# review

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**Asset Health Center helps AEP manage assets for AEP**

**Modular multilevel converter**



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ABB Ability™ digital substation



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**Extreme conditions are the ultimate test of the reliability of mission-critical operations, and they can be a result of structural conditions, such as remote or difficult locations, or circumstantial, like changes in weather or spikes in demand. ABB specializes in the hardware, expertise, and digital connectivity that ensure system performance in all conditions. This issue of ABB Review highlights such projects, and explores how they contribute to customer success in everyday conditions, too.**

**Your feedback is welcome.**
**abb.com/abbreview**

EDITORIAL

# Extreme performance

Dear Reader,

In 2012, Hurricane Sandy struck New York City, causing hundreds of deaths and delivering devastation estimated in the tens of billions. The utility company, Con Edison, suffered extensive damage as floodwaters surged into their installations. Con Edison called on ABB to help rebuild the infrastructure. Not content with reestablishing the previous configuration and functionality, the objective was to provide a greater resilience against future events. This was achieved in part through the physical design of equipment and in part through digitalization. Advanced connectivity and diagnosis functions permit not only the monitoring of regular operations, but support the reconfiguration of equipment in an emergency situation and the expediting of repair teams.

This and other examples of ABB equipment and solutions designed to perform under extraordinary conditions form the focus of this issue of ABB Review.

Enjoy your reading.

Bazmi Husain
Chief Technology Officer

# Extreme performa

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# nce

Keeping the lights on in a storm, or quickly getting them back online, requires a deep understanding of what could happen, not just what should be expected. ABB combines the right physical and digital technology to anticipate those requirements, and thereby ensure optimal performance in all conditions.

**08**

EXTREME PERFORMANCE

# Storm-proofing with ABB Ability™ digital substation

When a storm strikes, energy delivery systems must be resilient enough to allow quick repairs so the lights can be switched back on and commercial operations restarted. To accommodate grid resiliency, Con Edison replaced conventional technology with ABB Ability digital substation technology.

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When Hurricane Sandy hit New York City with full force in 2012, it brought levels of flooding (3.38 m/11.09 feet) that would usually be expected only once every 260 years [1]. In fact, Sandy's storm tide was the highest recorded since measurements began in 1700 →1.

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When Hurricane Sandy hit New York City with full force in 2012, it brought levels of flooding that would usually be expected only once every 260 years.

In addition to New York City, the New York Bight has three other cities on its shores – Newark, Jersey City and Hoboken – as well as a large number of smaller townships. In all, some 21 million people live near the Bight in a very densely populated conurbation that contains the large amount of infrastructure one would expect to find in a region that is a global economic powerhouse. Apart from the tragic loss of life,
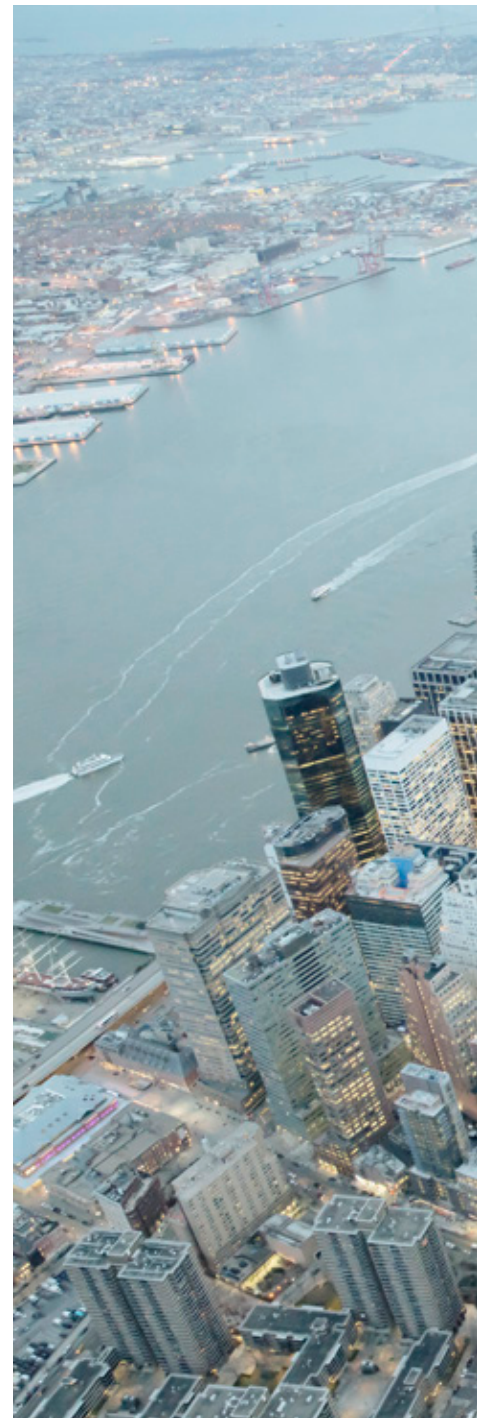
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01 Manhattan Island and
environs are low-lying
and densely populated,
which makes infrastruc-
ture vulnerable to natural
catastrophes such as
Hurricane Sandy.

Hurricane Sandy also caused infrastructure damage amounting to over $60 billion: Houses were destroyed, streets, tunnels and subway stations were flooded, and the salt water caused much deterioration. Large parts of New York City lost electricity, water, telecommunications and sewerage for several days.

Consolidated Edison, Inc., commonly known as Con Edison, is one of the largest investor-owned energy companies in the United States, with assets worth over $47 billion. One of these assets is the substation that serves lower Manhattan, including Wall Street.

This substation is among the largest of its kind in the United States and supplies electricity to hundreds of thousands of customers.

Con Edison staff still remember vividly the devastation caused by Hurricane Sandy. The huge quantities of seawater that flooded the substation seriously damaged copper

—
## Hurricane Sandy also caused infrastructure damage amounting to over $60 billion.

wiring and switchgear control cabinets. The corrosion that Con Edison engineers observed on some of the switchgear control systems, wiring and terminal blocks looked like it might have taken decades to develop, yet it had occurred in just a matter of hours.

**01**

02

Since Hurricane Sandy, Con Edison has invested $1 billion in their "Storm-Hardening Protection Plan" to make both overhead and underground energy delivery systems more resilient in the face of extreme weather. These measures include the protection of substations with reinforced perimeter walls, gates and floodwalls →2-3.

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The huge quantities of seawater that flooded the substation seriously damaged copper wiring and switchgear control cabinets.

A further critical part of Con Edison's storm protection program was to install ABB Ability digital substation technology to secure the power supply for the key Manhattan substation [2]. A central philosophy here was to replace several pieces of conventional power system equipment with digitally-enabled technology.

**ABB Ability digital substation**
An ABB Ability digital substation is a key component of a smarter grid. In the substation, digital communications via fiber optic cables replace the traditional copper wire connections that use binary control signals. This increases safety, flexibility and availability while reducing cost, risk and improved resilience in the event of the next storm of the century.

In particular, the entire control data, measurements from the relays and monitoring data flows over the highly reliable fiber optic digital communications bus. The resulting benefits are not only reduced operations and maintenance costs but also improved resiliency and reliability. For example, asset condition data is collected via standardized digital communication to optimize performance and improve the substation's efficiency and cost effectiveness – reducing transformer and breaker downtime by up to 50 percent.

**04**

The new ABB Ability digital substation also allows Con Edison to take advantage of big data. From this, critical asset data and business intelligence can be extracted so that faster decisions can be made in a crisis, for instance. The data can also be analyzed, trends identified and potential problems predicted. In other words, this wealth of new data facilitates a shift from traditional time-based maintenance to condition-based maintenance.

**Simplified controls**
Part of the digitalization process was to transition from multiple layers of legacy control systems – some of which had been compromised by Hurricane Sandy's floodwaters – to a new single automated system. This single-system approach greatly simplified the tasks carried out by the personnel and improved safety and reliability →4.

The Con Edison engineers maintained an ongoing dialog with ABB's team throughout the design, testing and installation stages and were successfully able to place phase one into service on schedule, within budget, without accident or injury.

Use of the open global substation communication standard IEC 61850 simplified matters further: The new substation automation protection and control system uses GOOSE messaging – which is based on IEC 61850 – to control the breakers in the switchyard. The use of IEC 61850 allows Con Edison to implement an interoperable multivendor protection and control solution that was previously not possible. The communication between the breakers and protection relays, and remote operation are enabled through the fiber optic communication networks.

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02 Some of the new measures taken against flooding such as perimeter walls are visible in this aerial view of the Con Edison substation in lower Manhattan.

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03 Flood damage prevention measures include high walls and raised conduits.

—
04 The simplified Con Edison control room makes life easier for operators.

The ability to share the information over a digital bus makes it possible to utilize all available data and combine it with historical data as well as fleet views. This can help to increase network reliability and extend the life of the assets in this substation and others.

Further, it is not only possible for the asset owner to increase the reliability of the substation itself in this way, but also to link the operational and the maintenance practices at the substation to those at the enterprise level.

**03**



**04**

05

**PASS hybrid switchgear**
A significant component of the new ABB Ability digital substation is the modular 420 kV Plug and Switch System (PASS) hybrid switchgear, which has been installed more than 10 m (35 feet) above the original substation level – safely above extreme flood levels – so power reliability will be improved and outages reduced →5-7.

The innovative PASS switchgear enables a 50 percent space saving by providing all high-voltage bay functions in a compact footprint, enabling the addition of new switching bays to an already densely-packed substation with no space penalty (real estate in New York City is both expensive and hard to come by). PASS equipment is easy to transport and installs quickly without the need to assemble active parts or conduct high-voltage tests on site.

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The resulting benefits are not only reduced operation and maintenance costs but also improved resiliency and reliability.

This ease of installation comes thanks to a simple, safe and effective feature that enables quick rotation of bushings from the transport to the service position. This results in a faster onsite installation and commissioning process.

06

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05 The ABB 420 KV PASS
switchgear in the Con
Edison substation.

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06 The PASS hybrid
switchgear is 10 m (35
feet) above the original
substation level.

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07 Overview of the PASS
installation. The bushings
are rotated out from their
transport position to
their operational position
once on site.

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substation helps New
York guard against storm
chaos." Available: https://
www.youtube.com/
watch?v=8AduBjK7Iic

**Less copper**
As a result of the digital upgrade by ABB, some
80 percent of the copper control cabling has been
rendered obsolete and has been replaced by a
few fiber optic cables. Less copper brings greater
safety: As a conductor of electricity, every bit of
copper in a substation is a potential electrical
shock risk for field personnel.

**Storm-proofed and future-proofed**
Enabling digitalization of the power grid is a core
element in today's increasingly connected world.

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In the substation, digital
communications via fiber optic
cables replace the traditional
copper wire connections that use
analog signals.

With ABB Ability technology, digital substations
allow customers to build electric power grids that
are more reliable and that allow more effective
human interaction when it comes to operation,
maintenance and worker safety.

It is very exciting to witness how Con Edison
in New York City has digitally transformed
their most critical substation and to see
the additional weather-fortification measures
that will bring greater grid resiliency and
improve the reliability of electric power supply
to Manhattan's consumers. The flexibility
delivered by digitalization accommodates any
eventual expansion that is needed, even on a
multivendor basis, and so ensures that the digital
substation is not just storm-proofed, but is
future-proofed too. ●

**07**

EXTREME PERFORMANCE

# Self-contained thermo-syphon heat exchanger for power converters

Modern power electronics products can generate a lot of heat. Water cooling is often undesirable or impractical, so ABB has developed a two-phase compact thermosyphon heat exchanger that is simple and entirely passive, hence very reliable. A compact air-to-air heat exchanger for enclosure cooling was developed with the same technology.

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The heat loss density in modern power electronics can exceed 100 W/cm² at chip level and 30 W/cm² at the heatsink base level – and these figures are expected to be even higher in future products. Water is a very effective medium for cooling power electronics but is often undesirable or impractical. However, two-phase cooling provides a promising alternative.

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Thermosyphons represent one particularly interesting approach to two-phase cooling because they are entirely passive and simple, hence reliable.

Two-phase cooling uses dielectric fluids in passive arrangements and benefits from very high heat transfer coefficients. Thermosyphons represent one particularly interesting approach to two-phase cooling because they are entirely passive and simple, hence reliable.

ABB has developed a compact thermosyphon heat exchanger – based on automotive technology – that uses numerous multiport extruded tubes with capillary-sized channels disposed in parallel and brazed to a base plate that receives the power electronics modules. This compact heat exchanger achieves a high cooling performance and low air pressure drop. A similarly compact air-to-air heat exchanger for enclosure cooling was also developed with the same technology. Both deliver the performance of water cooling with the ease of use of air cooling.
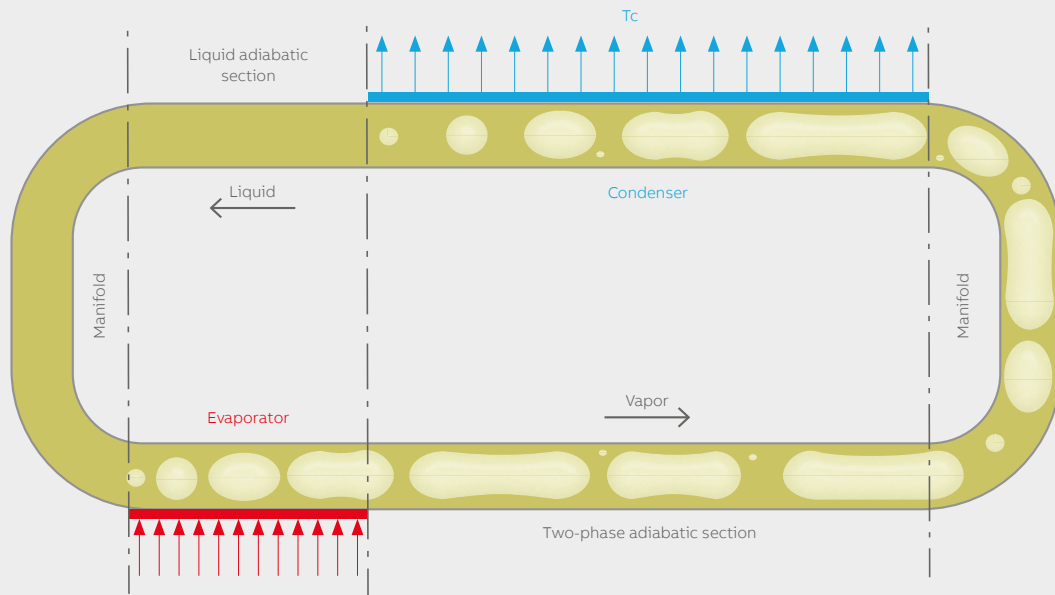
**01**

To bring this ABB self-contained cooling system technology to maturity required detailed work concerning manufacturability, working fluids, safety, applicable regulations and design as well as thorough investigation of performance, safety
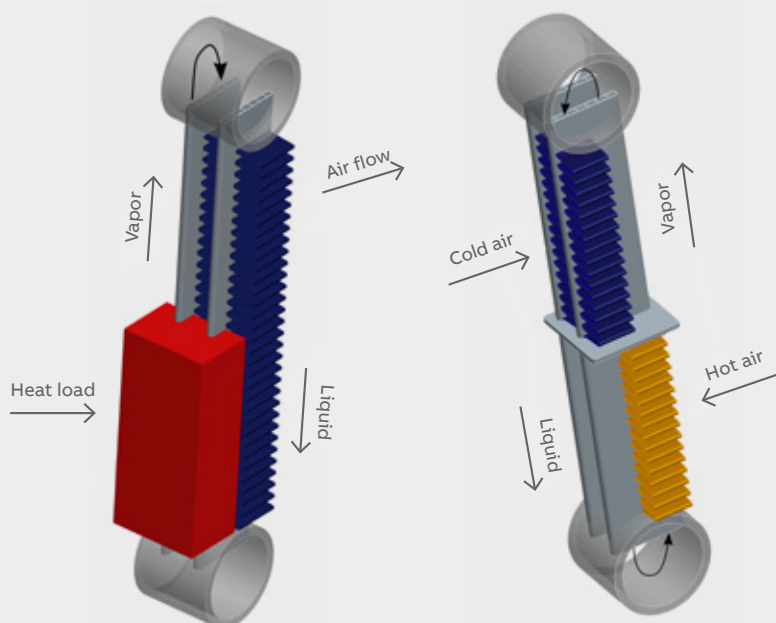
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The compact heat exchanger achieves a high cooling performance and low air pressure drop.

and reliability requirements. The technology has been meticulously tested in ABB laboratories as well in the field.
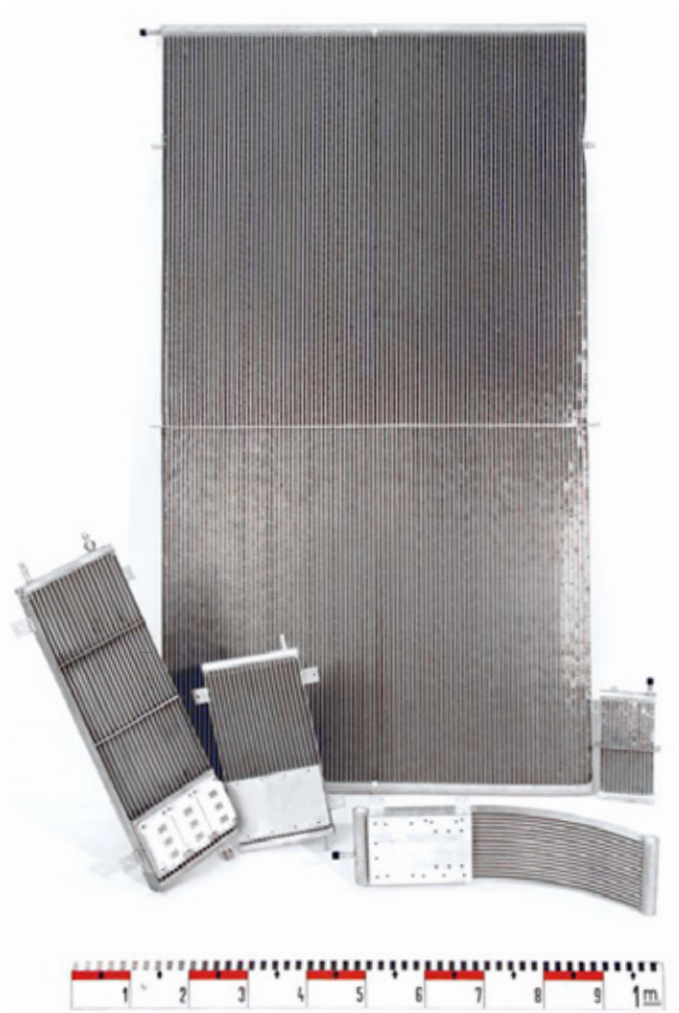
**Working principle**
The ABB self-contained cooling system technology aims to replace today's aluminium air-cooled heatsinks with a high-performance and compact thermosyphon cooler based on an automotive heat exchanger. The associated benefits are: reduced overall product size, increased power density, reduced fan noise and improved mechanical design. →1 and →2 show the working principle and the details of the design for a base-to-air and an air-to-air cooler (patent EP2031332).

**02**

03

The cooler is made of parallel aluminium multiport extruded (MPE) tubes whose ends are connected to a manifold tube at the top and

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ABB has developed a compact thermosyphon heat exchanger – based on automotive technology – that uses numerous multiport extruded tubes with capillary-sized channels.

bottom. The cooler is divided into an evaporator plus riser section at the bottom and a condenser plus downcomer section at the top. The MPE tube is composed of multiple minichannels (typically 7 to 13) in parallel. A few of these channels are dedicated to evaporation and are, therefore, brazed onto a baseplate where the heating electronics is fixed while louvered air fins are attached to the remaining channels for condensation. Thus, each of the MPE tubes behaves like an individual thermosyphon.

04
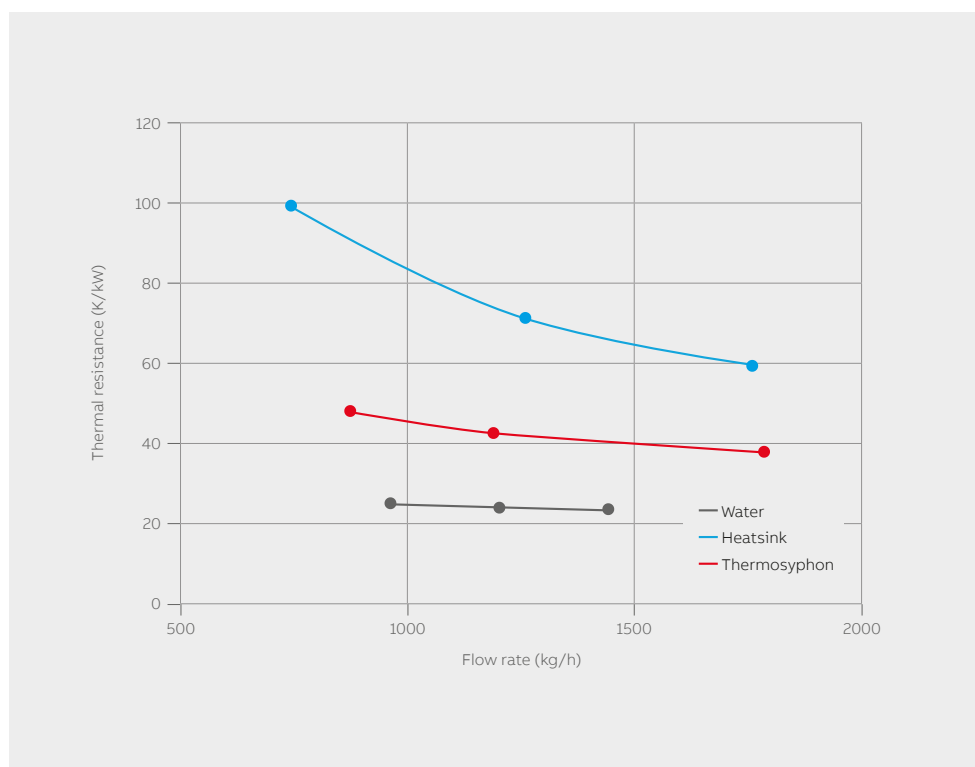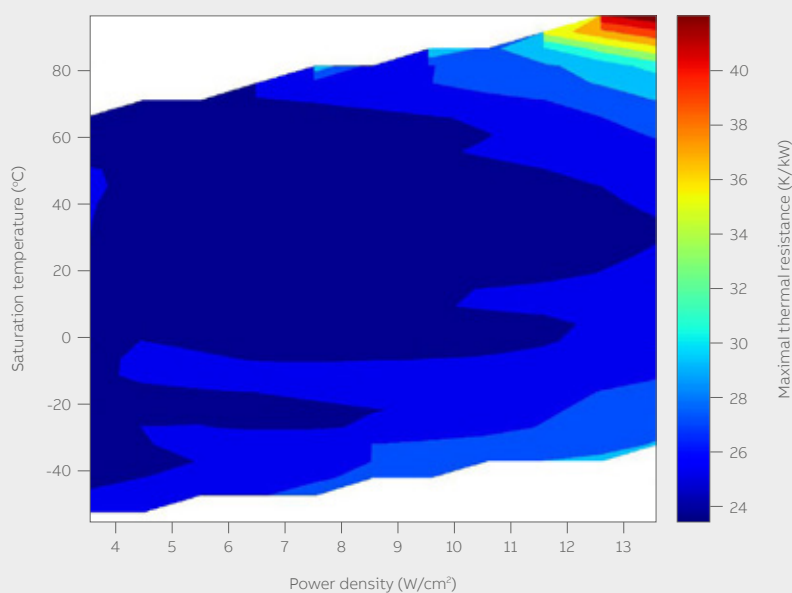
**05**

The number and length of MPE tubes can be selected to meet the cooling requirements →3. The design allows a high MPE tube density and can thus handle higher heat densities than classical heat-pipe coolers.

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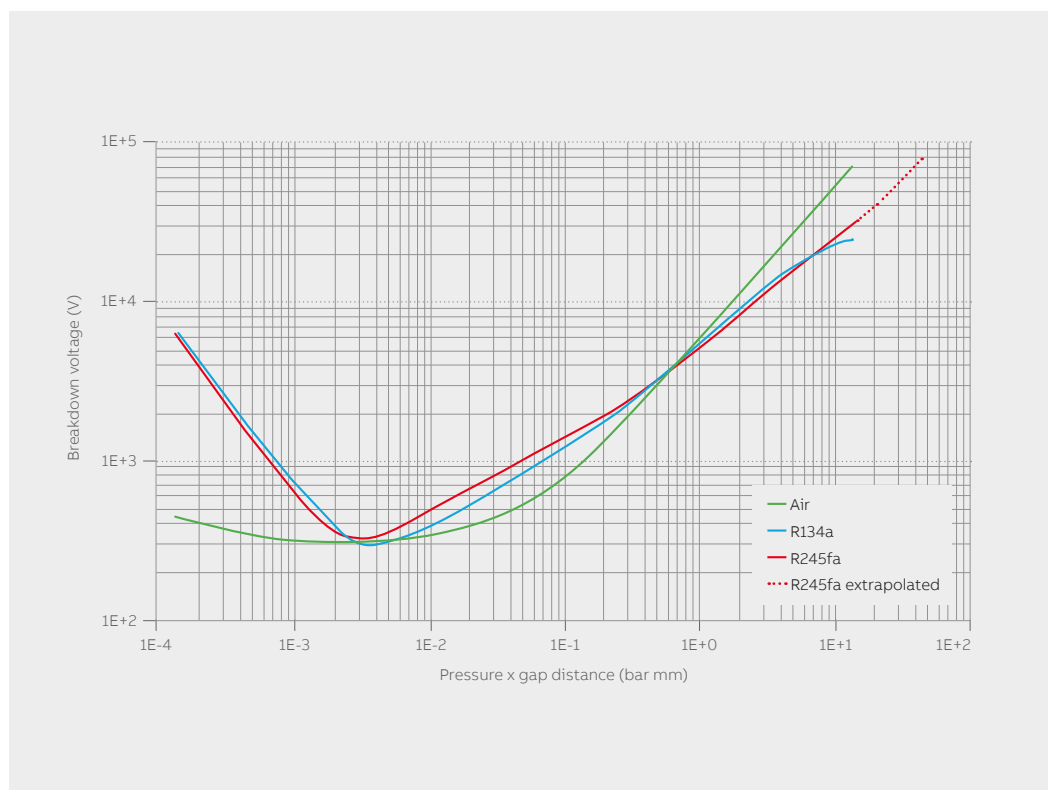
**Manufacturing**
Good corrosion resistance, formability and high thermal conductivity make aluminium an ideal material for the construction of the cooling system. The manufacturing process uses the aluminium Nocolok brazing process, which is the preferred method of producing automotive heat exchangers such as radiators, condensers, evaporators and heater cores. The Nocolok process is widely used by automotive heat exchanger manufacturers, so they should all be able to produce ABB self-contained cooling systems.

**Performances** [1]
A comparison with heatsink and water cooler performances was carried out →4. The performance of ABB's two-phase cooler lies between that of the classical heatsink and the water cooler, with a thermal resistance about 50 percent lower. Moreover, the air pressure loss is typically six times lower than that of a standard heatsink.

**Available fluids** [2]
The refrigerants of interest for ABB in the hydrofluorocarbon (HFC) group are R134a and R245fa. These HFCs are generally chemically very stable and tend to have good compatibility with most materials. Their thermodynamic and transport properties range from fairly good to very good, thereby offering the potential for high cooling efficiency. They have been in large-scale use since the 1990s for many different refrigeration applications.

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03 Family of ABB self-contained cooling system coolers, from 0.2 to 2 m.

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04 Comparison of performance with standard cooling technologies.

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05 Performance map of ABB self-contained cooling system in extreme air temperatures.

**06**

HFC refrigerants contain no chlorine and are thus not damaging to the ozone layer. However, due to their long atmospheric lifetime, they are typically strong greenhouse gases with high global warming potential (GWP). New legislation to control the use and emission of HFCs will

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## The ABB self-contained cooling system is very leaktight.

phase out R134a and R245fa after 2025. They will be replaced by R1234ze or R450A and R1233zd, which have much lower GWP and yield the same performances. However, the ABB self-contained cooling system is very leaktight: The total R134a leakage at 20 bars operation was evaluated to be around 2.7 g/year, which allows 30 years' operation without maintenance.

As regards fluid safety, the small dimensions of thermosyphons made from MPE tubes mean that they are not affected by pressure vessel or related regulation. Similarly, international norms related to GWP have only minor impact on ABB two-phase devices thanks to the fact that these hermetic cooling devices are classed as "stationary refrigeration equipment."

**Corrosion** [3, 4]
The alloy EN AW-3003 used in the cooler is an aluminium alloy that has good corrosion resistance in different environments. To test corrosion resistance, 12 ABB self-contained cooling systems were subjected to corrosive atmosphere testing under accelerated tests described by norms ISO 3231 ($SO_2$), 6270 (humidity) and 9227 (salt spray). These tests simulate about five years of use in real polluted atmospheres.

All systems tested were found to be leaktight and working after test completion. Temperature rises were also measured and found to be essentially unchanged, though the three samples that were exposed to salt spray had up to 8 K temperature rise due to salt clogging the fins. Once cleaned, original performance was restored.

### Extreme temperatures [5]

An experimental characterization of the ABB self-contained cooling system with R134a in temperatures between -60 and 60°C and vibrations up to 8 G was performed in a HALT (highly accelerated life test) chamber, showing that it works satisfactorily →5. In →5, the color represents the thermal resistance, which starts increasing only at a high air temperature combined with a high heat density. Vibrations had no negative effect on the performance.

### Breakdown voltage [6]

Where a device may be used in a high-voltage environment, the breakdown voltage becomes very relevant. The breakdown voltage of R134a

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All systems tested were found to be leaktight and working after test completion.

is superior to that of air as long as the pressure value multiplied by the air gap does not exceed 1 bar mm →6. If refrigerant leaks at atmospheric pressure, the electrical insulation will surpass that of pure air up to 5 kV, for any distance not greater than 1 mm. Beyond this point, the insulation capability will be between that of
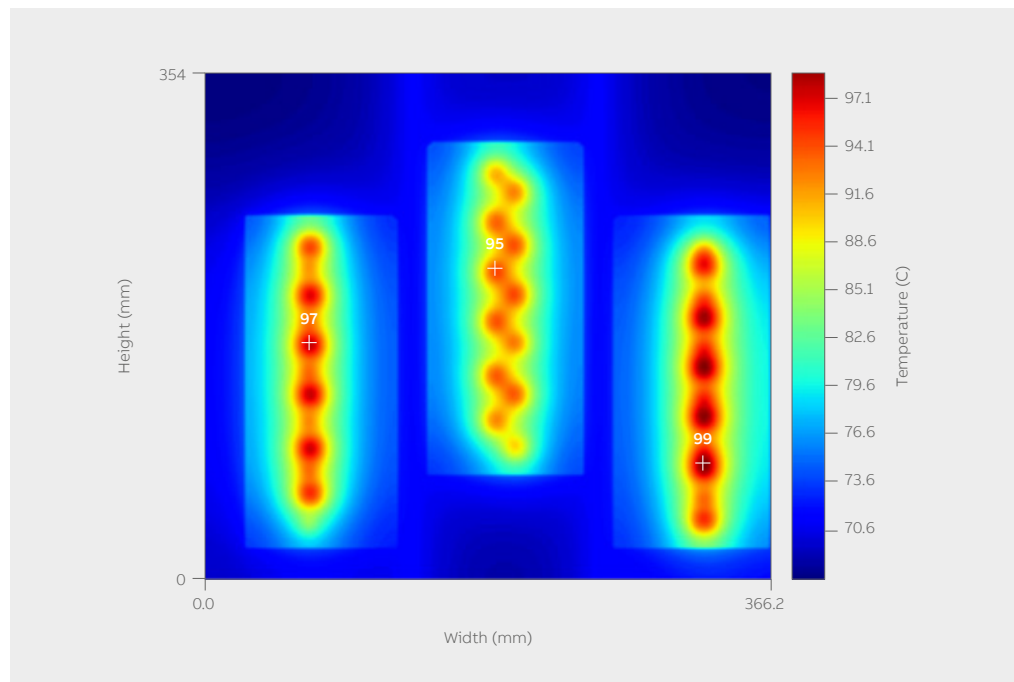


**07**

R134a and air. The conclusion is that for low-voltage applications, the insulation is actually improved, while for high-voltage, greater clearance might be needed compared to pure air. The conclusions are identical with R245fa.

**Design tool** [7-9]
A one-dimensional, numerical, two-phase flow model was used as an idealized representation of the thermosyphon. This model uses the solution of the three conservation equations (mass, momentum and energy) combined with a minimization algorithm in order to determine the mass flow rate, saturation temperature and evaporator exit vapor quality inside the loop.

Correlations from the literature are used to characterize the two-phase flow. A 3-D heat spreading solver is coupled to the thermosyphon solver in order to predict the silicon junction

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<span style="color:red">The small dimensions of thermosyphons made from MPE tubes mean that they are not affected by pressure vessel or related regulation.</span>

temperature and to take into account both the module packaging and the effect of the boiling heat transfer coefficient on the local heat flux, which affects the spreading. →7 shows a simulation of typical 3-D heat spreading on the module baseplate of a PVS980 photovoltaic (PV) inverter. There is good agreement between predicted and measured temperatures.

**A proven technology**
The ABB self-contained cooling system is a mature technology ready for integration in power converters and able to deliver the performance

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of water cooling with the ease of use of air cooling. ABB already has three products that use this two-phase cooling technology:
- Since 2011, ABB has been selling high-IP-rated dry transformers [4] with enclosure cooling performed by stacks of air-to-air ABB self-contained cooling systems. The first two units were installed in a marine environment.
- The low-harmonics ACS800-38 outdoor drive →8, has been sold since 2012, with the first pilot installation in a desert environment.
- The newest product using this cooling technology is the outdoor photovoltaic (PV) inverter PVS980.

The manufacturing methods and components related to the ABB self-contained cooling system are state-of-the-art; reliability history is

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A one-dimensional, numerical, two-phase flow model was used as an idealized representation of the thermosyphon.

comprehensive due to decades of experience in the automotive industry; and the technology has been thoroughly tested in ABB laboratories as well as in the field. ●
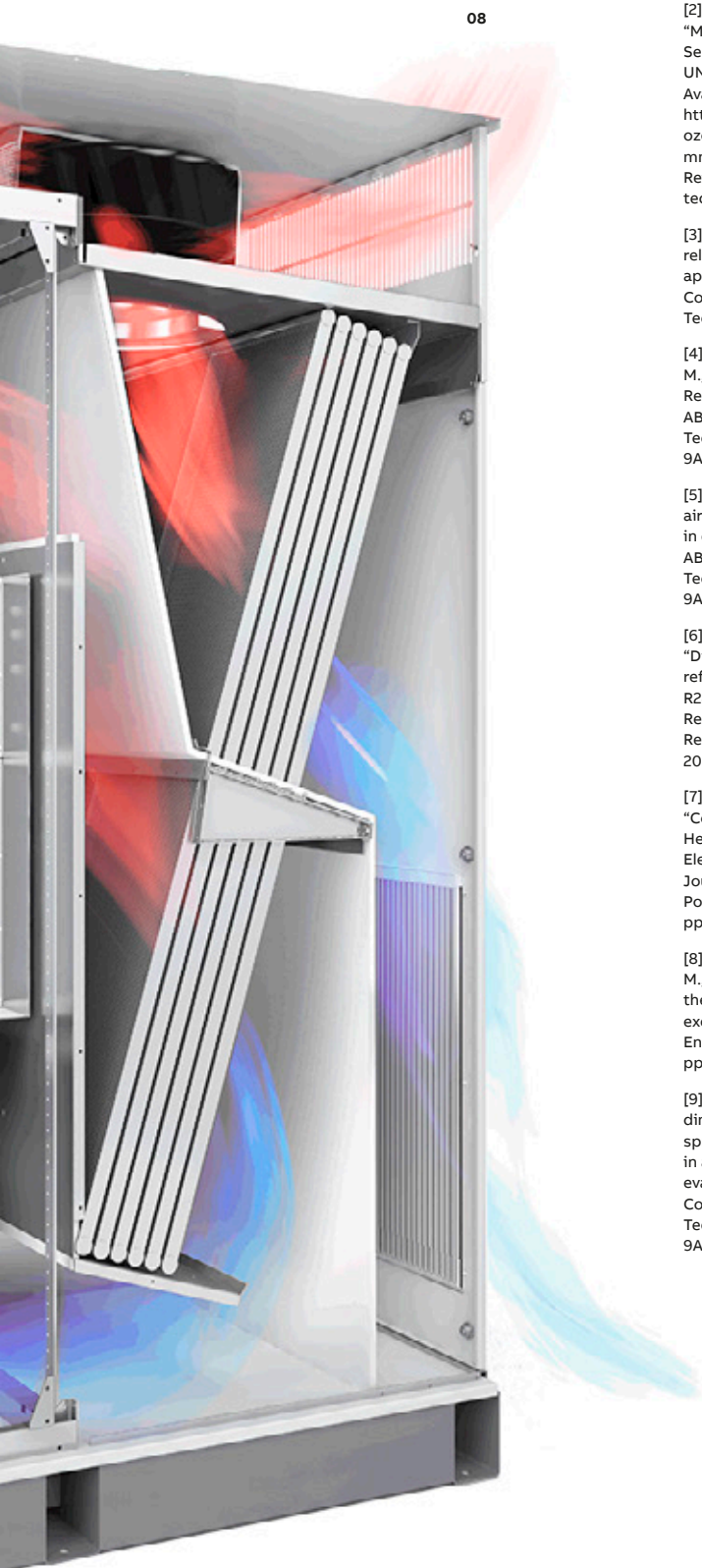
EXTREME PERFORMANCE

# A compact substation for extreme conditions

ABB's UniPack-G CSS compact secondary substation (CSS) has an outer shell made from glass-reinforced polyester (GRP) to protect it in harsh environments. The UniPack-G CSS was the ideal solution for the Mina Abdulla Refinery Sea Island Structure in the Persian Gulf.

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KNPC (the Kuwait National Petroleum Company) is one of the world's top refiners. The company has two refineries: Mina Abdullah and Mina Al-Ahmadi, both located in Kuwait. To increase export capability for refined products from Mina Abdullah, an offshore loading facility was constructed in the Persian Gulf. Located some 5 km off the east coast of southern Kuwait and nearly 6 km east of the Mina Abdullah refinery itself, the manmade Mina Abdulla Refinery Sea Island Structure has two loading berths for exporting liquid petroleum products and importing fuel oil in case of emergency →1.

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Because the UniPack-G CSS weighs only about one-third of its concrete equivalent, transportation costs are reasonable and installation in remote or difficult locations is far easier.

Each berth has six loading arms: four for white oil products and two for bunker/fuel oil products. There are six submarine pipelines leading to the island, one each dedicated to the transport of naphtha, kerosene, European gas oil (EGO), high-speed diesel (HSD), marine diesel oil (MDO) and high-sulfur fuel oil. The facilities can load 80,000 t of white oil products in 36 hours and the same quantity of black oil products in 40 hours.

The infrastructure that supports this high level of activity on the island needs significant quantities of electrical power. High-voltage undersea cables supply the island, but a substation is then needed to step the voltage down to the levels required by local power consumers. KNPC were determined to find a secondary substation that would easily cope with the island's excessive humidity, extreme temperatures and severe marine corrosion conditions, to say nothing of combustibility concerns.

For the job, KNPC decided on the ABB UniPack-G CSS.

**01**

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01 The manmade Mina Abdulla Refinery Sea Island Structure. Photo courtesy of Kuwait National Petroleum Company.

**ABB UniPack-G CSS**
Steel and concrete are the two usual options for substation construction. Concrete (or brick) is weather-resistant but very heavy and awkward to work with. Preassembly simplifies

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The ability to maintain the internal temperature, regardless of external conditions, is an inherent property of the UniPack-G's double-layer feature.

construction on site but increases transportation and rigging costs as an entire concrete CSS weighs around 24 t. Steel provides a lighter, more convenient and cheaper solution. With the comparatively lighter weight of a steel CSS, transportation is easier and heavy on-site installation work is not required. A steel CSS has an average weight of 12 t for the same functionality as a concrete CSS weighing twice that. However, while lighter, steel is not as strong as concrete and is even more susceptible to degradation in adverse environmental conditions.

Ideally, a CSS enclosure should have the advantage of concrete and steel but none of the disadvantages. To fulfill this need, ABB developed the UniPack-G CSS enclosure →2.

The UniPack-G CSS enclosure is made from GRP, which makes it very strong and stable. Because the UniPack-G CSS weighs only about one-third of its concrete equivalent, transportation costs are reasonable and installation in remote or difficult locations is far easier. Although lighter, GRP has greater durability than both concrete and steel and can withstand considerable impact – an important consideration for the UniPack-G CSS transported to Mina Abdulla Island.

The UniPack-G design has been tested to the highest relevant GB (Guobiao, Chinese) and IEC safety standards. In addition, the standard UniPack-G design, which is also highly fire-retardant, has passed the internal arc classification (IAC) test, which ensures it has the highest level of safety for the public and operating personnel.

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Because the UniPack-G CSS is built of GRP, including the roof and doors, maintenance requirements and, consequently, the cost of ownership, is low.

**Beat the heat**

One major environmental challenge of the Mina Abdulla Island location is the high ambient temperature and the intense sunshine. UniPack-G's double-layer design ensures that ambient

temperatures do not affect the equipment inside. →3 shows the high level of insulation provided by ABB's UniPack-G. The first image shows the internal wall of a typical steel enclosure in intense sunshine typical of that experienced on the Mina Abdulla Island. Here, the high internal temperature would affect the performance of the equipment and may require derating.

The second image shows the advantages of the UniPack-G's double layer insulating design: hot sun outside (red); cool inside (blue). The ability to maintain the internal temperature, regardless of external conditions, is an inherent property of the UniPack-G's double-layer feature, which is included in all standard solutions. This temperature stability also eliminates the mechanical expansion and contraction and accompanying mechanical stresses associated with steel or concrete constructions.



02

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02 The UniPack-G
CSS enclosure.


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03 The UniPack-G
(middle image) impedes
heat ingress far better
than steel (left) or
concrete (right).



Steel                    UniPack-G                    Concrete

Temperature (°C)

80
77
75
72
70
67
65
62
60
57
55
52
50
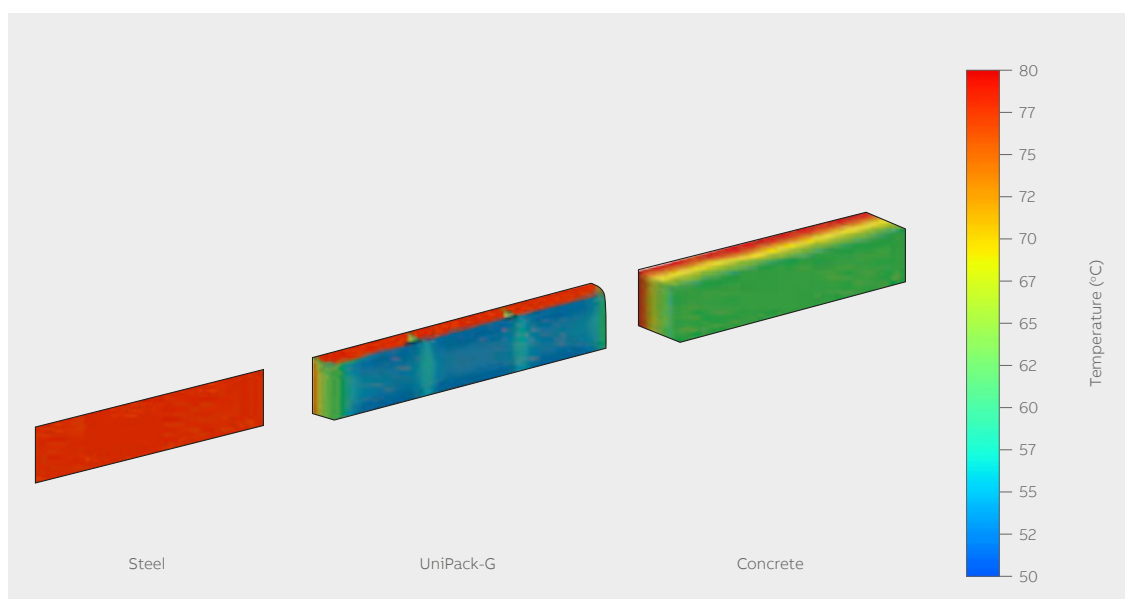
**03**

The third image represents a thicker, concrete enclosure wall where the light green shows that the interior wall is hotter than that of the UniPack-G.

**Low maintenance**
Because the UniPack-G CSS is built of GRP, including the roof and doors, maintenance requirements and, consequently, the cost of ownership, is low. Beneath its double-layered shell, which provides first-class thermal characteristics and rigidity, there is no need for any additional supporting frame. This simplification eliminates those locations where corrosion can gain a foothold while stabilizing the interior climate in the face of the challenging Mina Abdulla Island environmental conditions. The GRP construction material also renders repainting unnecessary.

UniPack-G's flexibility makes it the ideal enclosure not just for Mina Abdulla Island but also for the complete spectrum of ABB's smart grid product portfolio – including monitoring, control, measurement and protection products.

The ABB UniPack-G has been well received in this KNPC pilot project – which was completed and delivered in mid-2016 – and there is an optimism

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UniPack-G's flexibility makes it the ideal enclosure for the complete spectrum of ABB's smart grid product portfolio – including monitoring, control, measurement and protection products.

that the product could become a standardized solution for KNPC as well as other customers with a requirement to protect smart grid products from harsh environmental conditions. ●

# Ingenuity at work

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At ABB, there's a direct connection between preparedness for extreme performance, and the ongoing iteration necessary to keep everyday operations at peak capacity and reliability. Satisfying customers' current needs also provides the platform upon which future successes can be embraced, and new challenges addressed.

INGENUITY AT WORK

# Advancing industrial automation with software engineering practices

In order to maximize cost and quality gains, ABB researchers recognize the need for industrial automation systems to incorporate software engineering best practices in application development processes. This requires either the adaptation or the development of the right set of tools and methodologies to meet the unique needs of the automation domain. ABB has evaluated a number of software engineering practices and suggests possible adaptations of these methods to enhance automation engineering.

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Automation engineering requires the use of software activities such as the development of application logic, libraries and human machine interfaces. The automation development life cycle (HMI, AADLC) being proprietary in nature, is not typically compatible with commonly used software engineering tools, which are based on general-purpose programming languages like C/C++, Java, etc. Automation engineering, on the other hand, uses domain-specific programming languages (e.g., IEC 61131-3) [1]. ABB strives to combine automation technology with advances in software engineering developmental processes to meet future customer needs.

Some of the best practices used in software development include methods for requirement elicitation, static code analysis, computation of code metrics, impact analysis, test automation, and version management. The successful

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The automation development life cycle (AADLC) is proprietary in nature and is not typically compatible with commonly used software engineering tools.

incorporation of these software engineering best practices through further development or adaptation to industrial automation engineering tools and methodologies would improve the exploitation of advances such as SCDs in industrial automation engineering →1. At first glance this seems a simple task.

However, the heterogeneity in technology, terminology, and tools in industrial systems, including the diversity of domain engineering teams, pose challenges that ABB scientists address.

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01 Engineers and managers can use common software applications to increase performance.

**Adapting requirement elicitation techniques**

Industrial application requirements are given in diverse formats:

- I/O lists, which specify input and output tags,
- Cause and effect matrices (CEMs) that denote the relationship between input signals and controller outputs,
- Piping and instrumentation diagrams (PI&Ds) that describe how devices and actuators are connected,
- Control narratives in natural language that relay functional behavior of control algorithms and indicate how control components function in a plant.

Of these requirements, the first three are challenging but straightforward to standardize and formalize →2. For instance, ABB, together with researchers at the Helmut Schmidt University has, researched methods for extracting object oriented descriptions of PI&Ds [2].

Standardization and formalization of control narratives in automation will require much effort →2. Standard software engineering models use Statecharts and live streaming charts (LSCs) that enable features like advanced modeling, verification and validation techniques. The structure of the models, being either state-based or communication centric hierarchical models, can throw-off domain engineers comfortable with traditional function-based models. Furthermore, the formal notation used may be too complex for the automation engineers to fully understand. The adaption of LSCs and statecharts is therefore not the best starting point [3]. SCDs, defined by NORSOK standard I-005 describe the control function in automation and provide a better starting point for standardization and formalization of requirement documents.

Further development of the control function ability will ensure interrelation with I/O lists, CEMs and P&IDs. In addition, tools can be built to generate formal models like statecharts and/or LSCs that can lead to increased efficiency and lower costs.

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SCDs, defined by NORSOK standard I-005 provide a starting point for standardization and formalization of elicitation requirement documents.

**Static code analysis tools**
Static code analysis is used widely in software engineering to detect run-time errors and ensure conformance to safety coding rules and best coding practices. Standard techniques are:
- Pattern matching, which uses anti-pattern codes to identify unsafe structures in the program.
- Symbolic execution, which tracks symbolic values of variables to reason about all possible program paths.
- Program flow analysis, which sets up data-flow equations for each node of the control flow graph. Solutions are achieved through calculating the output from the input from each node.
- Constraint-based analysis, which derives relations in the program then uses a constraint solver to compute a solution for constraints.
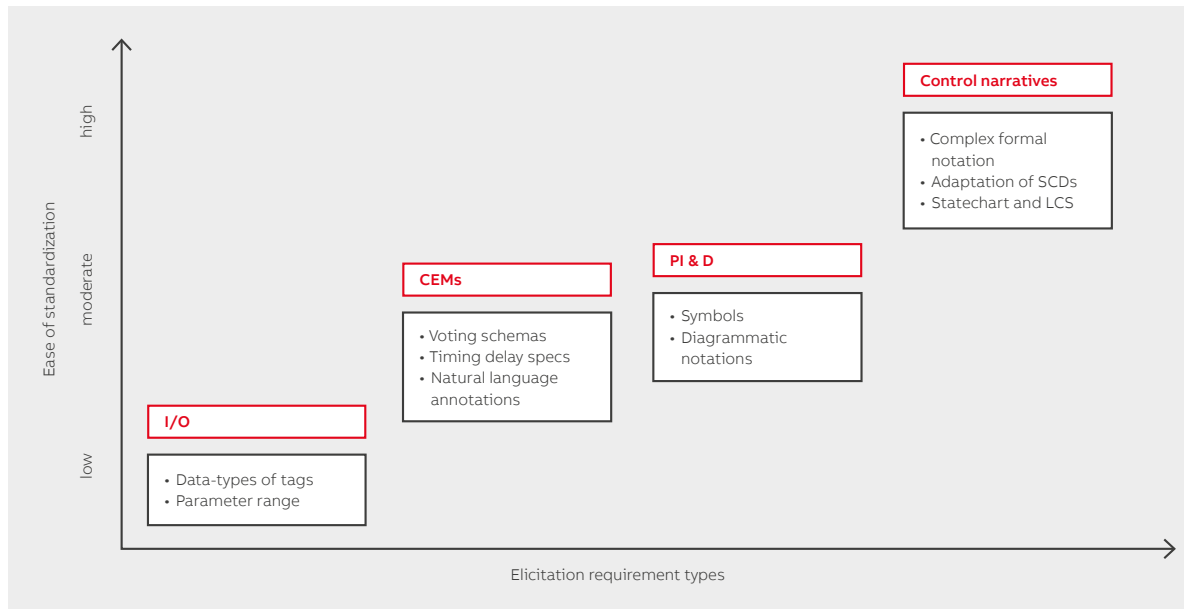
These techniques are not pervasive in automation engineering. Instead, the automation industry relies on testing to detect errors, typically conducted after the development phase, during Factory Acceptance Tests (FATs) and Site Acceptance Tests (SATs). These procedures are costly and may result in latent or undetected errors that could lead to failure of the application following deployment.

Adapting standard static analysis methods to software for industrial systems could be a step toward a solution. Using static code analysis could ensure software correctness and safety. However, the technique has some shortcomings, such as the generation of false positives, state explosion [4], and the limitation of pattern matching to detect some run-time errors. These need to be addressed adequately to achieve a wider acceptance of the technique in industry.

There have been efforts toward improving verification to ensure the safety aspect of control applications [5]. Some static analysis tools detect coding violations for all IEC 61131-3 languages but are limited to the base standard and cannot be extended easily [6]. In order to have a greater impact on automation engineering, a static analysis tool must access the internal representations of the application program (which vary across different platforms) to understand the execution model of the programming language and make it useful for ABB customer organizations characterized by diverse application engineering teams.A further unresolved obstacle is the absence of universally accepted coding standards for industrial languages. IEC 61131-3 guidelines provide a starting point for standardization. Development of tools that discover coding violations across standards and styles would be highly beneficial. Ultimately, in an industrial setting static analysis tools must balance false positives with false negatives and performance to make the results applicable for everyday use.

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02 Ease of standardization for common requirement elicitation formats and the main challenges is shown.



**Ease of standardization** (vertical axis: low, moderate, high)

**Control narratives**
- Complex formal notation
- Adaptation of SCDs
- Statechart and LCS

**CEMs**
- Voting schemas
- Timing delay specs
- Natural language annotations

**PI & D**
- Symbols
- Diagrammatic notations

**I/O**
- Data-types of tags
- Parameter range

Elicitation requirement types

02

**Adapting size and complexity metrics**
Typically, software size and complexity metrics are used to estimate cost and effort, manpower allocation, maintainability and testability, as well

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The automation industry relies on costly testing to detect errors that can result in failure of the application following deployment.

as program and developer evaluation in software engineering. ABB strives to develop metrics in automation engineering to provide program managers with the tools they need. Often, decisions for automation projects are based on the experience of key people involved. The development of a set of metrics with management ability would improve efficiency and cost but is met with apprehension. Convincing automation engineers of the need to use metrics is a necessary first step. An ABB example is to provide developers with a way to estimate effort such as by counting I/O to arrive at a number representing an estimation of effort →3a [7]. By finding a way to measure actual size of the developed
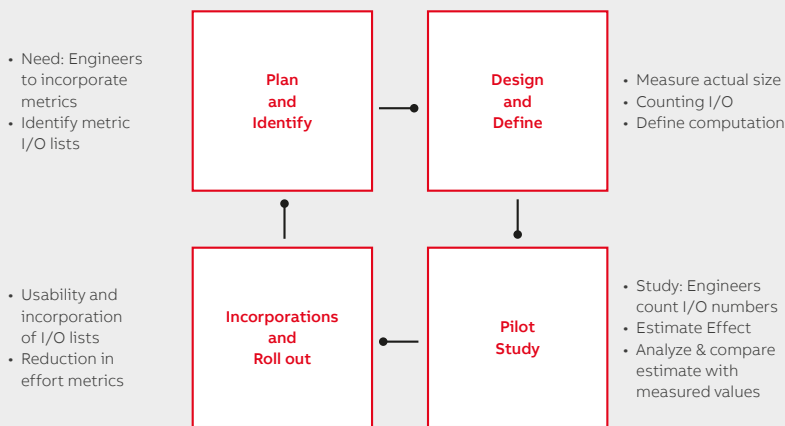
code, the engineers can compare estimated and actual effort. Repetition of the procedure allows correction factor(s) to be constructed and applied. The result is a reduction in estimated and actual effort over time thereby providing evidence of benefits that help automation engineers to transition to the use of metrics →3b.

The next step is the adaptation of existing size and complexity metrics practices to form standards for industrial automation. Because industrial languages consist of text and graphics, lines of code (LOC) is not a good means for measuring program size. When programming in IEC 61131-3 languages, developers spend time on I/O allocation and similar things which effect the complexity in application development and maintainability of the industrial system.

What is required, therefore, is the creation of a normalization scheme for the different elements from graphical and textual languages. It makes sense for Program Organization Units (POUs), defined in IEC 61131-3, to be used as the base units to define size metrics for industrial automation applications.

- Identify needs
- Feasibility
- Identify metrics of attributes to use

| Plan and Identify |
| Design and Define |

- Define and formulate measures
- Define computation of metrics
- Formulate software metrics

- Define strategy
- Determine usability
- Analyze & improve
- Incorporate

| Incorporations and Roll out |
| Pilot Study |

- Run Study and review
- Collect & calculate
- Analyze & compare data
- Identify changes

**03a**

- Need: Engineers to incorporate metrics
- Identify metric I/O lists

| Plan and Identify |
| Design and Define |

- Measure actual size
- Counting I/O
- Define computation

- Usability and incorporation of I/O lists
- Reduction in effort metrics

| Incorporations and Roll out |
| Pilot Study |

- Study: Engineers count I/O numbers
- Estimate Effect
- Analyze & compare estimate with measured values

**03b**

Other metrics can be used to measure the ease of understanding and maintainability of the application. For example, Cognitive Complexity can be used to determine how easy it is to understand and comprehend a POU, and Testing Complexity can be used to determine all control flaws for each execution path of the application. A tool to collect measures from the program and provide metrics to the developer would also be beneficial →4. Once pilot results are provided from implementation of these metrics, automation metrics could be developed leading to substantial benefits.

**Approaches and recommendations for impact analysis**

Predictive analysis is becoming increasingly important in industrial automation [8]. Changing a component of a control application program can impact other parts of the applications which can have critical consequences. More often than

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## The development of a set of metrics with management ability improves efficiency and costs.

not, automation engineers manually assess the impact of application changes on other parts. The need to automatically and visually analyze both the impact and dependencies of these changes throughout the control application would improve functionality and cost.
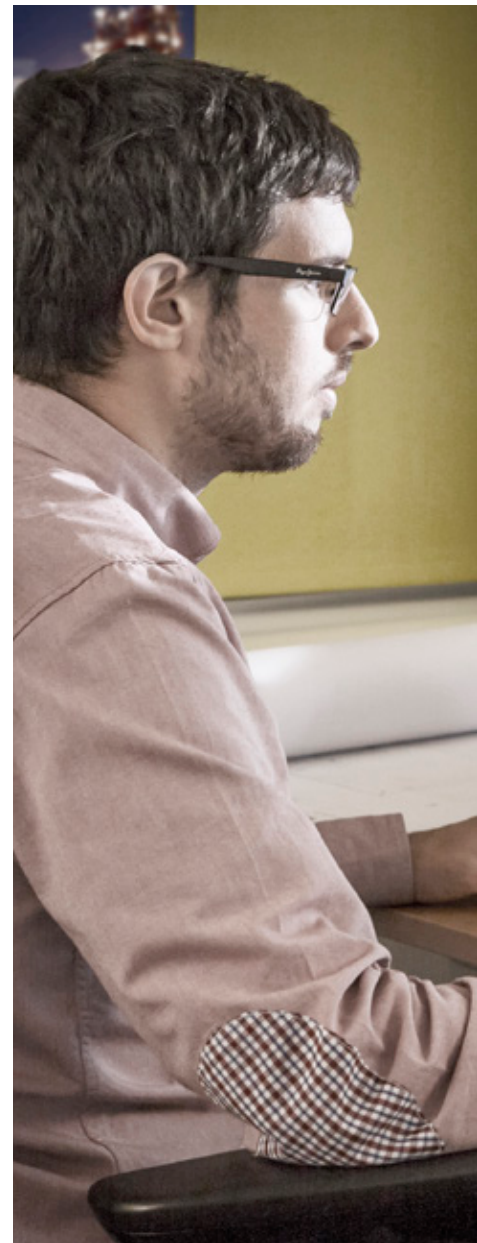
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03 General metric
appraoch along with
an example of a metric
approach using I/O
pathway is illustrated.

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04 Engineers use tools
to collect measures
from the program and
provide metrics.

Various approaches exist to compute change impact analysis in software. These have been used in a number of areas, such as embedded systems and distributed applications, but have yet to be applied to automation engineering. One major challenge is that domain-specific languages used in automation engineering have close dependencies on other components like hardware, Human Machine Interface (HMI) libraries, and I/O components. These are complex but essential dependencies that need to be taken into account when computing change impact for automation applications.

For instance, a control application engineer might wish to identify the impact and possible consequences of a change in application logic (control logic is written to parameterize large plant objects and implement sequence logic for plant activities like batch production) to reduce the risk of ripples of unintended modifications →5. The change can be detected by analyzing the dependencies between and

within the various POUs in the application. Program slicing, typically used to compute control and data flow dependencies for all altered components throughout the application, could be

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Another way to improve efficiency, specifically during software testing, is to use test automation for regression testing.

used for this purpose. The result would be improved engineering efficiency in the application development, testing and maintenance phase due to fewer errors and therefore lower costs, an advantage to ABB customers.

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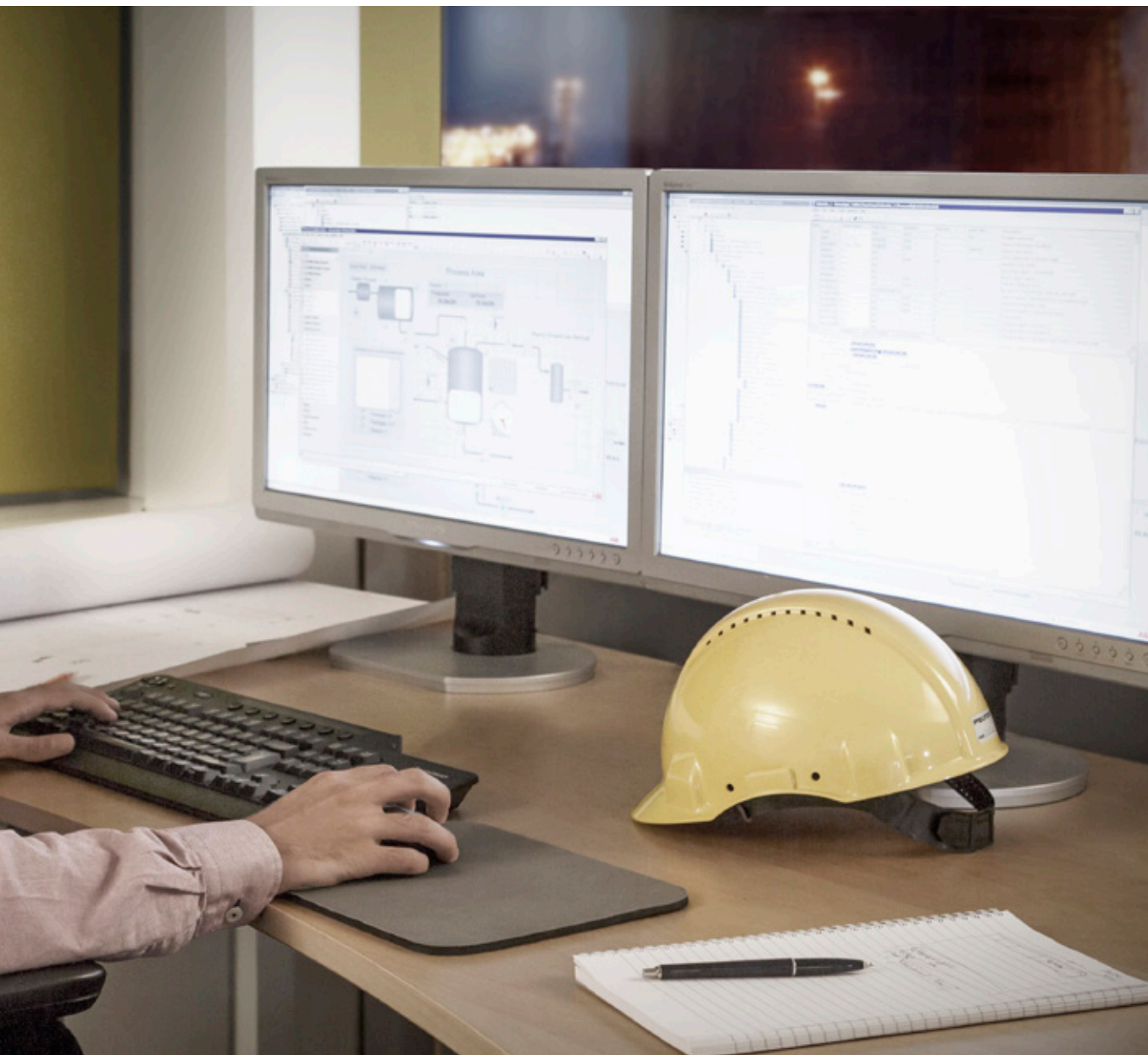
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**Test automation challenges and solutions**
Another way to improve efficiency, specifically during software testing, is to use test automation. While some organizations have started using automated scripts to run test cases (especially for libraries), automated testing is not widely

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Improvement in version management practices can positively impact engineering efficiency, project costs and project turnaround times by automating the process of tracking changes both in textual and graphical languages.

used in engineering. The generation of test cases and use-case testing are still mostly labor-intensive processes.

Test automation can be especially cost-effective when used repeatedly for regression testing. The focus of this type of testing is to ensure that new or changed code does not break existing functionality that currently works. Rather than run the individual test cases manually, this process can be automated to reduce the effort required in testing the application. Regression testing can be used in conjunction with impact analysis to facilitate Focused testing – testing only parts of the application that are changed, or may be impacted by the change.

Simulation testbeds can be used during integration (and functional) testing to uncover potential problems before the application is deployed at the client's site (for FAT/SAT). Simulation testing allows engineers to test for system properties against a defined model, or digital twin. These property-based tests are more expensive, but provide much stronger guarantees about the behavior during testing.

Finally, in order to ensure the exhaustiveness of the testing process, test cases can be derived automatically from the implemented applications. Coverage criteria can be used to enforce that all possible execution paths in the software will be tested by the test cases defined. Rather than have engineers manually create test cases to check for possible scenarios, this technique can ensure that different program states are covered by the generated test suite, thus increasing confidence in the testing process.

**Version management improvements**
Improvement in version management practices can positively impact engineering efficiency, project costs and project turnaround times by automating the process of tracking changes both in textual and graphical languages eliminating costly errors associated with manual methods.

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05 Code metrics
dashboard for
a sample control
systems application.

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06 Computation of
the difference between
two graphical programs
is shown.

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The creation of tools allowing developers to visually compare versions and show changes in graphical languages is required. A useful system displays and maintains a list of all changes on two versions of a program written in any of the five IEC 61131-3 languages used in industrial automation →6.

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## ABB recognizes the problems, challenges, and how to develop or adapt software practices to the unique automation domain.

Tools for text-based comparisons and change detection exist and can be directly applied. For IEC 61131-3 graphical programs such as those using function block diagrams and Sequence Flow Chart notation, an equivalent XML notation can be used to compare elements or components and to maintain different versions.

For control application specifications, hardware and I/O modules can influence the behavior of the software, thus requiring the creation of an elaborate version control utility to assess any impact of program changes on hardware modules and libraries. Versions of the entire system installation could be maintained.

The proprietary nature of automation engineering hinders the research and establishment of tools and techniques from general purpose language software engineering. Nonetheless best practices from software engineering can be evaluated and tools and techniques can be adapted and applied to industrial automation. ABB recognizes the problems, challenges, and how to develop or adapt software practices to the unique automation domain. The successful incorporation of these software engineering best practices requires joint effort from ABB's researchers and practitioners. ●
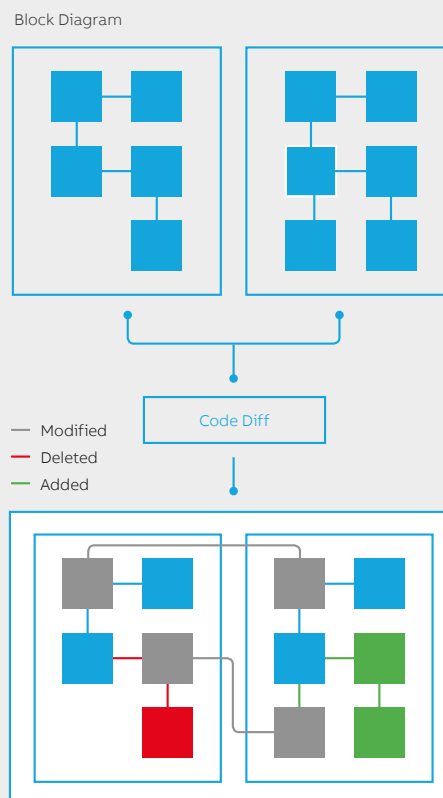
**06**



Illustration highlighted code
changes across version of a Function

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INGENUITY AT WORK

# Asset Health Center helps AEP

American Electric Power (AEP) faced challenges presented by its aging transmission infrastructure. AEP decided to work with ABB to integrate existing infrastructure and system data, which – together with algorithms – would transform operational data into actionable decision-support information.

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AEP is an integrated utility that has the largest electricity transmission system in the United States. AEP operates in 11 states and serves approximately 5.4 million customers throughout the country with more than 64,000 km of transmission and 360,000 km of distribution lines. AEP was in a situation where equipment was reaching a certain vintage – for example, one-third of its transmission transformers were older than 50 years and another 18 percent older than 60 years. The need to prioritize and streamline asset renewal and maintenance while upholding excellent service had become of paramount importance.

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A detailed overview of asset condition allows decisions to be made regarding which assets need urgent maintenance, which can wait and which have to be replaced, and by when.

Questions that AEP asked itself revolved around topics such as failure prevention and the optimization of maintenance effort. These are issues that concern all electric utilities →1.

AEP realized that a detailed overview of asset condition would allow decisions to be made regarding which assets need urgent maintenance, which can wait and which have to be replaced, and by when.

AEP decided to approach the matter by forming the AEP-ABB Transmission Technology Alliance. By establishing this alliance, AEP firmly committed to ensuring the reliability of their transmission infrastructure, properly prioritizing maintenance and addressing the replacement of their aging assets. To achieve these goals, AEP set out to create a robust asset health center.

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With an asset health center, it is possible to organize and prioritize asset data so that maintenance personnel in the field and operators in control rooms receive targeted support in decision making and are not inundated by a large influx of unnecessary or irrelevant data.

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A key function of an asset health center is to assess the condition of assets on a continuous basis and take appropriate action where needed, before a failure occurs.

A key function of an asset health center is to assess the condition of assets on a continuous basis and take appropriate action where needed, before a failure occurs.

With experience in designing and implementing systems that balance operational technologies and information technologies, ABB was brought on board to develop this highly strategic and forward-thinking asset health center platform. One important aspect to be considered in this project, and indeed in similar projects throughout much of industry, is the unprecedented surge of data now being collected by smart sensors in the field →2.

ABB is uniquely qualified to merge these practical, useful and actionable flows of data to create a system that integrates all the technologies concerned.

The asset health center solution delivered by ABB to AEP provides not only a framework for gathering data but also expert-system models that recommend both short- and long-term tasks, prioritized by urgency →3. These capabilities are essential to effective decision making at the asset level.

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The asset health center solution also provides expert-system models that recommend both short- and long-term tasks, prioritized by urgency.

AEP's expectations were to realize valuable operating and maintenance benefits from automating situational awareness of asset conditions in order to help identify assets requiring maintenance or replacement →4. AEP has already reported benefits in operations and maintenance and can point to multiple transformer failures that have been prevented.

AEP was an early adopter and realized that an asset health center is an example of technical innovation in which real-time and historical data is gathered from across the network and turned into meaningful and timely insights. AEP began this journey with transformers and as they gained insight from the optimized maintenance and reduced failures of those assets, they expanded the exercise to include additional asset types – for example, breakers. AEP's long-term vision is to proceed through their entire asset portfolio to include all their major asset types in the asset health center system.

ABB continues to improve its asset health center technology and has recently released a next-generation solution.

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**03**

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02 ABB's CoreSense™
is an example of how
data is collected and
used for asset health
care. With CoreSense,
the continuous online
monitoring of the
transformer provides
an early warning of
most incipient faults.

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03 ABB's asset health
center recommends
asset actions, prioritized
by urgency.

**Next-generation asset management solution
to improve efficiency and optimize costs**
In July 2017, ABB launched its next-generation
asset performance management (APM) solution:
ABB Ability™ Asset Health Center. This latest
software-based solution enables asset-intensive
industries to improve efficiencies and optimize
costs by combining ABB's APM offering with the
Microsoft Azure cloud platform.

ABB's industry-leading Asset Health Center
provides predictive and prescriptive analytics,
as well as customized models incorporating
decades of industry expertise, to identify and
prioritize emerging maintenance needs based
on the probability of failure and asset criticality.
These models not only consistently identify
degrading conditions, and risks and their
relative importance, but also provide expert
recommendations and priorities for resolution,
analysis and mitigation actions.

Asset Health Center is a key component of ABB's
Connected Asset Lifecycle Management solution,
which is aimed at delivering a holistic solution
for complete asset life cycle management →5.
It is now available in the form of a Software as

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ABB Ability Asset Health Center
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Microsoft Azure cloud platform.

a Service (SaaS) solution and implementation in
the Azure cloud platform enables a simpler and
faster execution. Additionally, visualization and
analytics have been improved, and there is now
an easier integration of predictive models using,
for example, Cortana Intelligence.

By combining the domain expertise embedded in ABB's software-based technologies with the global scale of Microsoft's Azure cloud platform, it is possible to deliver a powerful solution to help utilities gain new insights and drive faster decision making, so they can seize new growth opportunities. Asset Health Center on Microsoft Azure enables customers to leverage the power of the Azure IoT Suite and the Cortana Intelligence Suite to enhance business applications with

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Asset Health Center's issue tracking ensures that identified risks are reliably resolved or mitigated.

machine intelligence. In this way, the user can evolve from simple descriptive analytics to prescriptive analytical recommendations, facilitating the processes for risk-based investment optimization in alignment with ISO 55000 and PAS55 standards.

Asset Health Center's issue tracking ensures that identified risks are reliably resolved or mitigated. Alerts and monitoring can be enabled in order to stay actively informed of the status of these risks and ensure that they are appropriately addressed. Asset Health Center highlights key assets that are at risk, provides notifications of completion of important actions in the enterprise asset management (EAM) system and provides other tools to ensure risks that were identified early are resolved in time to prevent them from materializing.

Besides identifying and fixing issues through predictive asset analytics, utilities also need to fit in a lot of routine work – such as regulatory inspections and minor maintenance – into their daily schedules. Most utilities have a work backlog larger than resources can handle in short order. Asset Health Center will collect all open work and, using another algorithm, provide a suggested order that enables a risk-optimized maintenance schedule.

Asset Health Center is also a key component of ABB's digital substation concept where it collects condition data to optimize performance and improve the substation's efficiency and cost effectiveness – reducing transformer and breaker downtime by up to 50 percent.

**04**
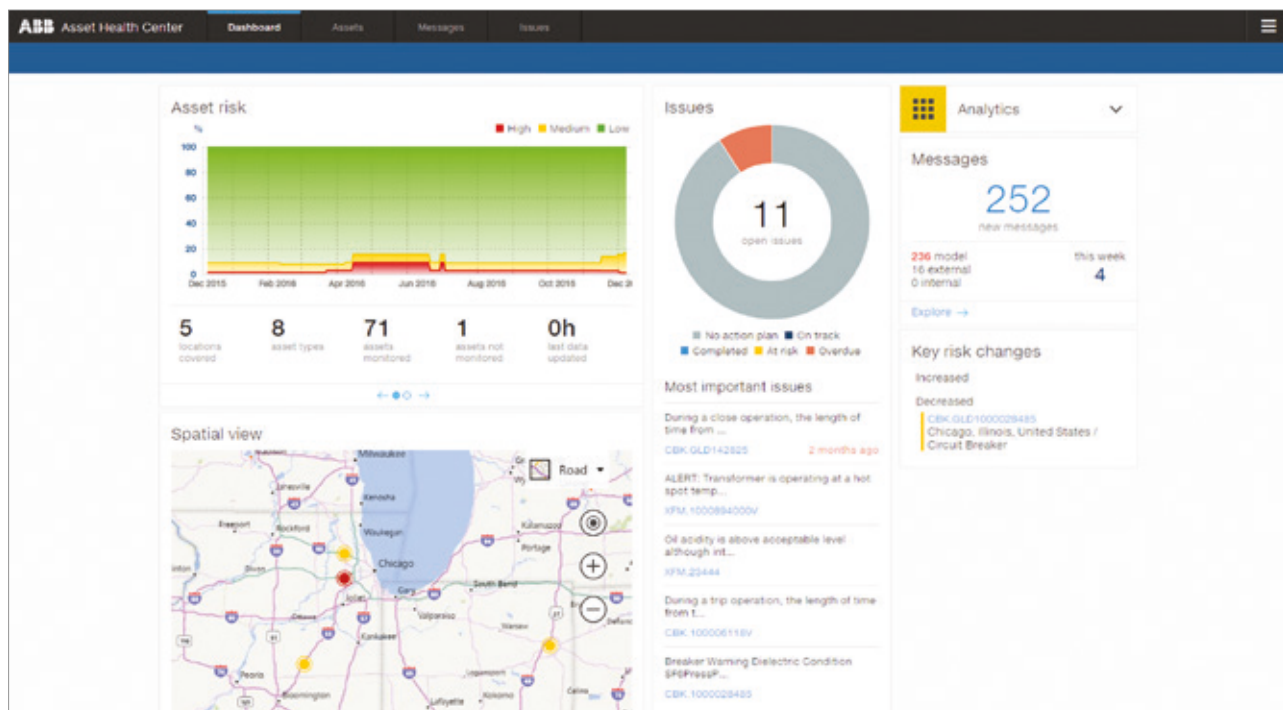
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04 The Asset Health Center's information pages provide operators with a clear overview of asset condition so that risk can be minimized.

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05 The Asset Health Center is an integral part of ABB's holistic, connected asset life cycle management approach.



Information

Inspection results/health status

APM
Asset performance management

Technology (IT)

Work requests/prioritization

ABB Ability integration platform

WFM
Workforce management

EAM
Enterprise asset management

Work orders/completions

05
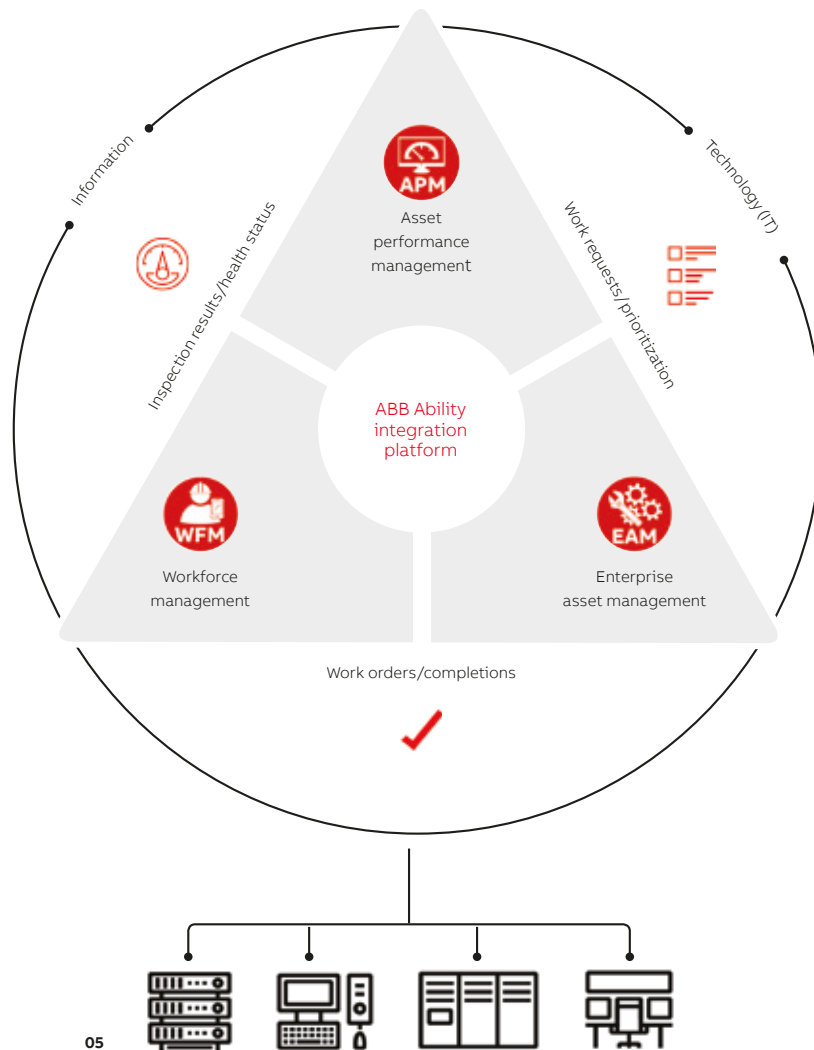
Asset Health Center is an example of how the ABB Ability range of digital solutions connects customers to the power of the Industrial Internet of Things, turning data insights into direct action that generate customer value in the physical world.

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Asset Health Center uses predictive and prescriptive analytics, as well as customized models incorporating decades of industry expertise.

**ABB Ability Asset Health Center via the Microsoft Azure cloud or on-premise**
Asset Health Center can be delivered as a service via the Azure cloud or installed on-premise. Its scalable architecture allows customers to be up and running within hours to allow for quick returns on effort and low-risk pilots.

Asset Health Center can be scaled up to an enterprise-level application, meeting core IT requirements such as cyber security, single sign-on and standardized integration with common third-party systems. The application is extendible so that the analytics can evolve with the maturity of the user's asset management program. Because Asset Health Center is built on Azure and Cortana Intelligence Suite, the extensions can be added by the user and maintained with commonly available skill sets, avoiding the need for specialized platform training. ●

INGENUITY AT WORK

# A new STATCOM modular multilevel converter technology

ABB's STATCOM (static compensator) products are finding ever-increasing use in power grids beset by stability and other issues. Now a new family member completes the STATCOM product portfolio: SVC Light Medium Power (MP), ABB's voltage source converter (VSC) technology based on modular multilevel converters (MMCs).

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The ongoing global shift toward renewable energy is having a major impact on the power generation, transmission and distribution businesses, and on the solutions they provide. An inherent part of this development is the transition from a centralized grid with unidirectional power flow from large power plants to one in which the consumers exist in a distributed grid with a mixture of centralized and decentralized power generation units and a combination of remote and urban consumption

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MMCs have found widespread use in recent years in applications such as FACTS and HVDC for power transmission and distribution systems.

with partly bidirectional power flow. A further factor is the move away from synchronous generation and, consequently, the reduction in the short-circuit strength and inertia of the power grid.
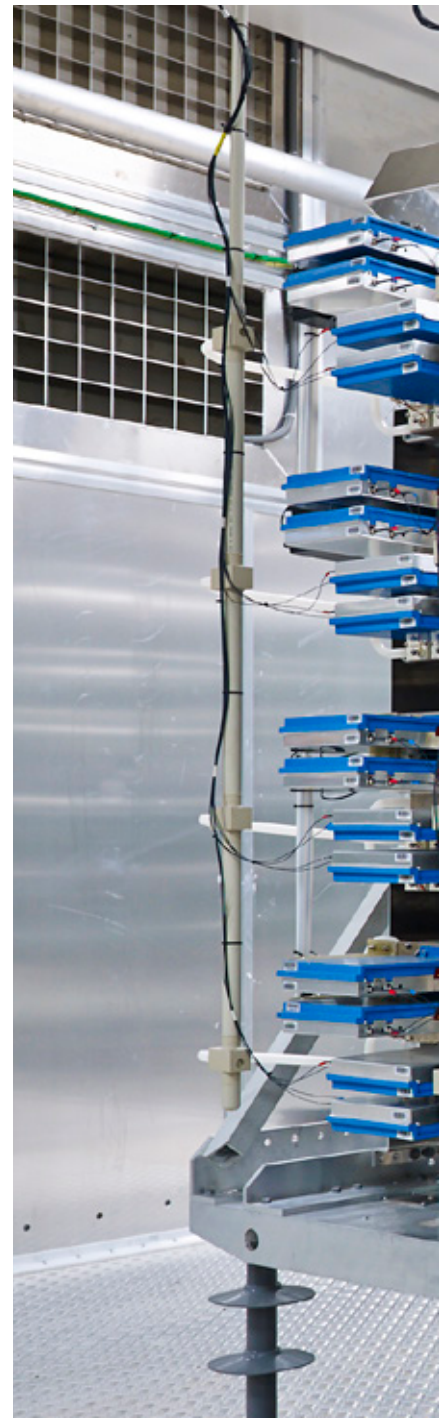
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01 FACTS solution
by ABB.

As a consequence of this evolution, the power grid configuration will be increasingly subject to dynamic changes that will require more consideration when planning size, type and location of installations with the FACTS (flexible alternating current transmission system) equipment that provides controllable reactive power compensation →1. This means that a broad and versatile reactive power compensation product portfolio is of increasing importance in order to provide optimal solutions to customers in this changing energy landscape.

Such compensation products can:
- Improve power system stability and limit the risk of power outages.
- Increase the transmission capacity of existing power lines, thus reducing utilities' investment (CAPEX) requirements.
- Ensure compliance with increasingly demanding grid codes, thus enabling, for example, the connection of renewable power generation.
- Flexibly adapt to dynamic changes in the grid configuration or industrial production through simple equipment upgrades.

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02a



Filter          TCR          TSC

02b



VSC
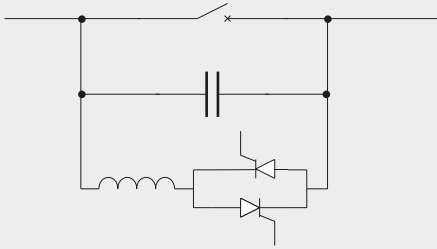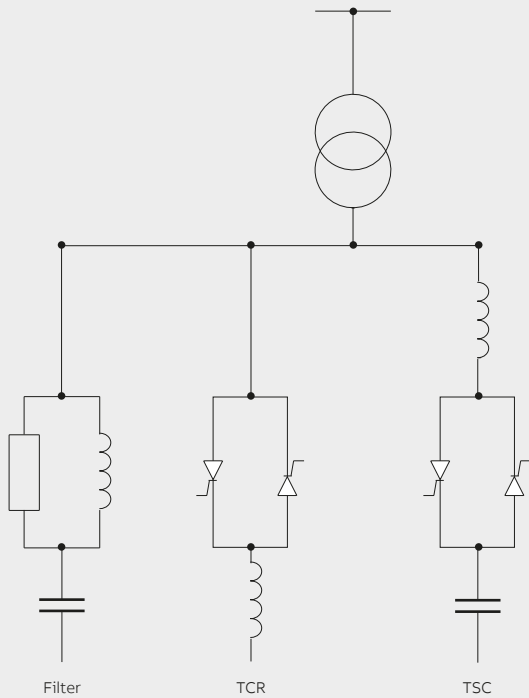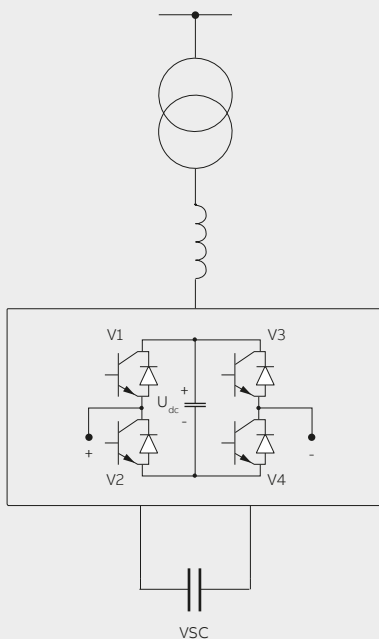
02c

Within the FACTS portfolio, ABB possesses technologies that extend from fixed series-connected compensation and thyristor-controlled series compensation (TCSC) via SVC Classic solutions – including thyristor-switched capacitors (TSCs) and thyristor-controlled reactors (TCRs) – to the most advanced STATCOM devices, based on VSC technology, that use self-commutated semiconductors like IGBTs (insulated-gate bipolar transistors) or IGCTs (insulated-gate commutated thyristors) in two-level, three-level or advanced MMC voltage-sourced converter (VSC) topologies →2. Even hybrid STATCOM and SVC Classic technology solutions exist [1].

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With the new SVC Light MP, ABB now has a complete FACTS portfolio with which it can fully support customers in solving power quality issues.

In the last few years, STATCOM technology has been adopted in an expanding range of applications. This expansion is spurred on by the changes in the nature of the power network and STATCOM's ability to mitigate the effects of weak grids.

A further factor is an important STATCOM technology development: the modular multilevel converter (MMC). MMCs have found widespread use in recent years in very-high-voltage and very-high-power applications including FACTS and HVDC for power transmission and distribution systems [2].

**Why MMC?**

The chain-link converters used in the latest SVC Light generation utilize series connection of identical VSC cells that can be switched independently of each other and that provide a negative, zero or positive voltage contribution to the total converter voltage →3. This configuration confers a number of advantages that explain why it has become so popular:

• Independent switching of the converter cells makes it possible to build up the terminal voltage in small steps that sum to give a high-quality sinusoidal voltage waveform – with greatly reduced harmonic content compared to other converter topologies.

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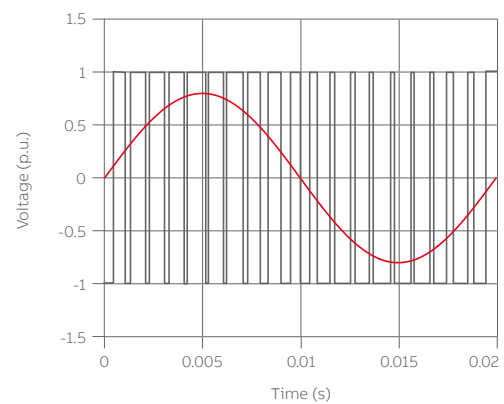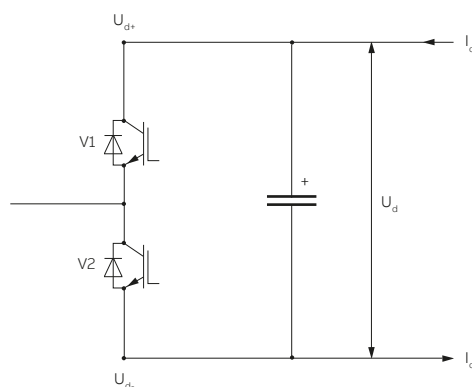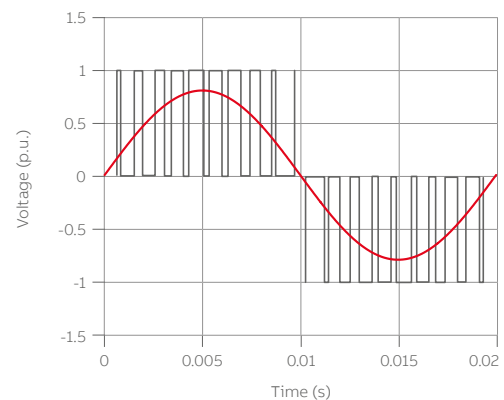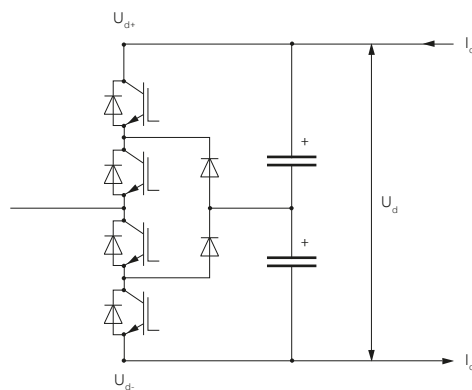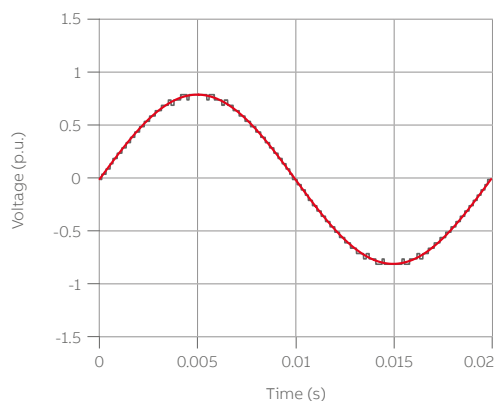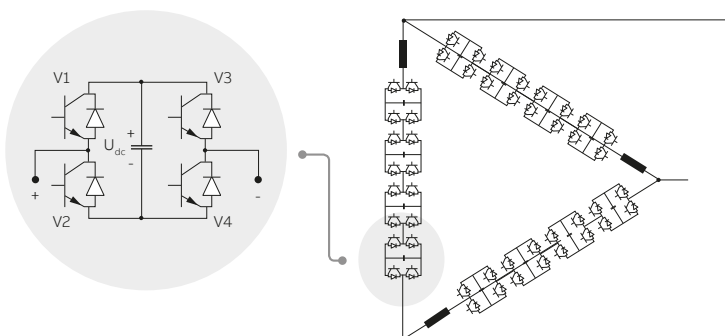
The press-pack technology improves plant reliability and operational cost compared to wire-bonded industrial modules.

• SVC Light can fulfill the most demanding harmonics requirements without lower-order harmonic filters, thus increasing robustness against harmonic resonances and reducing overall system losses. In some cases, a small high-pass filter is required to support grid-code compliance.



03a



03b



03c

| Low to medium power | Medium to high power |
|---|---|
| PCS 6000 | SVC Light |



| IGCT | IGCT | IGBT |
|---|---|---|

| Low power | Medium power | High power |
|---|---|---|
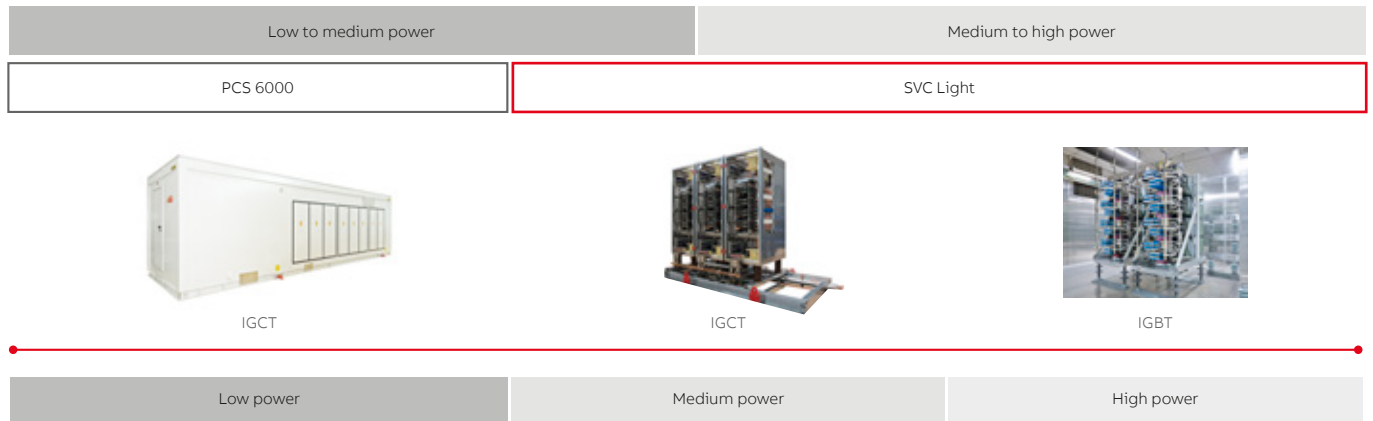
**04**

- Reduced overall footprint compared to SVC Classic and other STATCOM technologies due to reduced need for passive components in the substation yard.
- Possibility to achieve system redundancy and robustness to failures through series connection of redundant MMC cells, reaching extremely high values of reliability (>99.5 percent). Specific customer needs can be catered for by minor adaptations to the modular STATCOM design.
- Possible direct connection to the medium-voltage terminals without a transformer by series connection of MMC cells. Depending on the power required, transformer-less connection to the grid is achievable up to 69 kV grid voltage with an SVC Light product.

—
SVC Light MP uses IGCT semiconductors in press-pack technology and is the result of successful collaboration between application, converter and semiconductor development teams.

- A further consequence of using modularized chain-link converters in a number of identical cells is that a high degree of prefabrication and in-factory testing is possible. This leads to an overall reduction of project lead times and enhanced product quality. Additionally, the modularization of hardware enables standardization and scalability of layout and buildings.



**05a**
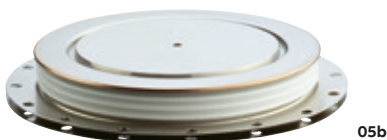


**05b**
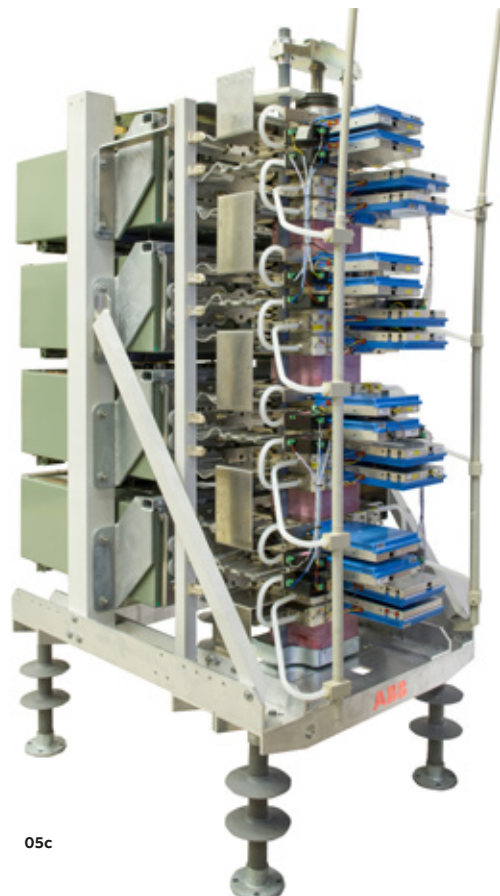


**05c**

—
04 STATCOM portfolio.

—
05 MMC cell and converter layout with IGBTs (SVC Light HP) and IGCTs (SVC Light MP).

05a IGBT
(without gate drive).

05b IGCT
(without gate drive).

05c SVC Light HP converter module press-pack IGBT-based, four cells in one submodule.

05d SVC Light MP converter module press-pack IGCT-based, two cells in one submodule.

05e SVC Light MP converter layout.

**The ABB STATCOM portfolio**
ABB has STATCOM solutions for ratings up to 425 Mvar and for different connection voltage levels. This is possible through diversified technology that always maximizes performance and customer value according to the specific application requirements.

The ABB STATCOM portfolio, for ratings above 10 Mvar, includes PCS 6000 as well as SVC Light →4. The choice of the specific converter technology is part of the full system solution optimization and takes into account performances, total investment and the operational cost of the installation.

At the lower end, the PCS 6000 uses IGCT press-pack semiconductors in a three-level voltage-sourced topology. At the high end, in the SVC Light HP (high power), IGBT press-pack switches are used in an advanced multilevel chain-link topology, which is an MMC variant. In between, the brand-new SVC Light MP (medium power) has now been added to complete the STATCOM portfolio →4.

**A new MMC converter**
Because of its advantages, mentioned above, MMC technology was chosen for the new converter. SVC Light MP uses IGCT semiconductors in press-pack technology and is the result of

—
The new SVC Light MP is fully integrated into the SVC Light control platform and makes use of well-proven control algorithms.

successful collaboration between application, converter and semiconductor development teams →5. This collaboration made possible important improvements in reverse-conducting IGCT (RC-IGCT) semiconductor technology [4], with an optimized fit to the needs of the MMC converter, thus achieving best-in-class efficiency and robustness of this key STATCOM component. Thanks to a superior load cycling performance and an inherently stable short-circuit failure mode, the press-pack technology used by ABB gives better plant reliability and operational cost compared to that achieved by wire-bonded industrial modules.



05d
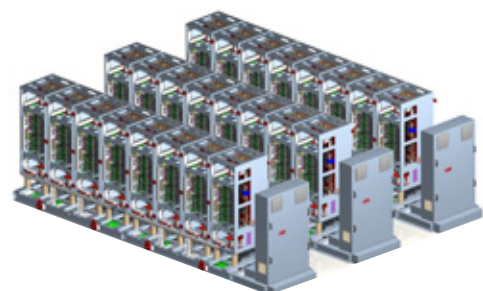


05e

Due to the very high semiconductor count in medium- and high-voltage/power applications, continued operation after a single fault is mandatory in order to achieve the availability required by customers.

—
## The thyristor can establish the bypass current path through the failed cell within microseconds of fault occurrence.

In the new IGCT-based chain-link converter, this functionality is taken care of by the single bypass thyristor switch, S5 →6. This thyristor can establish the bypass current path through the failed cell within microseconds of fault

occurrence and it can handle the discharge current of the cell capacitor without damaging the thyristor housing. Upon failure, the thyristor fails into an inherently stable and sustained short-circuited condition, which enables safe and reliable continued operation until the next scheduled service event →6b. This short-circuit failure mode (SCFM) capability has recently been proven in an 8,760-hour endurance test.

**The new product as part of winning overall portfolio**
With the new SVC Light MP, ABB, pioneer and leader in the FACTS field, now has a complete FACTS portfolio with which it can fully support customers in solving power quality issues in diverse applications – long transmission lines, renewable integration, industrial plants and so on.
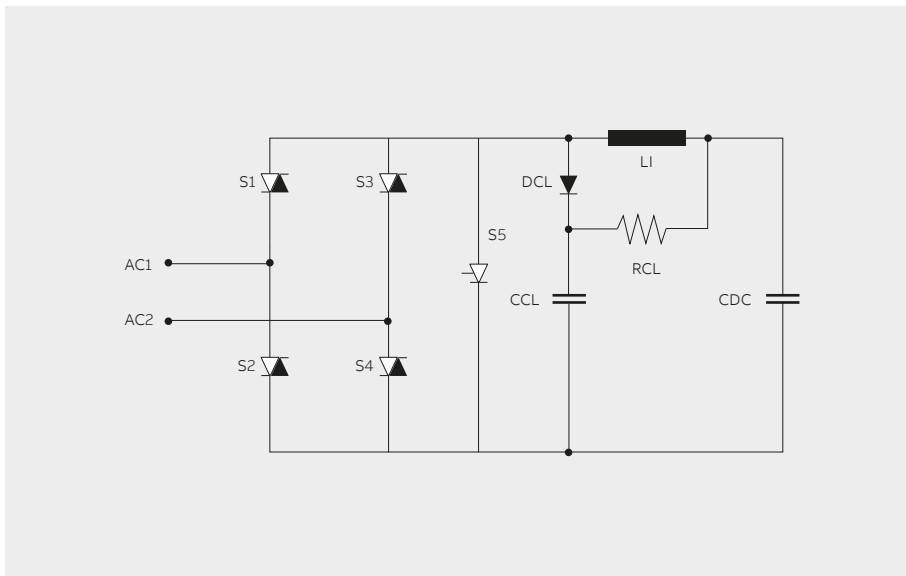
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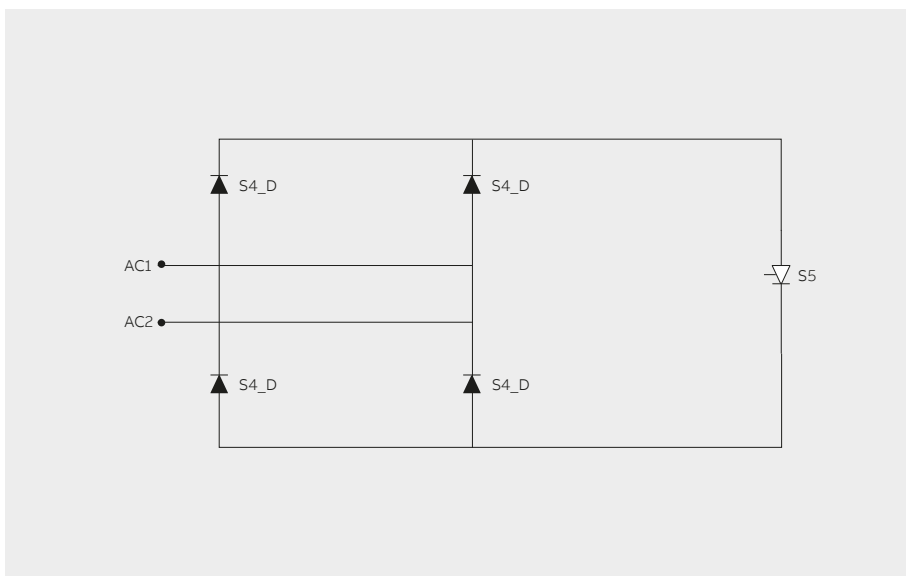
06b

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06 IGCT-based MMC cell power circuit.

06a Power circuit of SVC Light MP power cell.

06b Stable and sustained bypass current path of a failed power cell (rightmost limb).

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**References**

[1] Hutchinson S., Halonen M., "STATCOM and Hybrid STATCOM Solutions Based on Chain-Link Multilevel Converter Technology for the Electrical Transmissions Network," Gridtech 2015, Delhi, India, April 2015.

[2] Jacobson B. et al., "VSC-HVDC Transmission with Cascaded Two-Level Converters," Cigre 2010.

[3] Oedegard B. et al., "Rugged MMC Converter Cell for High Power Applications," EPE 2016, Karlsruhe, September 2016.

[4] U. Vemulapati, et al., "Switching the subject," ABB Review 4/2016, pp. 67-71.

[5] Grünbaum R. et al., "FACTS: Powerful Means for Dynamic Load Balancing and Voltage Support of AC Traction Feeders," Power Tech 2001, Porto.

[6] Bagnall T. et al., "PCS6000 STATCOM Ancillary Functions: Wind Park Resonance Damping," EWEC 2009, Marseille.

[7] Grünbaum R. et al., "STATCOM for Grid Code Compliance of a Steel Plant Connection," 19th International Conference on Electricity Distribution, Vienna, May 2007.

Indeed, the entire SVC Light STATCOM family is designed around customer requirements, with power system experts, designers and execution teams optimizing the performances and defining the best plant layout for each application. These considerations include the converter, control system, cooling system and enclosures as well as passive elements such as phase reactors, filters (if needed), breakers, disconnectors and the power transformer.

The complete solution is controlled and protected by the MACH (modular advanced control for HVDC and FACTS) control system, part of the ABB Ability™ portfolio. MACH is a powerful control platform developed specifically for applications that are highly demanding in terms of performance and availability, such as HVDC and FACTS. MACH is operational in hundreds of applications worldwide. It is built around a fully redundant real-time controller in which signals from all the main substation components and measurements from current and voltage transformers in the yard are processed and utilized for synchronization, supervision, control and protection purposes. A best-in-class control platform, MACH enables monitoring and operations both locally and remotely, with cyber security solutions as an integral part of all installations.

The new SVC Light MP is fully integrated into the SVC Light control platform and philosophy and makes use of well-proven (there are over 800 FACTS installations in the field) control algorithms that support demanding power-quality applications such as subcycle voltage control, load balancing [5], harmonic active filtering, wind park stabilization [6], flicker compensation in industrial plants [7] and many more.

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### The new SVC Light MP is fully integrated into the SVC Light control platform.

The entire life cycle of a FACTS supplied by ABB is geared toward supporting the customer with sustainable and profitable solutions and services that maximize uptime, system reliability and performance. The addition of the new SVC Light MP to the FACTS family will help achieve this. ●

# Perpetual
# pioneerin

ELOPMENTS IN PHYSICAL RESEARCH ON ATOM NUCLEI.

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...during these last ...a-transmutation may ...hysics appears to be ...t only able, by way ...cal elements, but also ...iously unknown sorts ...rtificially radioactive ...elocity atomic nuclei ...roduced in the most ...rtificial radioactivity ...ally for investigation ...e by way of atomic ...possibilities for tech-

...ticles we also find light-quantas or *photons*, which serve as energy transmitters in all kinds of electro-magnetic radiation, as γ-rays, X-rays, ultra-violet, visible and ultra-red radiations. We may also mention the last known light particle, the hypothetic *neutrino*, the existence of which can be only assumed as a result of experiments, but which cannot as yet be made directly visible. Photons and neutrini carry no charge, and have rest mass zero, which means that they exist only in movement and that their mass depends simply on their kinetic energy, (respectively on their momentum).

ENERGIES.

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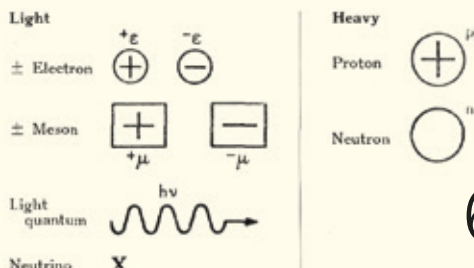
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**New technology is extreme because it challenges the status quo, and ABB has been doing just that since opening a lab for steam turbines in 1900. In the last 50 years alone, its researchers have yielded breakthroughs from laser optics to power electronics and automation, and it has put those technologies to work for its customers. More are on the way.**

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52

# Fifty years of ABB Corporate Research in Switzerland

In 1967, ABB established a research facility with a team of 34 scientists in Baden-Dättwil, Switzerland. In the fifty years since, the Swiss arm of ABB Corporate Research has grown significantly in size →1 and has produced a stream of fundamental breakthroughs and innovative product technologies.



01

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Special thanks are given to the many authors whose writings over the past 50 years have contributed directly and indirectly to the material presented here.

In 1891, Charles Brown and Walter Boveri created a start-up in Baden, Switzerland, to tap the opportunities of a promising new technology: electricity. Along with Asea, in Sweden, Brown Boveri & Cie. (BBC) was one of the precursors of ABB. Thanks to the vision and entrepreneurial spirit of its founders, BBC quickly became a success, pioneering many innovations that power

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Thanks to the vision and entrepreneurial spirit of its founders, BBC quickly became a success, pioneering many innovations that power the modern world.

02

the modern world. For the first decade or so, BBC's R&D was performed by the teams developing the products. However, in 1900, it was decided to create, in Baden, a distinct research labaoratory for steam turbines. Further acceleration in scientific advances necessitated the creation of a physics laboratory (1916) and a laboratory for high-voltage (HV) products (1943), both also in Baden.
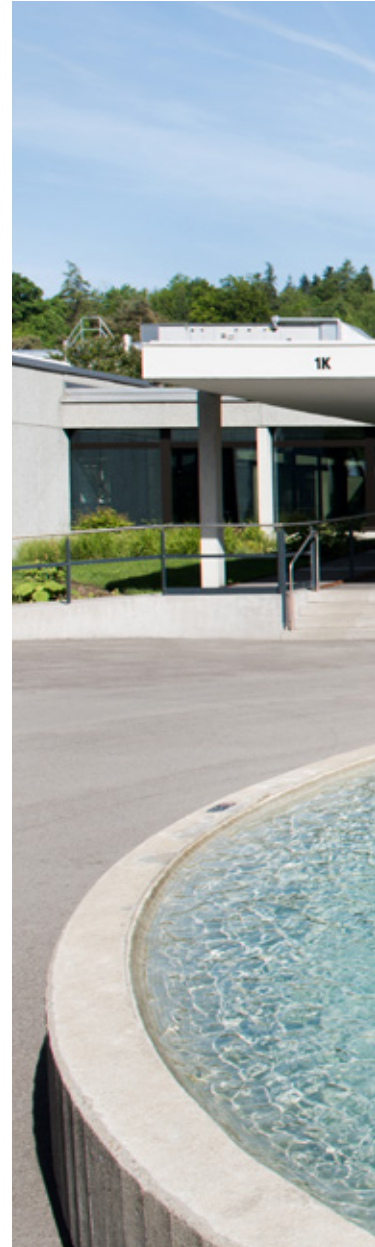
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01 The entrance to the
ABB Corporate Research
Center in Baden-Dättwil.

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02 Prof. Ambros
P. Speiser (1922 – 2003),
the first BBC Corporate
Research Director.

In 1957, the now-famous "Zentrallabor" in Baden was founded. From this establishment flowed a prodigious number of innovations for power and industrial applications, many of which are still evident in the technology of today. Recognizing that all basic technical innovations come from the basic sciences and that it was important for the company to contribute to this creation process as a whole, plans were made in 1966 to found a Group corporate research organization.

To this end, Professor Ambros P. Speiser was recruited as the very first Research Director and given the task of establishing the Corporate Research Center in 1967 →2.

Ambros Speiser was the perfect candidate for the job. A graduate of the ETH in Zurich, his academic career had included Harvard, Princeton, and pioneering work with Rutishauser and Stiefel on the first generation of electronic computers. ERMETH, the first Swiss electronic computer, was developed under his leadership. Ambros Speiser established, and served as director of, the IBM Research Lab in Rüschlikon, Switzerland, which later won two Nobel prizes: in 1986 (scanning tunneling microscope) and 1987 (high-temperature superconductivity).

# ABB Corporate Research Switzerland
## Highlights

### 1980 – 2017

**HV circuit breaker with self-blast principle**

**1970 to 1975:** Fundamental investigations to quantitively understand the arc and develop new diagnostic methods. From this work emerged a deep understanding, new concepts and an international reputation that survives to this day. The self-blast principle was born as a result of this activity and further investigated between 1975 and 1980. At first, the movement of the arc by magnetic forces was exploited and employed in BBC's MV products (1977). It was discovered that the self-blast principle can be used for HV circuit breakers by exploiting the ablation of PTFE nozzles for HV circuit breakers (CBs).



**1980**
Technology evaluation, followed by tests from 1981 to 1985.

**1985**
First product: CB for 72.5 kV and 25 kA short-circuit current.

**2017**
The properties of plasma arcs are nowadays studied with spectroscopy and high-speed imaging. Using 3-D multiphysics field simulations and purpose-designed high-power experiments,

ABB Corporate Research in Switzerland is at the forefront of fundamental science in this domain → picture (High-voltage experimental setup). The self-blast principle is still the most widely used concept by all manufacturers of HV CBs.

**A time of great change**
The Swiss Corporate Research Center was founded at a time when the world was entering a completely new technological era →3. Just a couple of years earlier, the first widely-used analog integrated circuit was introduced, by Fairchild; the developers could scarcely have guessed at the impact their invention would have in the coming decades. The race to the moon was in full swing – a mission which itself would result in major technology spin-offs. Nuclear power was booming. Color TV was introduced in many European countries for the first time. And at this time, BBC was a technology leader in energy production, transmission and distribution, plus many other areas. It was, indeed, an auspicious time to open a new research center.

**Basic research as a mission**
The remit of the research center focused on development and execution of a mid- to long-term research program in basic sciences that was measured not only by practical applicability

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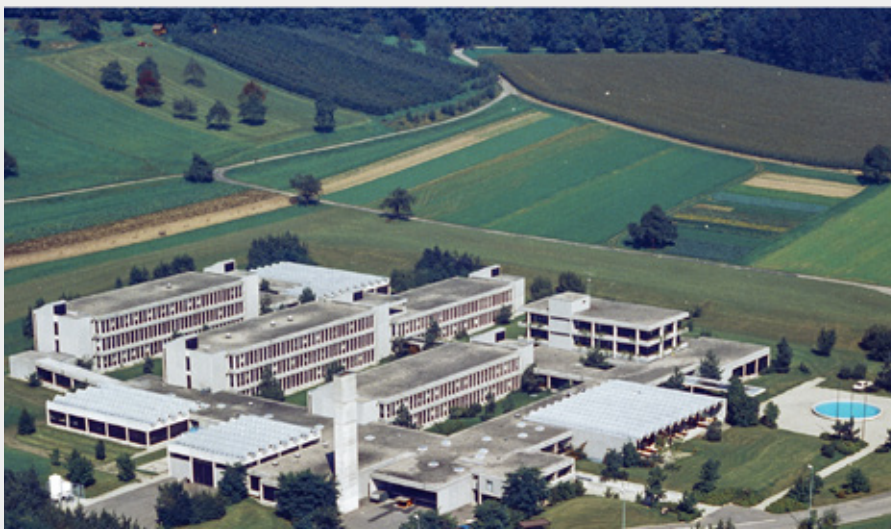
03b

**1990 – 2017**

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## Eco-efficient gas-insulated switchgear (HV and MV)

Though widely used in gas-insulated switchgear (GIS), sulfur hexafluoride ($SF_6$) is a potent greenhouse gas. ABB is the first company to offer MV GIS with a climate-friendly insulation gas based on a new molecule. ABB Corporate Research in Switzerland made a major contribution to this technology leap by evaluating the compatibility of the new insulation gas with the material components in the GIS under various operating conditions.



**1990s**
Extensive screening and testing of $SF_6$ replacement gases.

**2008 – 2012**
Combined corporate research and business area R&D effort toward the development of a $CO_2$-based HV CB.

**2009**
3M develops fluorinated ketones for use as a component of eco-efficient dielectric gas mixtures.

**2009 – 2015**
R&D on dielectric and physical properties and material compatibility of ketone-based mixtures.

**2015**
Inauguration of Oerlikon substation for ewz (Zurich) – first substation with eco-efficient switchgear (MV and HV).

**2016**
Product releases of compact $SF_6$-free MV switchgear – SafeRing AirPlus™ and ZX2 AirPlus.

**2017**
Further scouting for eco-efficient solutions with higher performance.
→ picture (SafePlus AirPlus $SF_6$-free switchgear).

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03 ABB Corporate Research Center

03a 1972, the new greenfield site on the outskirts of Baden. The original 1967 team were temporarily housed in the area while the new complex was constructed.

03b 2015, the ABB complex in Baden-Dättwil has been expanded and other buildings have sprung up around it.



but also scientific importance. Promising developments were passed to the business units for productization. Over the first decades, the range of topics of interest grew:

—

In 1973, the BBC research laboratories in Germany and France were integrated into the global BBC corporate research organization.

1967: Laser optical measurements, silicon carbide (taken over from the "Zentrallabor")
1968: Plasma physics, magnetism, physical metallurgy, theoretical physics
1969: Semiconductors
1970: Automation and liquid crystal displays
1973: Fracture mechanics
1974: Fluid mechanics
1979: Electrochemistry and sintered materials
1980: Computer science
1984: Electromagnetic compatibility, communications and encryption
1985: Manufacturing technologies, optoelectronics and environmental technologies
1986: Microelectronics and robotics

In 1973, the BBC research laboratories in Heidelberg, Germany and CERCEM Le Bourget, France were integrated into the global BBC corporate research organization. An even more dramatic change came in 1988 with the fusion of Asea and BBC to become ABB (Asea Brown Boveri).

**1967 – 2017**

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## Metal-oxide (MO) surge arresters (varistors)

Properly rated and well-located surge arresters – such as the ABB Polim series – are essential in power networks to limit excessive overvoltages. Thanks to work done by ABB Corporate Research Switzerland, ABB has the full MO surge arrester value chain in-house – from raw material to finished product.

**1967**
Discovery of ZnO varistor effect at Matsushita by accident.

**1972**
GE takes license from Matsushita for low-voltage (LV) MO varistors.

**1976**
ABB Corporate Research Switzerland demonstrates its own HV MO varistors but BBC hesitates to enter production.

**1976**
ASEA buys technology from Matsushita and starts production.

**1980**
ASEA offers full range of MO HV surge arresters.

**1982 – 1987**
BBC ramps up varistor and arrester production, based on fundamental work done in ABB Corporate Research Switzerland.

**1984**
BBC pioneered polymer-insulated surge arrester for MV distribution.

**1988**
BBC and ASEA join forces and become world market leader for MO arresters in MV, HV-AIS/GIS, AC/DC, UHV, railway, etc., → picture (From 2001, an early suspension line insulator-arrester of type POLIM-S in which the mechanical support function and the surge protection are combined in the same device).

**1988**
Start of joint Swiss/Swedish R&D on MO technology.

**2011**
ABB high-field MO varistors for compact GIS.

**2017**
Continuing research and product development for new power electronics applications.

This led to coordinated management programs for the 800+ scientists in the now six corporate research centers in Switzerland, Sweden, Germany, Norway, Finland and Italy. At this time too, the role of corporate research was redefined to lessen somewhat the focus on basic science and bring activities closer to the business units and markets.

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### The role of corporate research was redefined to bring activities closer to the business units and markets.

This shift defines the research programs carried out by the research center in Switzerland today.

**Today's research areas**
The ABB Corporate Research Center in Switzerland employs about 200 employees from more than 35 different countries who focus on automation, power electronics, energy and materials, and power products and systems. The following sections give a flavor of some research topics in these areas.

**Automation**
Industry is now moving to the next level of automation systems, which not only execute simple control loops or rule-based processes but also optimize overall performance based on a holistic understanding of the system state, prediction of the future and even automatic adaption of the process abstractions. ABB is driving this revolution in automation systems with ABB Ability™.

**1968 – 1984**

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**Liquid crystal
displays (LCDs)**



**1968**
RCA presents first
results on dynamic
scattering LCDs.

**1969**
BBC makes a strategic
decision to enter
medical electronics
market.

**1969 – 1972**
Collaboration with
Hoffmann-La Roche.

**1970**
Hoffmann-La Roche:
Twisted Nematic (TN)
LCD.

**1973**
World's first LCD watch
presented at MUBA
consumer show, Basel.
A joint effort of
Hoffman-La Roche
(liquid crystal material),
BBC (LCD), Faselec
(integrated circuit) and
Ebauches (watch).

**1973**
LCD pilot production
line in vacuum tube
factory in Birr.

**1974**
LCD factory in
Lenzburg, 110
employees, displays
for Casio (Casiotron)
and Swiss watch
makers.

**1978**
Assembly line in
Hong Kong.

**1980**
Videlec, BBC/Philips
joint venture.

**1983**
Discovery of supertwist
nematic (STN) effect,
patent 12.3.1983.
High resolution,
excellent contrast,
low power → picture
(Passive matrix STN
LCD, 540 × 270 Pixels).

**1984**
Videlec sold to
Philips, research
team refocused on
optoelectronics.

**1984**
BBC decided to keep
STN LCD patent, very
lucrative license
revenue stream.

**ABB Ability digitalizes industrial automation**
ABB Ability is a unified, cross-industry digital
capability – extending from device to edge to
cloud – with devices, systems, solutions, services
and a platform that enable ABB customers to turn
data insights into the direct action that "closes
the loop" and generates customer value in the
physical world. In many ABB Ability applications –
or, indeed in virtually any industrial automation
setting – it is the field instruments that are closest
to the process. ABB is a leading manufacturer of
field instruments and ABB Corporate Research
in Switzerland contributes to these products
with research in optics, laser spectroscopy, radar
applications and acoustics. Researchers also focus
on the embedded computations needed to run
advanced control algorithms that solve challenging
optimization problems in real time.

**System architecture**
With systems becoming smarter and more
digital, their inherent complexity increases.
How, then, can one build systems that are
correct, dependable, scalable, secure, safe

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The ABB Corporate Research
Center in Switzerland employs
about 200 employees from more
than 35 different countries.

and that deliver high performance? To answer
these, and other, questions, ABB Corporate
Research is developing the next generations
of software and systems architecture.

**1970 – 2016**
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**Fiber optic
current sensor
(FOCS)**
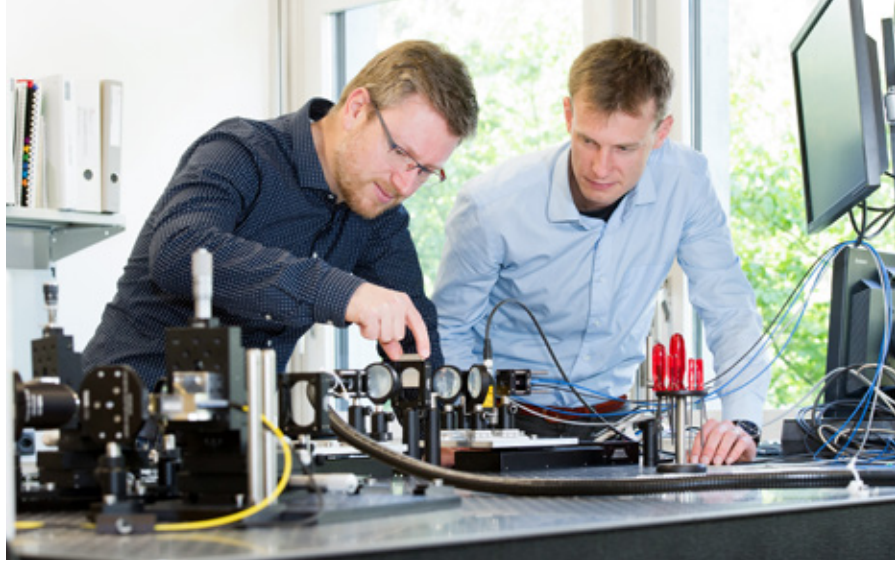
**Circa 1970**
Research on early
Faraday-effect devices,
abandoned.

**1992**
Fundamental ABB
patent on modern
FOCS, Ph.D. thesis.

**1997 – 2001**
Basic FOCS
development, FOCS
demonstrated in 170 kV
circuit breaker at ENEL
substation.

**2000**
ABB in the United
States launches
magneto-optic current
transformer (MOCT).

**2005**
Product launch – FOCS
for industrial DC.
Finalists of the Swiss
Technology Award and
Hermes Award
(Hannover Fair). FOCS
production starts in
Baden-Dättwil.

**2007**
Produced 100th FOCS;
FOCS production
moved from Baden-
Dättwil to Turgi,
Switzerland.

**2006 – 2008**
FOCS second-
generation (G2)
technology developed:
IEC 61850-9-2-
compliant ABB
electronics.

**2009**
FOCS G2 product
development starts.

**2010**
Pilot installation of live
tank CB with FOCS at
Swedish National Grid.

**2016**
First commercial
disconnecting CB with
FOCS installed at a
State Grid China
Corporation (SGCC)
next-generation smart
substation → picture
(Physicists work on new
developments in the
optics laboratory).

Increasing computational power and the
adaptation of general-purpose operating systems
enable more applications to exploit real-time
monitoring and control. ABB Corporate Research
in Switzerland focuses on several aspects of
real-time systems to provide corresponding
solutions, including system architectures,
dependable digital communication and
real-time test systems.

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The revolutionary approach of
homomorphic encryption allows
sensitive data to be encrypted
and sent for analysis without
sharing a decryption key.

**Security and privacy for cyber-physical systems**
Customers demand that their data is treated
securely. The revolutionary approach of
homomorphic encryption allows sensitive data
to be encrypted and sent for analysis without
sharing a decryption key. Only the customer
can access the data and results. ABB Corporate
Research has found ways to massively reduce
the computational overhead of homomorphic
encryption, thus making it usable in an effective way.

Blockchain is another technology that helps to
establish secure transactions between parties
that do not trust each other. Researchers are
investigating new business-use cases for which
the blockchain and its computational effort can be
justified as well as alternative technologies that
incur significantly less overhead.

## 1988 – 2016

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### Power electronics: semiconductors, packaging, integration, converters and control

Power electronics is a core competence of ABB Corporate Research in Switzerland. A key asset is the PEARL (Power Electronics Advanced Research Lab) facility, which enables research into next-generation power semiconductors, modules and applications. New devices are designed in-house, then samples are fabricated in the lab's cleanroom. The semiconductor dies can then be packaged and integrated into larger power modules. The "Mikrolabor" was an earlier semiconductor manufacturing facility for applied R&D of power electronic devices.



**1988 – 1994**
Period of the "Mikrolabor."

**1988 – 1994**
Field-controlled thyristor (FCTh) R&D forms the basis of the IGCT (integrated gate-commutated thyristor).

**1988 – 1994**
MOS-controlled thyristor (MCT) R&D enables the ABB IGBT.

**1995 – 1998**
IGBT production transferred to an external company.

**1995**
100 MW IGCT-based PCS power converter.

**1995 – 2000**
IGBT-based Flatpack and StakPak power modules.

**1998**
IGBT production transferred from external company to the ABB semiconductor factory in Lenzburg, Switzerland.

**1999**
ACS6000 5 – 30 MVA drive (IGCT).

**2010**
4.5 kV StakPak modules for HVDC Light.

**2014**
The new PEARL, → picture (PEARL state-of-the-art facilities for advanced packaging) is opened.

**2016**
STATCOM (static synchronous compensator) based on a new topology and improved IGCT.

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**Power electronics**
Where high voltages and currents have to be controlled, power electronic devices are to be found. ABB, a pioneer in this field, is continuously improving the power density, efficiency, functionality and reliability of power electronics equipment. A key asset in this endeavor is the new PEARL facility, the establishment of which means that the Swiss research center now has all core competencies – semiconductors, packaging, thermal integration, topologies and control – under one roof.

**SiC developments**
Silicon carbide (SiC) semiconductors have many advantages over silicon-based devices. ABB Corporate Research in Switzerland has long experience in, and a fundamental understanding of, the science of SiC. To exploit the benefits of SiC, researchers are developing SiC devices, such as Schottky diodes and MOSFET switches, that can be used in ABB products.

**ABB's StakPak power module stabilizes electricity grids**
StakPak is a family of high-power insulated-gate bipolar transistor (IGBT) press-packs and diodes in an advanced modular housing that guarantees uniform chip pressure in multiple-device stacks. ABB Corporate Research in Switzerland is

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ABB Corporate Research in Switzerland has long experience in, and a fundamental understanding of, the science of SiC.

heavily involved in the development of cutting-edge power module material combinations and structural concepts to provide highly reliable and failure-safe package solutions for HVDC transmission applications.

## 1996 – 2017

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## High-temperature superconductivity

With the high-temperature superconductivity (HTS) Nobel success at Prof. Speiser's IBM laboratory in Rüschlikon, it was inevitable that the subject would become one of interest for ABB Corporate Research and one in which notable successes would be scored.

**1986**
Discovery of high-temperature superconductivity at IBM; Nobel Prize in 1987.

**1996**
ABB Corporate Research, Switzerland: 12 MW fault-current limiter (FCL) pilot project based on HTS materials installed in Switzerland (first HTS FCL in grid).

**1997**
630 kVA (18.7/0.42 kV) transformer using superconductive wire at SIG in Geneva (first HTS transformer in grid).

**2002**
6.4 MVA resistive FCL passes laboratory test.

**2001 – 13**
Collaboration with University of Geneva on a superconductive FCL.

**2012 –17**
Single-phase 577 kVA (20/1 kV) current-limiting transformer test device using superconductive wire in collaboration with Karlsruhe Institute of Technology (KIT) shown at Hannover Fair 2017 (by KIT) → picture (Collaboration with KIT: current-limiting transformer using superconductive wire (test device)).

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04 Multidisciplinary teams at ABB Corporate Research investigate the fundamental principles of power systems.

**Innovative cooling technology for harsh environments and renewables**
ABB's innovative and highly efficient self-contained cooling system uses phase transition and thermosiphon technology. With the simplicity of air cooling and with the power

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Involvement in energy and materials ranges from fundamental understanding to advanced material development and process technologies.

density of liquid-cooled systems, it provides low maintenance and easy commissioning – ideal for any outdoor application. ABB Corporate Research performed the fundamental scientific work needed to design the cooling system, which is currently employed in drives, photovoltaic inverters and dry transformers.

**04**

## 1996 – 2017

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## Automation

**Substation Automation –
The ecosystem around the
IEC 61850 standard series**
The IEC 61850 standard is the enabler for the digital substation. Since its early days, ABB Corporate Research has provided key contributions to both the standard itself and ABB's implementation of the technologies and tools:

- Key contributions to all aspects of the standard and the engineering guidance documents as members of the IEC technical committees and working groups (eg, IEC TC57)
- Systematic modelling in UML of the standard to drive automatic software generation and documentation (eg, ABB 61850 base libraries)
- Concepts and architecture for substation automation engineering, testing and commissioning tools (eg, ITT, IET and DST600)

**Railway communication and control technology**
Corporate Research in Switzerland has a history of key technology contributions for railway applications:

- TCN (train communication network) is used on trains worldwide.
- ETCS (European train control system) – significant contributions
- Adhesion control for sensorless traction chains were pioneered
- Remote diagnosis for trains (ROSIN) established
- Electrical systems Compatibility for railway vehicles

**Automation – always leaders**
ABB Corporate Research has always been a pioneer in information and communications technology:

- Procontrol P215 as common control platform for BBC
- Pioneered graphical software engineering in 1992 with "FuPla", leading to CoDeSys and IEC 61131 as groundbreaking innovations
- Error-tolerant processors enabling Pacific intertie HVDC project
- WISA concept for wireless sensors and control in factories winning Gold Award for Technology Innovation by the Wall Street Journal
- GLASS – remote monitoring of embedded systems using internet technologies as a precursor of the Industrial Internet of Things
- Identified the need for and pioneered robust industrial cyber security years before 9/11 and Stuxnet. Later, secure data storage and computation in the cloud

**LEAP – LEarning for PlAnt Process Improvement**
- Explore emerging machine learning technologies for automatic model generation and decision making within advanced process control
- Provide the missing pieces: accountability, robustness, maintainability
- Machine Learning expected to be a game changer
- Improve engineering efficiency and facilitate development of advanced control solutions
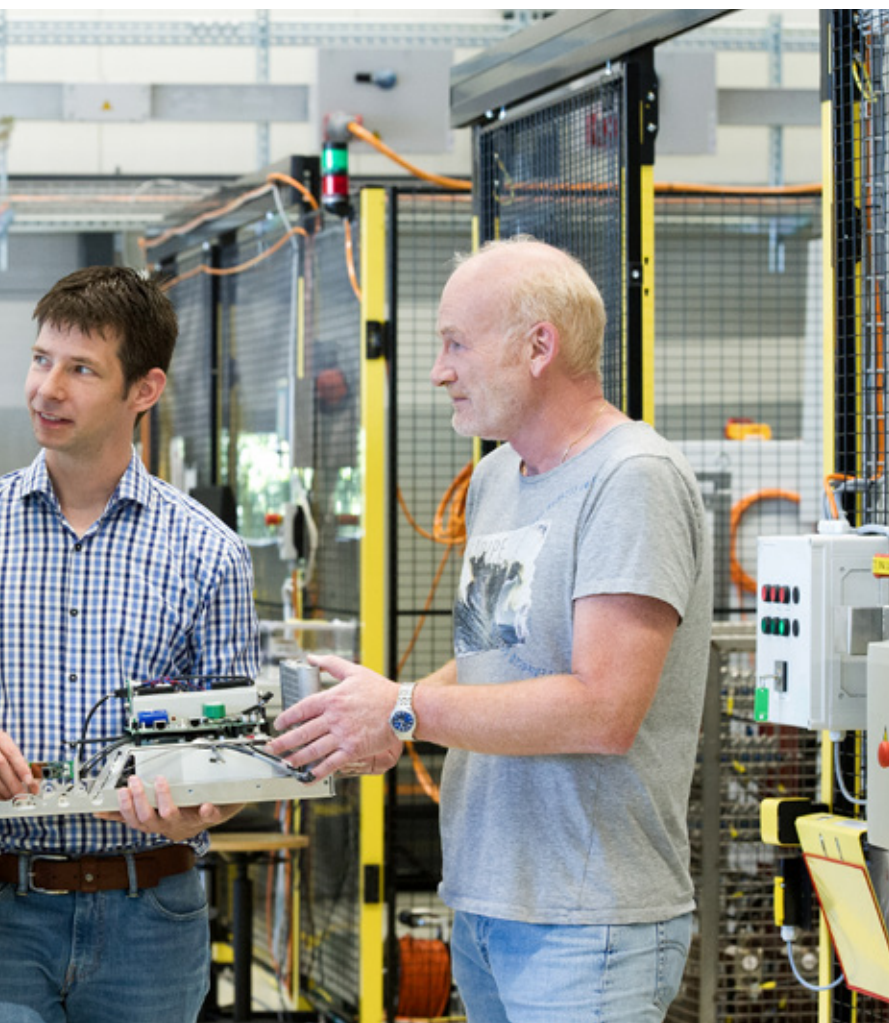


**Energy and materials**
ABB Corporate Research's involvement in energy and materials ranges from fundamental and first-principle understanding to advanced work on material development and process technologies. In the physics domain, for example, the first-principle understanding of charge transport in HV components as well as other complex multiphysical interactions are topics for exploration. This knowledge is used, for instance, in the system simulation of circuit breakers. In the applied physics area, researchers in Switzerland help optimize thermal management to improve power ratings and product footprints.

**1973**
Self-blast
circuit breaker
for high-voltage
switchgear

**2001**
Electronic gas
meter

**1975**
Metal-oxide surge
arrester made from
sintered ceramic
material

**2000**
190 kA generator
circuit breaker

**1984**
Super-twisted
liquid crystal
display (LCD)

**1996**
High-temperature
superconducting
current limiter

**1992**
Graphical
software
engineering

**1994**
Presspack
semiconductor
module
for high-voltage
direct current
power transmission

The Swiss research center is the focal point of expertise in energy storage solutions – in particular, battery systems. Researchers contribute to the full value chain from understanding battery cells, through integration into modules and cooling aspects, right up to battery systems and business evaluation.

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The work carried out by ABB Corporate Research establishes the scientific and engineering fundamentals of power systems and of many of the power products involved.

Activities in material research and manufacturing methods include the development of novel metallic compounds as high-performance contact materials in circuit breakers; the development of hard permanent magnets by innovative methods

such as 3-D metal printing and spark plasma sintering; and new material concepts based on thermoplastics, thermosets and elastomers together with novel manufacturing processes for bushings that are completely oil- and paper-free.

**Power products and systems**
The work carried out by ABB Corporate Research establishes the scientific and engineering fundamentals of power systems and of many of the power products involved →4. The Power Systems of the Future research program, for example, uses a framework of data collection, scenario generation, and technical and economic analysis to investigate how new technology, policy and business models can shape the electric power sector.

**2003**
Wide-area
protection for
high-voltage
grids

**2017**
Full SiC power
module LinPak
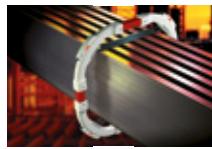
**2004**
Optical direct
current sensor

**2015**
170 kV ecoGIS

**2007**
6.5 kV power
module for
traction

**2014**
525 kV
HVDC
Cable

**2008**
Generator circuit
breaker with heat
pipe cooling

**2012**
PE Traction
Transformer

**05**

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05 Some of the signif-
icant breakthroughs
that emerged from ABB
Corporate Research in
Switzerland, 1973 to 2017.

Thus, potential technical challenges can be
evaluated, such as the increasing need for
adequate operating reserves and transmission
or distribution feeder capacity, reduced system
inertia and short-circuit capacity.

Increased electric power transmission distances
have led to significant penetration of embedded
HVDC into existing AC transmission grids
worldwide. Swiss researchers have developed
novel control schemes to exploit HVDC capabilities
and thus maximize overall grid transfer capacity.

**The next 50 years**
The 34 scientists who signed up to the embryonic
ABB Corporate Research in Switzerland in 1967
could scarcely have envisaged that their efforts
would lay the foundation for so many significant
and successful ABB technologies →5.

They could certainly never have predicted how the
world of technology in general would change over
the next five decades.

Now, when technological change is more rapid
than at any time in human history, it is almost
impossible to imagine what technologies will exist
in 2067, a further 50 years hence. What is certain,
though, is that the pioneering, inquisitive and
inventive nature of a whole new generation of ABB
Corporate Research scientists will be there to write
the future. ●

PERPETUAL PIONEERING

# Wireless but connected

ABB may be well known for its power and productivity products. It is less commonly recognized that the company also played a pioneering role in mobile telecommunications.

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01 Wireless telephony was no new field for ABB

01a Mobile telephony system inside the luggage space in a police car in Zurich, Switzerland (Brown Boveri Review, December 1941)

01b Handset inside police car in Zurich, Switzerland (Brown Boveri Review, December 1941)

The present age of Industry 4.0 and the Internet of Things is seeing a rapid transformation of virtually every branch of industry. This is only possible thanks to the prevalence of high-performance and affordable wide-area communication systems. Most of the data exchanges that enable their functionality use a wireless mode for at least part of the transmission path.

**01a**
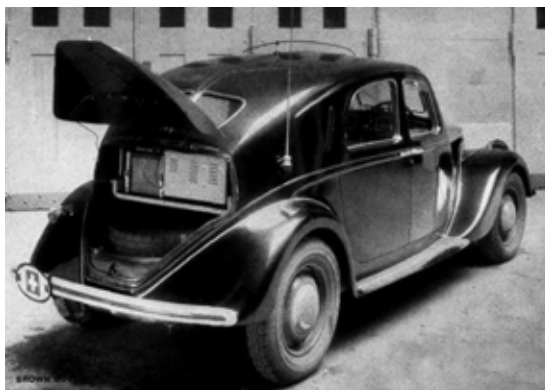
**01b**

The ongoing convergence between industrial software and telecommunications might create the impression that wireless communications are a new field for ABB. But little could be further from the truth. ABB's predecessor company, BBC, was already doing research on wireless communications in the 1930s. In 1939, a communication system was supplied for air traffic control at the Kloten airstrip, near Zurich in Switzerland (now Zurich Airport). A mobile telephony system for police use was also developed →1 with the Zurich police force becoming the pilot customer in 1941. This system was notable in being an early commercial application of frequency modulation (FM) →2.

These mobile telephones were still a far cry from today's handheld devices, consuming much of the luggage space of a police car →1a. More than a quarter of a century was to pass until a commercial public wireless telephone system was to be launched by the Swiss post office (PTT) in 1978 BBC's mobile telephone weighed 15kg and fitted in an aluminum suitcase – and that did not even include the battery →3. The telephone had to be connected to a car battery or a mains supply, hence the name under which PTT marketed the network: NATEL, standing for Nationales Autotelefon (national car telephone). The name is still used colloquially in Switzerland today to refer to any mobile phone.

## FREQUENCY MODULATION.

Decimal index 621.396.619.018.4

Frequency-modulation characteristics and advantages are discussed and compared to amplitude modulation.

This system, in full development in the United States, has had our attention for a considerable time. Researches made as well as experience acquired on a frequency modulated installation have fully confirmed the favourable properties of this system.

TRANSMISSION of a-f signals can be produced, as is well known, in the form of modulated h-f oscillations. For these oscillations, having an amplitude a and a pulsation $\omega$, the following equation is generally verified:

$$e = a \cdot \sin \varphi (t) = a \cdot \sin \int \omega \, dt \qquad (1)$$

In amplitude modulation (AM), the pulsation $\omega$ remains a constant, while amplitude a, corresponding to an instantaneous value of the a-f signal, deviates from the average $a_0$ by a variable quantity $a_n$. The signal may be composed of an a-c voltage, having a pulsation $\omega_N = 2\pi f_N$ (with a capital letter index). Equation (1) therefore becomes:

$$a = a_0 + a_n = a_0 (1 + m_a \cdot \sin \omega_N t);$$
$$\omega = \omega_0 = constant \qquad (2)$$

The rate of modulation $m_a$ can attain the value of 1, according to the signal amplitude.

In *frequency modulation* (FM), the amplitude a remains a constant, while pulsation $\omega$, corresponding to the signal to be transmitted, deviates from the average value $\omega_0$:

$$\omega = \omega_0 + \omega_n = \omega_0 (1 + m_f \cdot \sin \omega_N t);$$
$$a = a_0 = constant \qquad (3)$$

The shift $\omega_n = 2\pi f_n$ (characterized by the non-capital letter index) between the instantaneous value $\omega = 2\pi f$ and an average one of $\omega_0 = 2\pi f_0$ of the pulsation, has the maximum value of $\omega_s = 2\pi f_h = m_f \cdot \omega_0 = 2\pi m_f \cdot f_0$. The maximum frequency deviation $f_h = m_f \cdot f_0$ is usually much smaller than the average frequency $f_0$; which means that in FM, the shift ratio $m_f$ is always small as compared to 1. A comparison of both modulation systems, and notwithstanding the apparent analogy between the equations (2) and (3), shows important differences in the nature of the oscillations, perturbations and distorsions which are caused, as well as in the transmitting devices.

02

03

These networks were all analog. In the late 1980s, work began on creating a standard for digital mobile telephony by the European Post and Telecommunication bodies in a working group called Groupe Spécial "Mobiles" (GSM). The standard later also became known as GSM, but standing for Global System for Mobile Communications. Although BBC was no longer actively involved in manufacturing car telephones at that point, it had much knowledge on digital communications. PTT asked BBC to represent Switzerland on their behalf in the group.

This responsibility was entrusted to a scientist from ABB's corporate research center in Daettwil, Dacfey Dzung. To this day, the GSM connection protocol contains a data bit that was defined by Dzung. No GSM connection can be initiated anywhere without using this bit: a long lasting but invisible tribute to ABB research.

ABB is no longer active in commercial mobile telephony, but is still active in digital wireless communications, for example within factories – a field of growing relevance in the Fourth Industrial Revolution. ●



**Paul Scherrer**
1890-1969

# Atom nuclei, a view from 1941

In issue 3/2017, ABB Review published an article on transformer it supplied to CERN. ABB's interest in atomic research is nothing new. In its December 1941 edition (p436), The Brown Boveri Review published a guest article by Paul Scherrer (1890-1969), professor of experimental physics at ETH Zurich Scherrer was later to play a role in the setting up of CERN in 1954. The Debye-Scherrer method, used for studying crystals structures is named after him, as is the Paul Scherrer Instiute, a research institute in Wuerenlingen, Switzerland. In this article, Scherrer explains the understanding of atom nuclei of the time. This historic document can be read in full on the ABB Review website www.abb.com/abbreview. ●



## SOME RECENT DEVELOPMENTS IN PHYSICAL RESEARCH ON ATOM NUCLEI.

Decimal index 539.152.1 – 539.17

Among all scientific achievements accomplished during these last years, research work carried out on artificial atom-transmutation may well stand in the first place. A new branch of physics appears to be in rapid development. Physicists are at present not only able, by way of reliable experiments, to transmute known chemical elements, but also to produce artificially a large number of new, previously unknown sorts of atoms. Among these elements especially the 300 artificially radioactive kinds of atoms are of great interest. The high velocity atomic nuclei required for artificial atomic transmutations are produced in the most satisfactory way with the help of the cyclotron. Artificial radioactivity is of greatest importance for chemistry and especially for investigation of biological processes. The huge energies set free by way of atomic transmutations appear to contain undreamed-of possibilities for technical application.

### I. NUCLEAR CONSTITUENTS AND ENERGIES.

PHYSICISTS are to-day of the opinion, that all the happenings of Nature may be accounted for by field-transmitted interactions of a few simple *elementary units of matter*. These elementary particles to which, according to wave mechanics, we must ascribe at the same time corpuscular and wave nature, we divide into light and heavy particles.

Above all, electrons belong to the group of *light elementary particles*. They occur as negatively charged negatrons $-\varepsilon$, as well as positively charged positrons $+\varepsilon$. The mass of an electron expressed in atomic units, is equal to $0 \cdot 000543$. (The mass of oxygen has been arbitrarily assumed as $= 16 \cdot 000$.) The electron is, therefore, about 2000 times as light as a hydrogen atom. There also exist the so-called *mesons*, or heavy electrons. They carry the same charge, but are about 160 times heavier than electrons. Among light particles we also find light-quantas or *photons*, which serve as energy transmitters in all kinds of electro-magnetic radiation, as $\gamma$-rays, X-rays, ultra-violet, visible and ultra-red radiations. We may also mention the last known light particle, the hypothetic *neutrino*, the existence of which can be only assumed as a result of experiments, but which cannot as yet be made directly visible. Photons and neutrini carry no charge, and have rest mass zero, which means that they exist only in movement and that their mass depends simply on their kinetic energy, (respectively on their momentum).
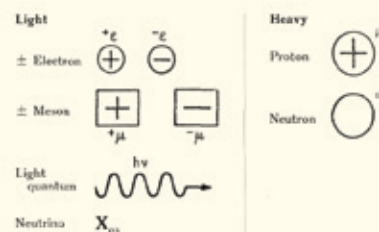
We also know two *heavy elementary particles*, namely the *proton* p and the *neutron* n. The proton carries the same positive charge as the positive electron, while the neutron carries no charge. The mass of both particles is about 1, expressed in atomic units, in

Fig. 1. — Elementary particles.

BUZZWORD DEMYSTIFIER

# Artificial intelligence

The second installment of ABB Review's "Buzzword demystifier" series looks at artificial intelligence. This guest article is by Derik Pridmore, CEO of Osaro, a San Francisco-based company partnering with ABB in the domain of machine learning.

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Osaro is a company specializing in machine intelligence. Osaro partners with ABB in bringing machine learning to ABB products.
www.osaro.com

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**Footnote**
1) For a technical overview of this definition, see https://arxiv.org/pdf/0712.3329.pdf.

I'm often asked "what is artificial intelligence?" and "why is artificial intelligence important for industrial robotics?" The term artificial intelligence seems to intrigue, confuse, and frustrate businesses that hope to use it to better serve their customers.

Before we define artificial intelligence, it is useful to define intelligence. Intelligence is the ability of an agent (human or otherwise) to achieve goals in a wide variety of environments [1].

For instance, when presented with a new goal or situation, humans are often able to achieve that goal. Their intelligence gives them robust capabilities. An artificial intelligence is an algorithm (computer code) that has this property – the ability to achieve goals in a variety of environments.

Adding to the confusion, we often hear the terms "machine learning" and "artificial intelligence" used interchangeably. They have become synonyms because learning is a very useful method for increasing intelligence. Machine learning simply means algorithms that are designed to learn from data. Two machine learning techniques which have shown particular promise in the past five years are deep learning and reinforcement learning.

Deep learning is a supervised learning technique that uses neural networks to form compressed and generalized representations of a data set. Reinforcement learning is a separate technique which takes a representation of an environment and a goal (called a reward function), and then uses trial and error to discover actions that maximize the reward. (It might also take in examples of how to achieve the goal – this imitation learning is how Osaro's software works.) In theory, by combining these two techniques we can simultaneously learn a representation and discover how to achieve a goal.
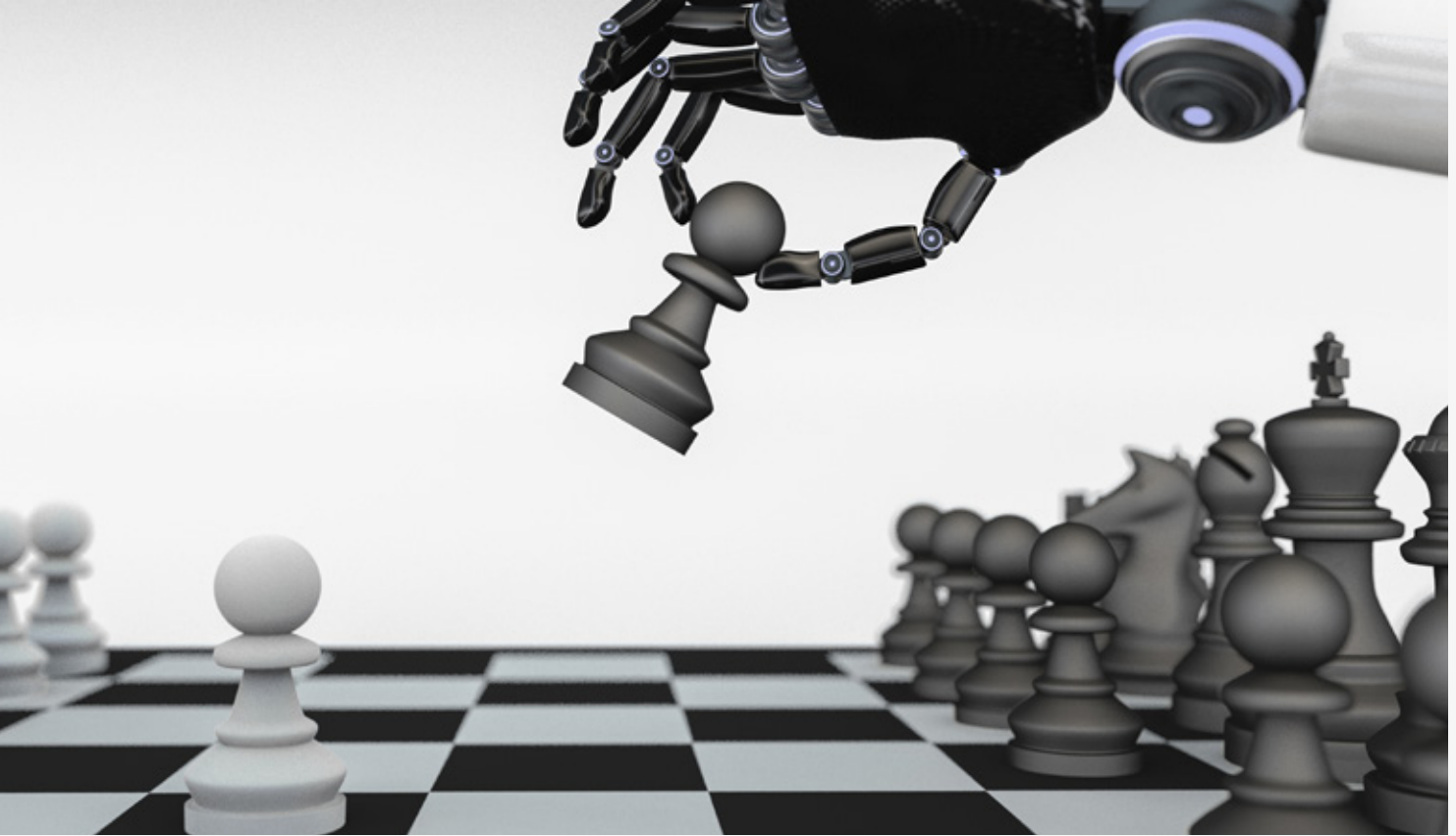
The only questions that remain are how fast, how well, across what types of environments, and with what guarantees can we learn? This is the focus of most modern machine learning research.

With these definitions in hand we can understand why artificial intelligence is important to industrial robotics. If a business changes a part or workplace even slightly, today's robots fail and need to be given a new set of instructions.

The algorithms controlling conventional robots have very little intelligence. Artificial intelligence will increase the range of tasks and environments in which robots can used. It will also decrease the total cost of robotic deployments by saving time and alleviating costly reprogramming. ●

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**03**|2017
## ABB Ability

**04**|2017
## Extreme performance

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Next 01/2018
**Innovation**

**The next ABB Review is the annual issue focused on innovation, which will look behind the scenes of some of the most successful innovations to reveal how they were accomplished. It will also provide exclusive glimpses of the cutting edge technology and research that will drive the next successes.**