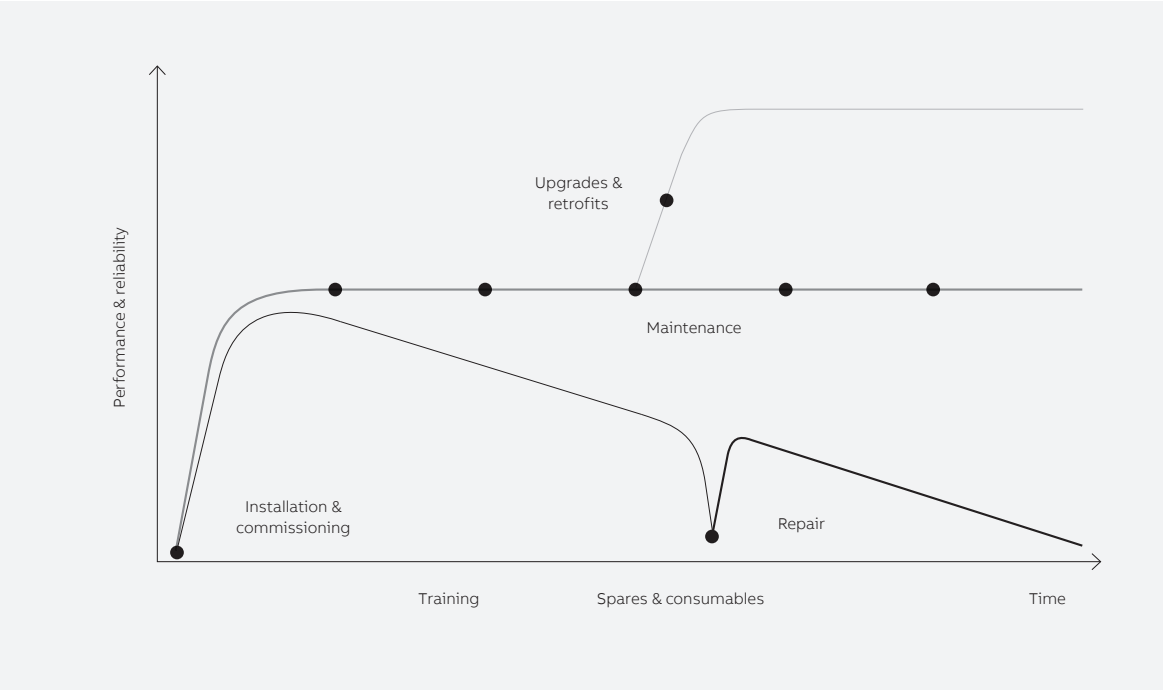
History of retrofits

The starting point for designing a retrofit is often complicated since retrofits require sophisticated engineering skills to deploy the newest drives technologies into the various generations of drives products while, in parallel, the customer's needs like fast installation time, customization needs and the variable conditions on site must be kept in mind. To efficiently provide ABB customers with the best-value cost, ABB started a project to standardize its retrofit offering in late 2000s. In 2007 Marjukka Virkki, Finland's current country service manager, was working as a drives service R&D manager and simultaneously managed the retrofit standardization and concept development project: "When I started working as a retrofit project manager in 2007, I realized that to scale up the production volume of high quality retrofits for all potential customers, we cannot sell every retrofit solution on a case-by-case basis. Sure, a case-by-case ensures a design based on the customer's exact needs, but it can challenge the quality of documentation and the installation time after sales support. Additionally, it was not possible to optimize the supply chain to achieve the product cost targets. Based on customer feedback, we needed to decrease our delivery times and, together with the volume increase, this would not have been possible without standardization. We further needed to increase our field service capabilities as

—

ABB's broad offering allows industrial companies to choose the drive services that best support their strategies.

the number of installations was growing globally and therefore the need for high quality documentation, training material and courses became more evident. A continuous learning process was set up to decrease the probability of risks materializing.



02

We started the development work by assessing the market situation and needs and, with the help of a small project team, we continued by defining product structure with standardized subassemblies and by creating documentation, instructions, and process descriptions. In close cooperation with sourcing, we selected the suppliers and built up the volume production line with clear KPIs and targets."

Retrofit service development has always been about the customer and meeting the customer's needs. Marjukka further explains how to ensure the best quality service for the customers: "In the retrofit service development we aimed to primarily use the same components as in the newest drive products. Consequently, the installation and assembly would be more efficient and the retrofit's reliability would be improved, as the existing components had already been tested and approved by the product factory. We further used the existing design and documentation standards and ways of working in the product development. Fast forward to today, everything from air gap dimensions to controlling electrical eddy currents in retrofits are expected to meet the same design criteria as our new products. This too illustrates our high-quality standards."

Retrofit service development has always been about the customer and meeting the customer's needs.

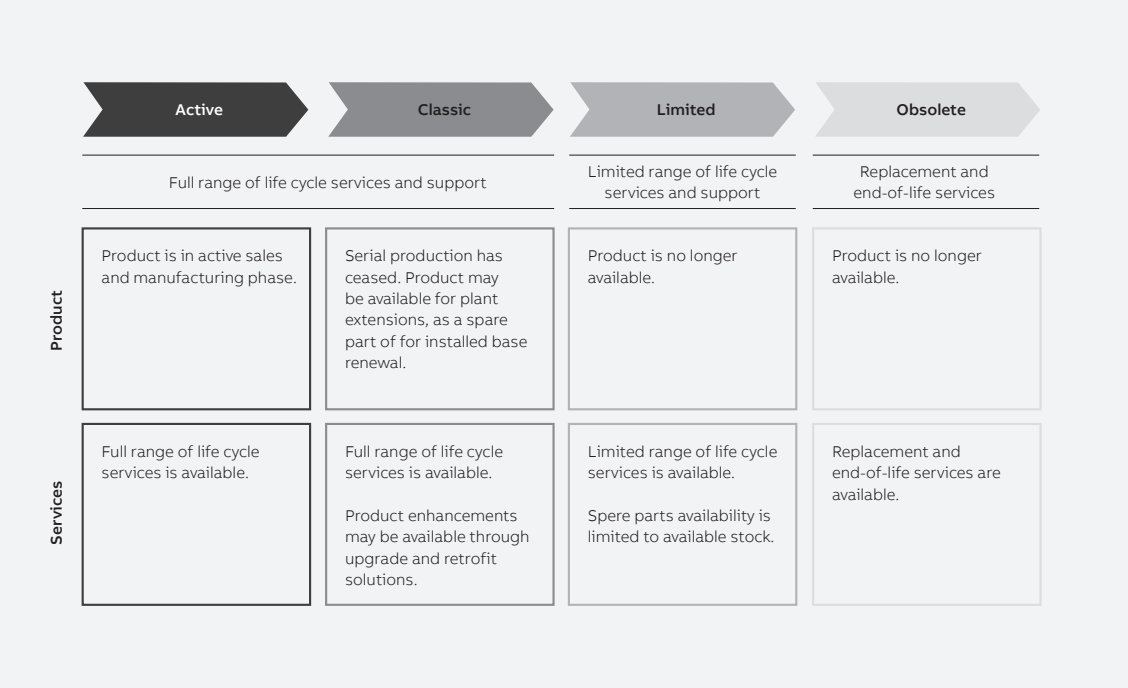
Today most retrofits are delivered as a standard package. By utilizing continuous learning principles, ABB ensures the highest quality and most cost efficient retrofit solutions with fast delivery and installation times. Additionally, the standardized packages can minimize the time and risk of retrofit projects.

04

—
02 A product's performance and reliability over time.

—
03 ABB's life cycle management model.

—
04 151 aging ACS600 drives at SSAB's Hämeenlinna galvanizing line 3 will be modernized within 5 years to ensure their maintainability and reliability.



03

Even though standardized packages provide many advantages, ABB still develops some retrofits on a case-by-case basis to ensure that the customer's various needs are fulfilled. In all of ABB's retrofits, systematic documentation methods, quality assurance and highly trained engineers ensure the high quality and long lifetime of the drives.

Successful new service products pilots

Under new service development, ABB has successfully executed several pilot projects in multiple countries with customers operating in numerous industries, such as paper and pulp, metal, mining and food and beverage. Through these pilot projects, ABB ensures the reliability of new retrofit

05

designs and verifies the functioning of internal processes from order to delivery until final installation and commissioning of the retrofit.

One of these pilot projects was successfully conducted with SSAB, who, following the pilot, made a decision to modernize all of the drives in its galvanizing line 3 at its Hämeenlinna, Finland plant. The project includes retrofitting 151 drives, which are to be installed in a step-by-step manner over a five-year period →4.

ABB ensures the highest quality and most cost efficient retrofit solutions with fast delivery and installation times.

SSAB is a global steel manufacturer that focuses on highly specialized steel products. The company is a leading producer of advanced high-strength steels, as well as quenched and tempered steels. SSAB's Hämeenlinna plant's galvanizing line 3 produces zinc-coated steel plate for the construction and car industries. Its smooth operations are crucial, since the line's highly specialized products cannot be manufactured elsewhere.

A tailored retrofit

Some years ago ABB informed SSAB that the ACS600 drives were approaching the end of their life cycle and hence the availability of technical support and spare parts would become limited in the future. After considering multiple options, SSAB chose ABB's retrofit service to modernize and restore the products back to the active life cycle phase.

"The step-by-step retrofit was a good solution for us," says Tero Saarenmaa, Electrical Maintenance Section Manager at SSAB's Hämeenlinna."
"It gave us the possibility to do effective preventive maintenance with the original spare parts, while getting full support and service on these crucial drives. In addition, the project allowed us to utilize the old products as spare parts for the older ACS600 drives until the retrofit was completed. The overall cost-effectiveness and reduced shutdown time were key elements for us in choosing the retrofit service."

Additionally Matti Aaltonen, ABB drives and controls service sales manager, added that the ability to tailor the solution specifically to SSAB's needs was important. "Since a standard retrofit solution didn't fully fit their requirements, we tailored a solution according to SSAB's specific needs.
So all the components inside the old cabinets are being removed and ACS880 tailored retrofit kits

— 05 Old drive (left) and retrofitted drive (right).

— 06 ACS880 retrofit for ACV700/SamiStar mechanical design with 2 modules.

for the ACS600MD cabinets, which are wider, are being installed →5. Control of the drives will still be implemented with the existing AC80 control system, with some modifications to the AC80 software. The scope of the project includes commissioning and the minor program changes for the new ACS880 drives will be carried out during each maintenance shutdown."

Modern service business

While the reasons behind a customer's decision to choose a retrofit service vary, there are some clear advantages. One of the most common reasons to choose retrofit is that the service enables companies to make new step-by-step investments rather than relying on a one-time investment.

The retrofits do not only decrease the customer's capital expenditure since investments can be made over a longer period of time, but the service also allows the installations to be made during shorter production breaks. The retrofit further benefits from new technologies and therefore also often increases the efficiency of the drive. For example, new drives generations have embedded capabilities for remote connection and self-diagnostics that enable remote support and condition monitoring services, improving the availability and optimization of the drive and the response time in case of failure. Additionally, by using an existing drive's cabinet, cables and motors, the customer saves a significant amount of money and time as there is no need to re-engineer or work out any changes, for instance in the cooling system or cabling.

As the global population stretches the earth's resources to the limit, a company's environmental impact and use of resources have become increasingly important. To this end, the retrofit service minimizes material waste by using the existing cabling, motors and cabinets, while simultaneously employing the latest technology with better tools and diagnostics →6. According to one pulp and paper case study conducted by ABB in 2015, retrofit's total CO_2 emissions were over 65 percent less than a new line up; the CO_2 emissions for a new line up added up to 6,405 kg, while the retrofit kit's emission were only 2,215 kg. This was saved both in production and transportation of equipment.

— Through retrofits, the customer is further guaranteed a full range of life cycle services and support for years to come.

A retrofitted drive is guaranteed with an up-to-date drive system and product support. Retrofitting drives is a fast and efficient way to modernize an installed base, bringing immediate performance improvements to the customer's plant and process. Through retrofits, the customer is further guaranteed a full range of life cycle services and support for years to come. ●

SERVICE AND RELIABILITY

Generators for the age of variable power generation

Grid-support plants are subject to frequent starts and stops, and rapid load cycling. Improving the design of the plant's alternator so it can withstand additional stresses is fundamental to reliability. What are the design parameters to which special attention must be paid?

Timo Holopainen
Jari Jäppinen
Juhani Mantere
John Shibutani
Jan Westerlund
ABB Motors and Generators

Helsinki, Finland
timo.holopainen@fi.abb.com
jari.jäppinen@fi.abb.com
juhani.mantere@fi.abb.com
john.shibutani@fi.abb.com
jan.westerlund@fi.abb.com

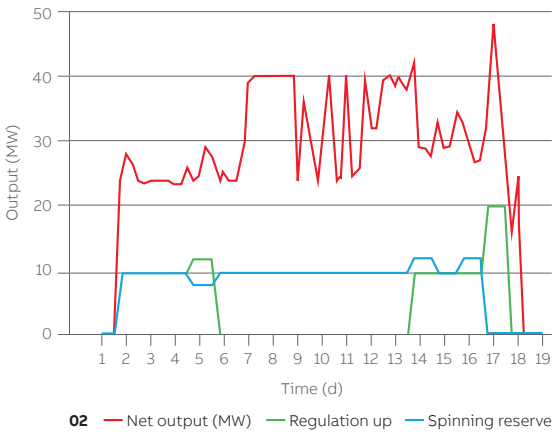
Mats.Östman
Wärtsilä Finland Oy
Helsinki, Finland

Joonas Helander
Former ABB employee

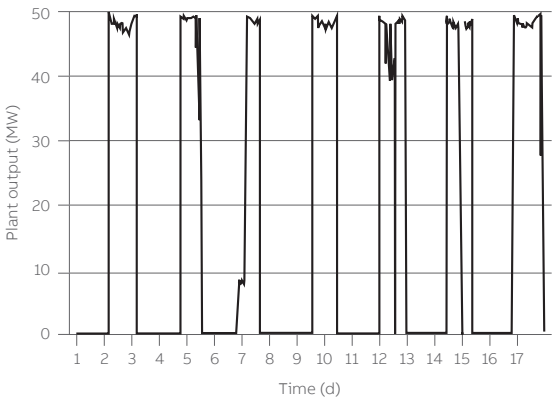
More and more renewable power generation sources are connecting to the power grid. The power output of many of these sources can be highly variable and their fluctuations have to be compensated for by flexible, grid-support plants. In contrast to traditional power generators, grid-support plants are subject to frequent starts and stops, and rapid load cycling. As is confirmed by studies of real-life loading cycles in grid-support duty, the key factor that must be taken into account in the design is the increased number of thermal and speed loading cycles. Improving the design of the alternator so it can withstand additional stresses is fundamental to the reliability →1.

Driven by legislation and the underlying climate concerns, renewable energy penetration is on the rise. The increased usage of renewable power generation, which in many cases is variable and without inertia, creates new challenges for the

It is expected that the thermal stresses are mainly generated in the windings and the core region of the alternator.



02



03

01

—
01 The alternators in grid support plants must be designed to accommodate the thermal and mechanical stresses caused by the need to ramp up and down in response to variable renewable generation on the grid. Shown Is power generation equipment with separate generating units at the Kiisa power plant in Estonia.

—
02 The measured balancing power of a combustion-engine-based plant over an 18-hour power production period.

—
03 Power production of a plant over one week in August 2013.

—
04 Generator loading profiles used in the thermal cycle analyses.

04a Repeated five-minute ramp-up from zero to full load for five minutes, then one-minute ramp-down to no-load, with five-minute standstill period.

04b Rapid ramp-up in five minutes to full load staying at full load for two hours, followed by a rapid ramp down in one minute to no-load.

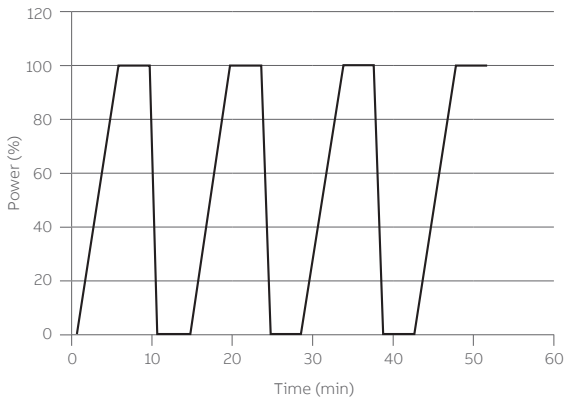
electrical grid, system control and the existing power generation facilities. More frequent starts and stops, and increased ramping and cycling capability is required from other power generation plants, all of which may impose additional costs and stress on the existing assets.

Power plant load cycles

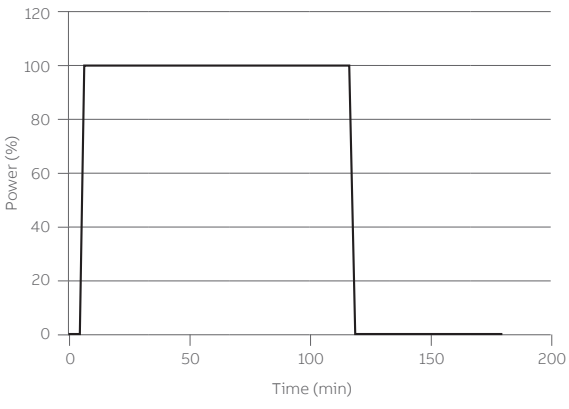
Traditionally, alternators are operated at rated conditions and constant speed over long, uninterrupted periods. This has determined the design principles and dimensioning of alternator structural parts. Grid-balancing operation entails rapid alternation of operation and standstill periods – resulting in a much higher number of starts and stops →2.

In principle, the difference between the traditional and grid-balancing generator is the number of loading cycles and the steepness of the load change.

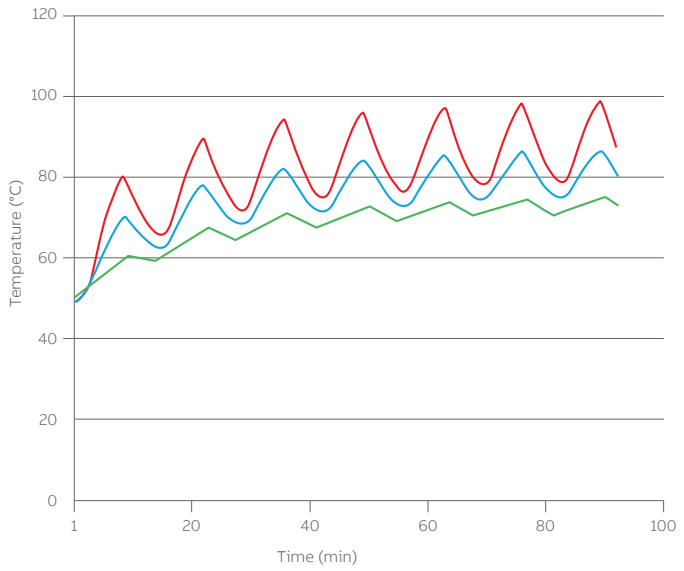
Modern generating sets can get from zero to full speed in 30 seconds and to full load in five minutes; stopping time from full load to standstill is one minute. The plant shown in →3 had nine starts and stops over a six-day period, averaging to 500 annually. In practice, the number of cycles can be even much higher.



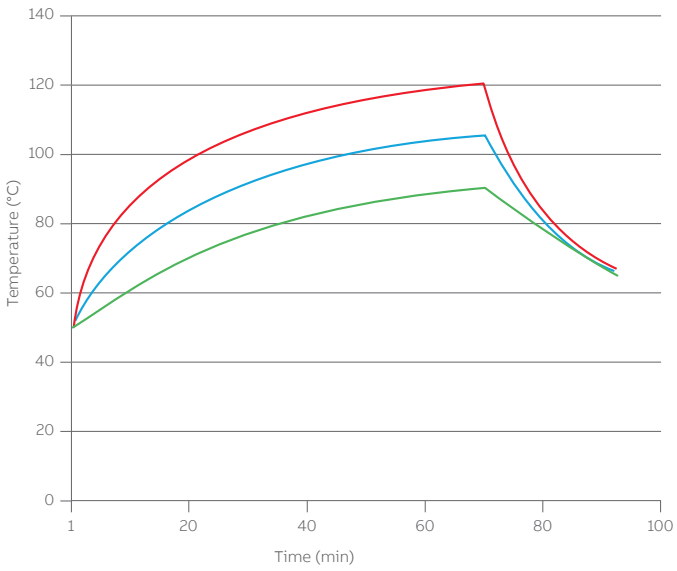
04a



04b



05a Stator winding in slot — Stator core teeth — Average stator core yoke



05b Stator winding in slot — Stator core teeth — Average stator core yoke

Loading profiles

In general, the warming and cooling of alternator parts is not even and their thermal time constants differ. This transient anisotropy is the main contributor to thermal stress and makes the analysis of thermal cycles demanding.

To analyze and simulate thermal behavior, two different load profiles – derived from the real site described above – were selected →4. These examples provide a maximum number of load/standstill cycles, which also gives a maximum number of thermal loading cycles for evaluation →4a, as well as a temperature gradient between the winding and core that is close to its maximum value →4b.

Analysis of the thermal cycles

It is expected that the thermal stresses are mainly generated in the windings and the core region of the alternator. The prediction of thermal stresses requires that the temperature distribution can be simulated. The thermal conductivity of copper is excellent and that of steel is good. Thus, the largest temperature gradients are in the electrical insulation layers between the copper-copper and copper-steel joint surfaces. The temperature difference between these parts defines thermal stress in an alternator.

A thermal network method was applied to predict the transient thermal behavior of the active parts of an alternator, such as the stator. In the case with several consecutive short loading/idle cycles, the temperature difference between the winding and core can vary by as much as 10 to 25 K during the load cycles →5a. Where there is a longer full-load period reaching close to maximum operating temperatures, the temperature difference between the winding and core can reach 30 K →5b.

As the stator coils are bonded to the slot walls due to the impregnation treatment and cannot move freely internal stresses are generated in the insulation layers, which can lead to cracking if appropriate measures are not taken.

The difference between the traditional and grid-balancing generator is the number of loading cycles and the steepness of the load change.

Analysis of the speed cycles

Usually, the origins of alternator vibrations are the reciprocating forces of the combustion engine. A four-stroke internal combustion engine creates excitation forces on full and half harmonics of the rotational speed. The generating unit is so complex that only numerical simulations can predict the vibration behavior with the required accuracy. The only way to reliably investigate the fatigue strength of the structural design is to perform a response analysis for the whole generating set. The vibration design of continuously operating alternators is based on the avoidance of main resonances. Due to the high number of starts and stops, fatigue design of grid-balancing application requires the analysis also for start and stop cases.

—
05 Predicted stator temperature of an alternator (20.8 MVA, 13.8 kV, 60 Hz and 514 rpm).

05a At maximum thermal cycle frequency, the temperature difference between the winding and core varies between ca. 10 K and 25 K, peaking after the first cycle.

05b At maximum thermal cycle amplitude, the temperature difference between the winding and core reaches a level of 30 K.

—
06 Example of the verification test results for winding insulation lifetime (Arrhenius equation fitted to collected test data using the least-square method.)

Implications for alternator design
Based on the thermal and speed-cycle analysis, as well as experience from other high cyclic generator and motor applications, there are several parts in the alternator that must be carefully considered when designing reliable alternators for grid balancing application.

Insulation and winding system
As discussed above, winding and insulation are detrimentally affected by thermal cycling. Experience has shown – and analysis has confirmed – that global vacuum pressure impregnation (VPI) gives outstanding characteristics to the whole stator and rotor (laminated steel core and windings).

—

The warming and cooling of alternator parts is not even and their thermal time constants differ. This is the main contributor to thermal stress and makes the analysis of thermal cycles demanding.

In the development process, the verification of the system by testing is always important. In a typical thermal cycling test procedure, several sets of test bars are heated in an oven to different temperatures and cycle times. The test bars are then exposed to mechanical stress on a vibration bench, to humidity and finally to voltage testing of conductor insulation and main insulation.

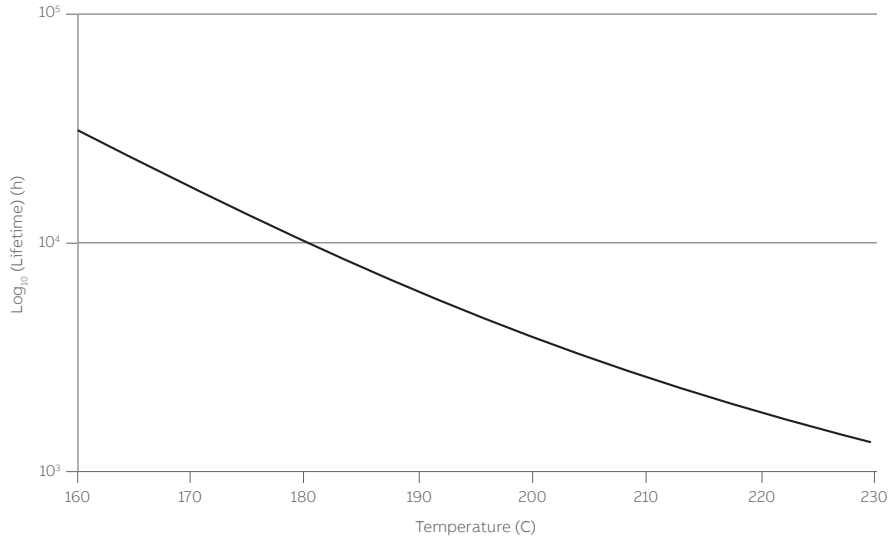
Test cycles are repeated until a certain number of test bars in each set fails voltage testing. The lifetime is then calculated from the test results of each set using the so-called Arrhenius rule →6. Successful tests have been recently performed for the impregnation system in use.

End windings
End windings, along with their support construction and connections, are exposed to thermal cycling and vibrations caused by acceleration, deceleration and frequent grid switching.

The vibration of stator end windings is of major concern in large electric machines. Particularly in two-pole machines the natural frequencies of winding ends tend to decrease to close to the twice-line frequency (100/120 Hz). Thus, in these machines special support structures are needed in order to increase the winding end stiffness and natural frequencies. However, in multi-pole alternators the winding ends are inherently short and the natural frequencies sufficiently high without any additional support structures.

In the development and design of the end winding construction a set of modern methods is used, including 3D finite element analysis (FEA). This method is used for the calculation of forces together with static and dynamic response →7.

The construction and design of the end winding support system with global VPI gives very good characteristics given existing forces and stresses. This means that the end-winding design of medium-speed grid-balancing alternators is robust and resilient against vibrations.



06

—
07 Examples of end-winding analyses.

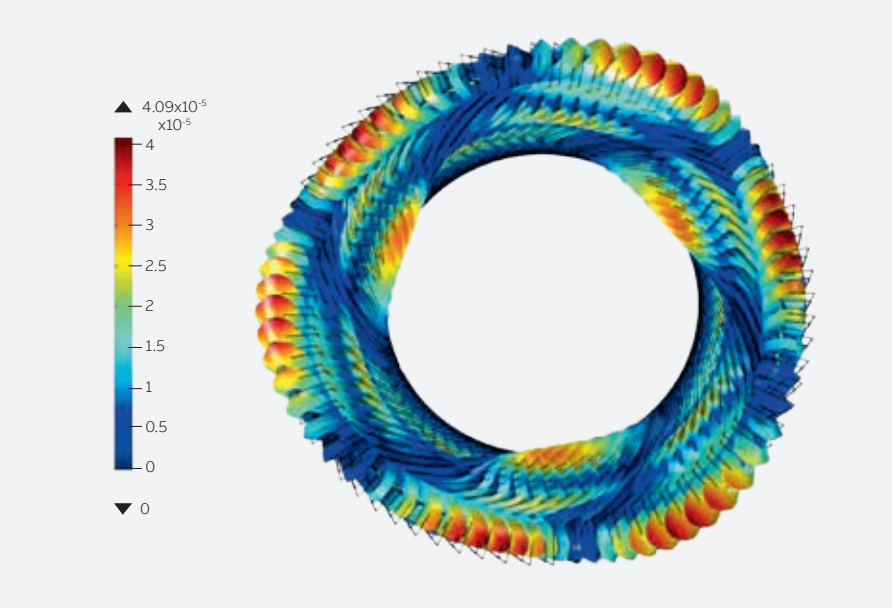
07a A mode shape.

07b The exerted magnetic force distribution at one instant.

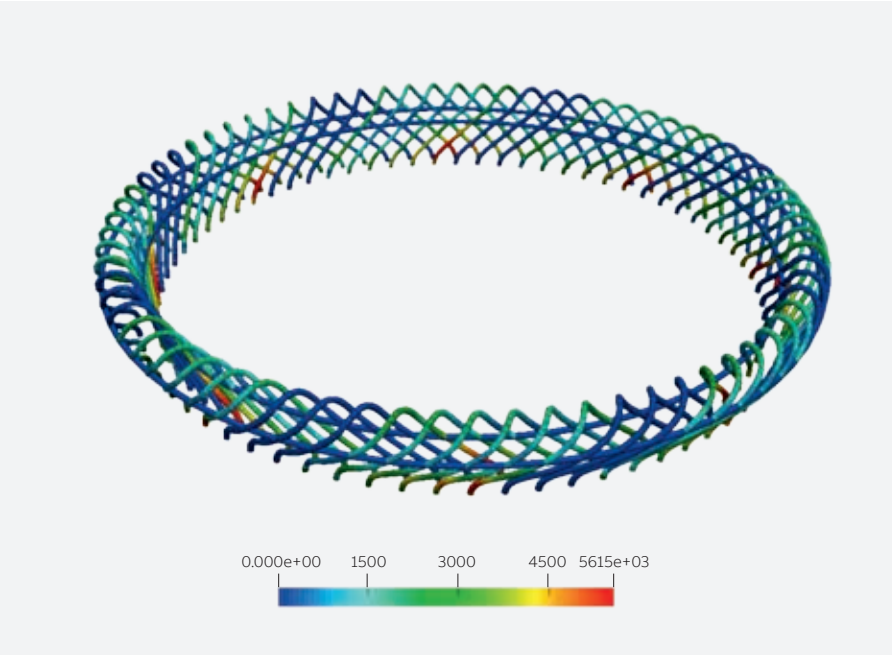
Operation at underexcitation (consuming reactive power) causes thermal stresses in the core-end region. In the case of medium-speed alternators (high pole number), this effect is less severe thanks to the smaller coil width and more favorable flux distribution at the end region.

Frame

The frame of the alternator is mounted on the common base frame together with the combustion engine. The design of the alternator frame is determined significantly by the vibration excitations of the engine transmitted to it by the base frame. This leads to a slightly more robust frame design compared to alternators mounted on a concrete foundation.



07a



07b

The alternator frame design is determined by fatigue resistance. Ability to design reliable alternators, and still have a cost-efficient frame structure, requires thorough knowledge of the dynamics of the whole generating set. A response analysis (numerical simulation) of the whole generating unit is the key to success here.

The fatigue stresses can be simulated during the start-up and shut-down periods. Based on the calculated stress histories, the fatigue life can be evaluated by conventional methods and the critical

—

Global vacuum pressure impregnation gives outstanding characteristics to the whole stator and rotor.

structural details can then be modified to resist the fatigue loads. Ultimately, this approach ensures that the alternator frame reaches the desired lifetime without any fatigue failures.

Rotor and bearings

Regarding rotor design, medium-speed alternators are always sub-critical. This means that the first flexural critical speed of the rotor is above the rated rotational speed of the alternator. The rotor does not cross any flexural critical speeds during the cycling loading, thus giving freedom to rotor and bearing design. This is clear advantage over higher speed alternators (eg, two-pole design). The thermal cycles have effects on the rotor similar to those on the stator. The prevailing principle of rotor design is to retain the contact between the components over the temperature cycles – thus avoiding the resin mechanical fatigue. Moreover, the bearings are equipped with a jack-up system, enabling a very large number of starts without any wear.

Good design ensures long life

The age of variable renewable generation means that grid-balancing generators must endure a much larger number of thermal and speed cycles than traditional generating units. The design of the grid-balancing alternator requires particular attention for reliable operation. However, with an optimal design, alternators will be well able to withstand these new, greater stresses and deliver high reliability over very long lifetimes. ●

SERVICE AND RELIABILITY

IGBT converters extend life of Re460 locomotives

ABB is supplying state-of-the-art IGBT converters to modernize and extend the lives of the Re460 locomotives of Swiss Federal Railways (SBB).

Thomas Huggenberger
ABB Discrete Automation and Motion, Power Conversion

Turgi, Switzerland
thomas.huggenberger@ch.abb.com

Switzerland's railway network is famous the world over. Admired for its network density and the punctuality and frequency of service, the system provides well over one million passenger journeys every day. To further build on the rail network's success and prepare it for the needs of the future, the ambitious "Rail 2000" program was launched in the late 1980s. The project set out to add capacity and reduce journey times. A central part of the plan was the introduction of the Re460 locomotive. 119 of this type entered service between 1992 and 1996 →1. They were equipped with GTO (gate-turn-off thyristor) converters and asynchronous traction motors (both manufactured by ABB), and represented the state of the art at the time.

More than 20 years later, the Re460s are still providing excellent service. They account for about half of all kilometers travelled by SBB trains in passenger service. Each locomotive has covered on average 5.5 million km in its lifetime so far, the equivalent of seven times to the moon and back.

Although the Re460s are of robust construction and designed for a long life, power electronics has made huge progress over the last decades. For example, GTOs have been broadly supplanted by more flexible IGBTs (integrated gate bipolar transistors) in traction applications. SBB decided to embark on a mid-life refit program that will bring the locomotives up to date. The overhaul, which includes an optimization of overall electrical systems, will ensure a further lifespan of at least 20 years while also improving energy efficiency and maintenance. The improvements are expected to deliver savings of around 27 GWh/year, corresponding to the consumption of 6,750 Swiss households.

ABB expertise
ABB is a leader in the research, development and manufacturing of energy efficient traction converters as well as traction motors and transformers. The company can look back on more than a century of experience in electric railways across the world.

Besides supplying new equipment, ABB has extensive experience in lifecycle service support for rolling stock. For example, in 2008 ABB successfully replaced the GTO-based traction chains of the ICE 1 fleet of high-speed trains of German Federal Railways (Deutsche Bahn), using state-of-the-art IGBT converters. Building on the company's commitment to customers and its extensive knowledge and experience, ABB was awarded an order of around CHF 70 million by the SBB in 2014 to supply the latest generation of traction converters for the Re460 fleet. The objective was to provide greater energy efficiency, higher reliability and easy maintenance.

01

—
01 SBB's Re460 locomotive [Photo copyright SBB CFF FFS].

—
02 Switching topology and waveforms for two and three level IGBT converters. The voltage is shown in black and the current in red.

—
03 Three-level phase-module IGBT converter of the type used for the Re460 refit.

Modernization specifications

The SBB required the refit locomotives to fulfill a challenging set of specifications. These were defined for example by the demanding gradient profile of Zurich's cross-city-line and the environmental conditions of the Gotthard Base Tunnel (neither of these lines existed when the Re460 locomotives were first delivered). The cross-city line called for a redundancy concept: The steep gradients on this high capacity corridor pose a critical risk as a train failing there would have system-wide repercussions. The refit permits a failed traction motor to be isolated, with the train being able to continue its journey using the remaining three motors. In the new Gotthard Base Tunnel, specific challenges were posed by heat and humidity as well as latest fire safety standards.

—

A higher switching frequency would have led to increased switching losses and acoustic emissions.

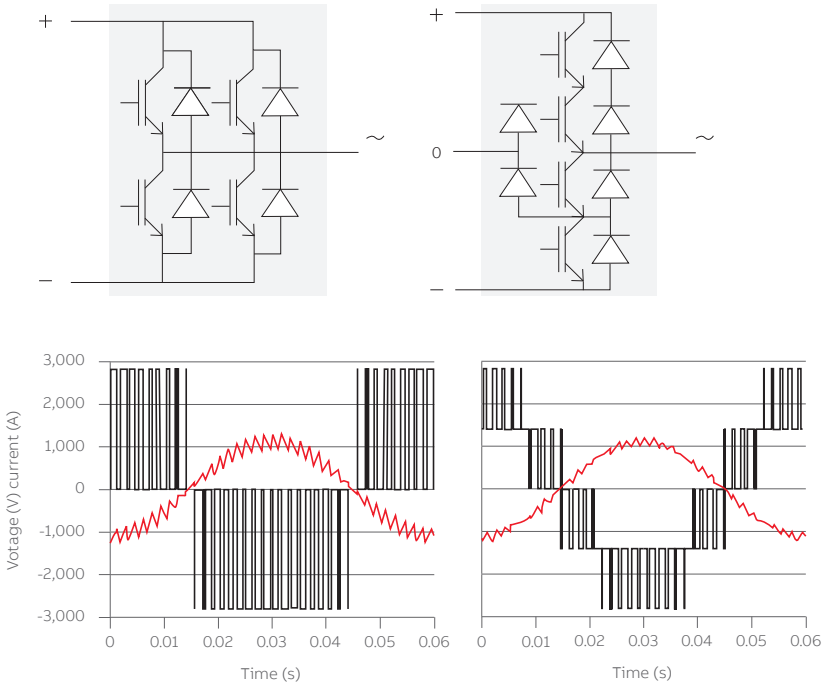
Technical solution

Diagnosis of the locomotives showed that the traction motors, transformers and vehicle control systems were in good condition. These elements are thus being retained, with their parameters defining the design of the new traction converters. They also define that the 3.5 kV DC-link voltage must be retained.

Two possible converter topologies were considered, both using IGBTs →2. The first variant was a two-level topology rated at 6.5 kV. The second was a three-level topology in which the upper and lower levels carry half the overall link voltage with respect to the middle level. This is ABB's preferred technology for retrofitting locomotives to IGBT-based traction converters and was chosen for use in the Re460.

The three-level topology results in a flow of traction current that more closely reflects the desired sinusoidal waveform. The original GTO system also featured a three-point topology: The resulting low level of harmonics influenced the design of traction motors and transformer. Achieving the same level of harmonics with a two-point topology would demand a high switching frequency. This implies greater switching losses as well as increased stress on the insulation materials. Besides the electrical and energy advantages, the solution adopted features low acoustic emissions.

Adoption of 3.3 kV three-level typology also avoids the need to connect IGBTs in parallel. Specifically, the grid side converter (there is one such converter for each of the two bogies) is made up of a total of four phase-module units. The two motor-side converters each have three →3. The matching of IGBT modules as necessary in parallel connection is not required.



02

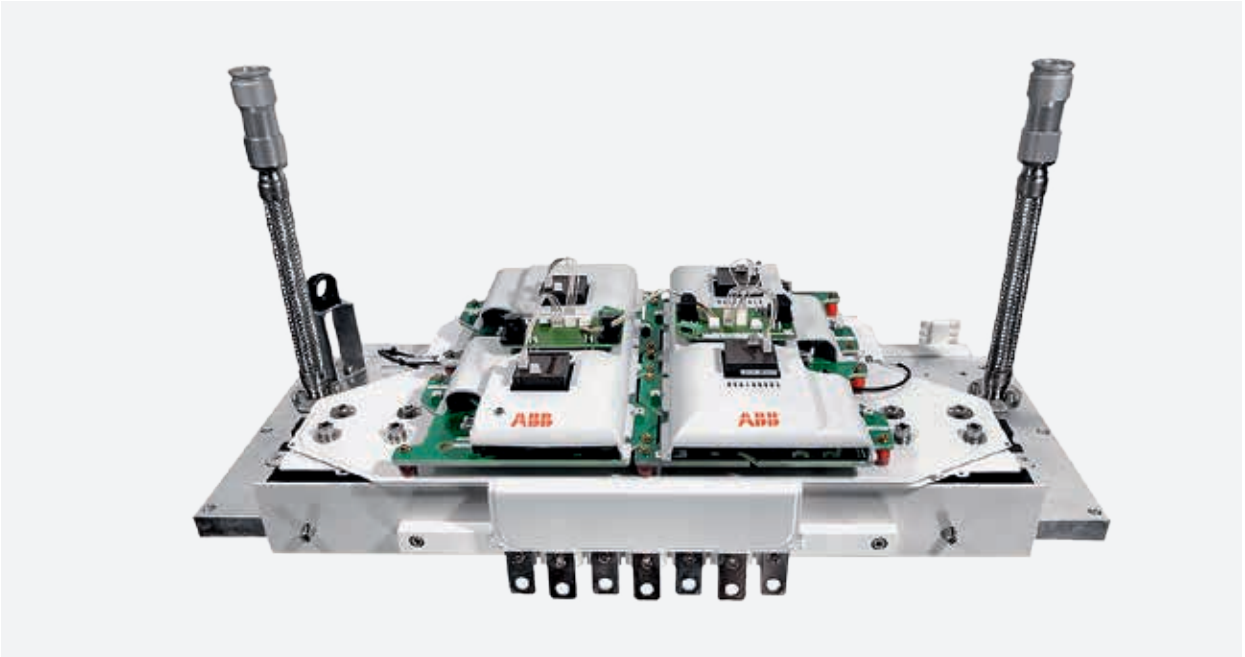
Power circuitry and mechanical construction
The use of IGBT technology aside, the topology of the power circuit is largely identical to the original. The water-cooled IGBT phase modules are based on ABB's BORDLINE traction converter platform. The phase modules used in the grid side converter are identical to those in the motor-side converter. The type was also used in other refit projects including the German ICE 1.

The transformer has four secondary-side coils, two of which connect to each of the two respective converters →4. Each coil connects to a rectifier unit, which draws power from the transformer but can also feed it back to the grid when the locomotive is braking.

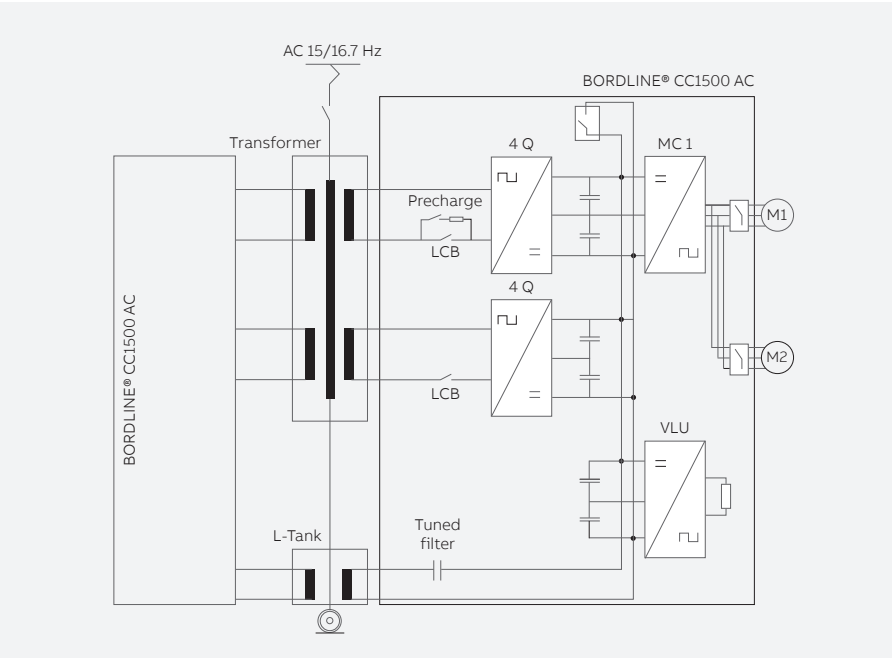
The DC-side voltage of the converters connects to the DC link capacitors, which smooth it with the help of a resonant circuit tuned to 33.4 Hz. This step is necessary because the 16.7 Hz single-phase railway grid does not feed power continuously. The power is supplied to the motor-side converters in pulses at double the grid frequency.

The DC-link voltage is rectified to three-phase AC by the three-level motor-side converter, creating the voltage wave patterns required to control speed and torque.

Each of the two traction converters supplies the two motors of one bogie in parallel connection. The new means of motor separation allow a failed motor to be disconnected.



03



04

05

—
04 Circuit diagram of the converter.

—
05 Stator of a Re460 locomotive motor on the dynamometer in ABB's lab in Turgi, being tested to determine the voltage on the coil during switching operations.

—
06
Measurement results of the stator tests. The diagram shows the transient overshoot of local winding voltages during IGBT switching. These must be limited to avoid harm to the motor.

Mechanical construction

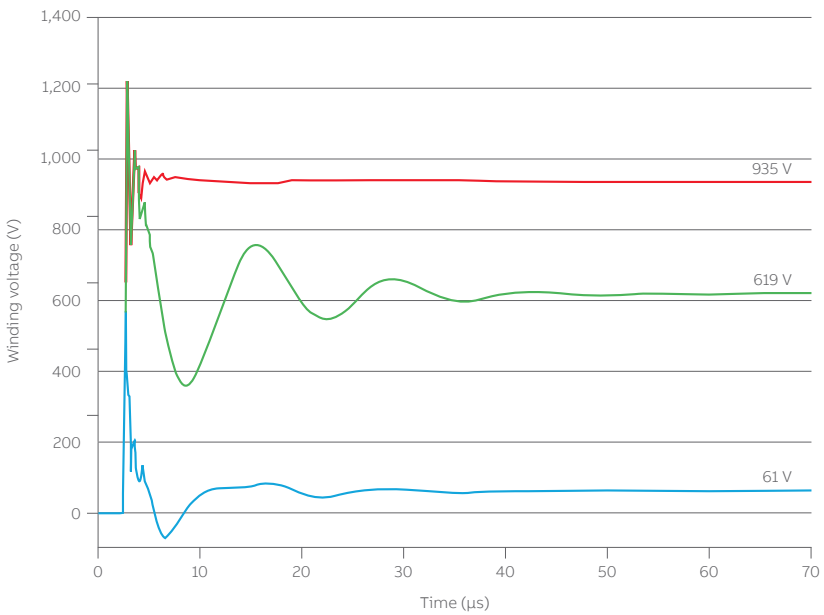
The new compact IGBT converters are water-cooled. The previous oil circulation system is being totally replaced by a water-cooling system. The new system reduces energy use as well as being ecological and safe.

The new cooling equipment is lighter and requires less space, freeing room available for additional components or future refurbishments. Ballast is used to offset the disadvantage of the decreased weight for traction adhesion.

Control technology

The new converter uses ABB's AC800 PEC control platform, one of the most powerful control systems available. In terms of its interfaces, the MVB (multifunctional vehicle bus) is identical to the one it replaces. Functional adaptations are minimal (one of the few changes is support for the previously described disconnection of individual traction motors).

Internally however, the PEC offers powerful computational abilities. These are used to offer advanced control functionality for the dynamic behavior of traction motors and energy usage.



06 — V_{in}: testing voltage applied to the motor
— V_{WM}: voltage measured inside the motor across one winding
— V_{coil1}: voltage measured across the first turn of one winding.

This article was first published in eb – Elektrische Bahnen 114 (2016), Issue 8–9, pages 485–489.

Further reading

Press release: "ABB wins $70 million order to modernize locomotives for Swiss Railways SBB", September 23, 2014.

H. Hepp, "A perfect fit – ABB's powerful propulsion converters are energy efficient, reliable and very compact, making them suitable for all rail vehicle designs". ABB Review 2/10 2010, 60–65.

Isber, J. and M. Curtis, "Standardizing the traction motor – ABB's innovative modular induction traction motor sets new heights in adaptability". ABB Review 2/10 2010, 66–69.

Moine, V., Hepp, H. and S. Maciocia, "Dedicated service – ABB offers a broad service palette for rail customers". ABB Review 2/2010, 70–76.

Swiss Federal Railways (SBB) Action plan 2015 www.confederation-exemplary-in-energy.ch, retrieved January 2017

SBB annual report 2015

The control software was created using Matlab Simulink®, supporting an efficient and intuitive implementation while also facilitating any future functional adaptations of the locomotives.

Testing

Extensive tests and measurements were conducted in ABB's labs in Turgi, Switzerland. These provided an accurate simulation of operating conditions and verified the design configuration while ensuring compatibility with existing components.

> The complete substitution of the GTO converters using new IGBT-based traction converters is an efficient and economical way of extending the operating life of locomotives.

Because the existing traction motors had been developed to match the locomotives' original GTO converters, the new IGBT converters had to be tested with these motors →5. The compatibility of the new output voltage with the existing motor insulation is critical. The three-point topology generates a similar harmonic pattern to the original converters and is therefore unproblematic. Evaluations were conducted in the ABB test laboratory to ensure that overvoltage does not result from the steeper switching voltage slope of IGBTs →6. These tests were successful.

The first two converters were successfully fitted to a Re460 locomotive in SBB's Yverdon-les-Bains workshop. This locomotive is presently being tested on SBB railway lines. These tests will continue for a year. In total 202 IGBT water-cooled converters, with an option of 38 more units will be supplied by ABB and fitted by SBB. The refit program will be concluded in 2022.

Ready for the future

The three-level AC train drive systems introduced more than 25 years ago continue to demonstrate energy efficiency and minimal maintenance costs. Like the Re460 itself, these systems reflect basic design eloquence and remain in good mechanical condition, permitting them to continue to operate for another 20 years. Nonetheless, if not addressed, technical difficulties associated with outdated converters, increased down time, higher maintenance costs and the challenges of securing spare parts threaten to negatively impact their operation. The complete substitution of the GTO converters using new IGBT-based traction converters is an efficient and economical way of extending the operating life of these locomotives. IGBT technology elevates the system to that of modern rolling stock with respect to energy efficiency, traction power regulation and ease of maintenance. ●

Imprint

Editorial Board

Bazmi Husain
Chief Technology Officer
Group R&D and Technology

Adrienne Williams
Senior Sustainability Advisor

Christoph Sieder
Head of Corporate Communications

Reiner Schoenrock
Technology and Innovation Communications

Ernst Scholtz
R&D Strategy Manager
Group R&D and Technology

Andreas Moglestue
Chief Editor, ABB Review
andreas.moglestue@ch.abb.com

Publisher
ABB Review is published by ABB Group R&D and Technology.

ABB Switzerland Ltd.
ABB Review
Segelhofstrasse 1K
CH-5405 Baden-Daettwil
Switzerland
abb.review@ch.abb.com

ABB Review is published four times a year in English, French, German and Spanish. ABB Review is free of charge to those with an interest in ABB's technology and objectives.

For a subscription, please contact your nearest ABB representative or subscribe online at www.abb.com/abbreview

Printer
Vorarlberger Verlagsanstalt GmbH
6850 Dornbirn/Austria

Layout
DAVILLA AG
Zurich/Switzerland

ISSN: 1013-3119

http://www.abb.com/abbreview

Affix address label here

Next 02/2017

Focus on Africa

Africa represents one of the greatest development opportunities on the planet, but also some of the greatest challenges. With the continent's population expected to reach 4.4 billion by 2100, ABB is innovating technologies to serve Africa's needs. Key examples will feature in the next issue of ABB Review.