

review

04|2018 en

Autonomous collaboration



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Conveyor Roller Inspection Services



Integrated solutions for buildings

Short-circuit values for circuit breakers



Digital twin in Industry 4.0



Opportunities for electrical sensors

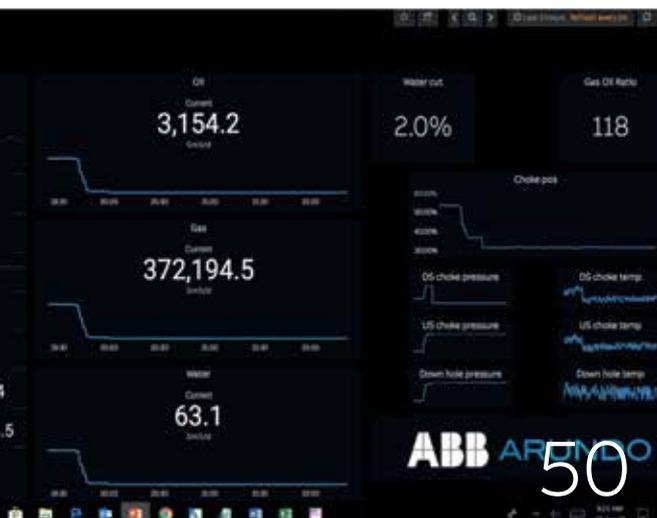




University collaboration



Individualization
of production



Cloud-based multiphase flowmeter

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A mechanical wristwatch will run without supervision for a long time, but it doesn't adapt to operating in different temperatures, respond to changes in geographical location, or possess the intelligence to recalibrate to new maths of seconds, minutes, or hours. Truly autonomous systems are programmed to embrace variability, and this issue of ABB Review explores the dimensions of how these systems work, evolve, and deliver results.

As always, your feedback is welcome at abb.com/abbreview

EDITORIAL

Autonomous collaboration



Dear Reader,

Intelligence has at times been defined as the ability to adapt to change. An advanced chess computer is able to think many moves ahead and can outperform even the best human players, but it cannot cope, for example, with a change in the rules or objectives of the game.

The transition towards autonomous systems in manufacturing and utilities is not merely a step up in terms of the complexity of the tasks being solved or the raw computing power being used to solve them. Rather, it is about creating systems with the ability to adapt and even learn in changing situations. The stepwise increase of autonomy in automation systems will massively widen their scope and reach.

I trust that this issue of ABB Review will provide some glimpses into the vast potential and possibilities that lie ahead.

Enjoy your reading,

A handwritten signature in red ink, appearing to read 'Bazmi Husain'.

Bazmi Husain
Chief Technology Officer

Autonom collabora





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ous tion

A manufacturing system that self-configures for individual product designs? Building functions designed to yield a unified information model for what (and how) things get done? Autonomous collaboration can yield immense change in processes, and ABB is pioneering that work.

- 08 Autonomous systems
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08

AUTONOMOUS COLLABORATION

Autonomous systems

“Autonomous systems” is a term that is frequently used (and often misused) to describe systems that – without manual intervention – can change their behavior in response to unanticipated events during operation [1]. This article introduces a more comprehensive definition. It is a work in progress and is published here as an opinion piece to encourage discussion.

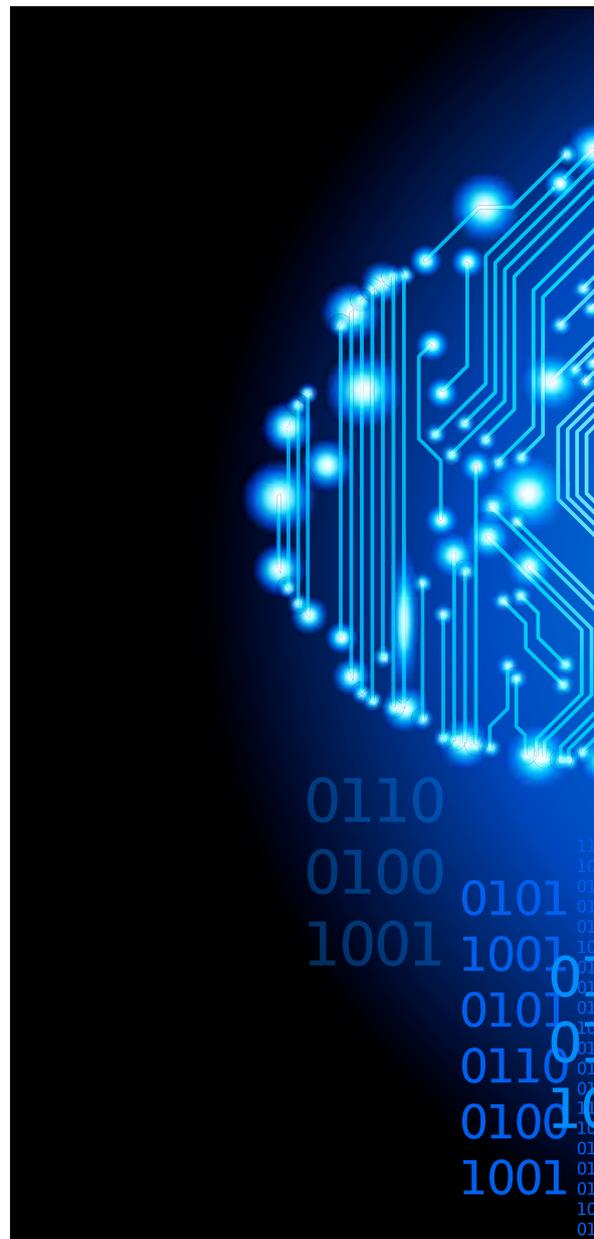
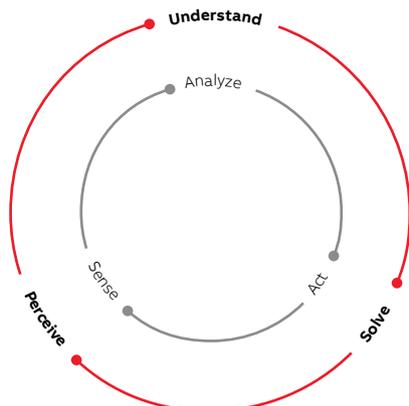


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There is nothing new about a system that reacts to changing inputs in realtime. Cars, for example, already feature a considerable amount of low-level automation, such as the electronic stability control (ESC) or anti-lock braking system (ABS). Although the algorithms may act on myriad inputs and attain considerable complexity, the input data is highly structured and the range of possible actions is limited. In contrast, a self-driving car must deal with inputs that are considerably less structured and that call for a greater range of reactions. The algorithm needs to react to all sorts of vehicles it may encounter, as well as pedestrians, road geometries, weather conditions, erratic behavior of others, and any number of random objects and events that the programmers did not necessarily anticipate.



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01 Loops in classical control (grey) and autonomous systems (red).

Conventional automation systems enable low-level processes to run without human intervention under normal conditions. Human decisions are still required

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AI is a technological means through which a specific level of autonomy can be achieved. Autonomy is the target that AI can help achieve.

for more complex tasks. Making automation systems more autonomous is about progressively handing over more and more of these tasks to the system.

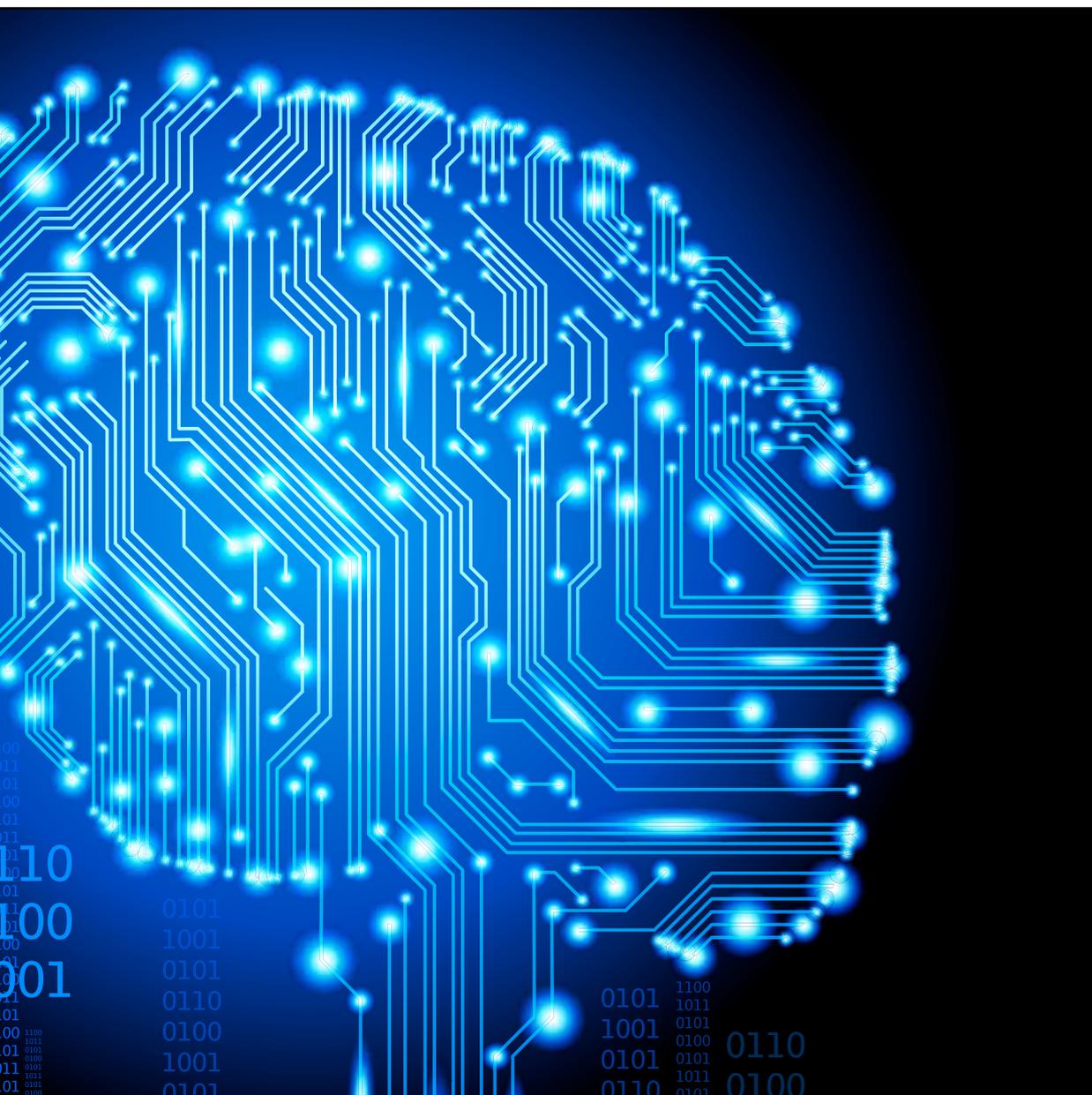
Achieving an autonomous system

Many of the inputs required for increased autonomy are already available digitally. These include the sensor and process data of classical automation, but also inputs from numerous other sources including surveillance cameras, weather and market data.

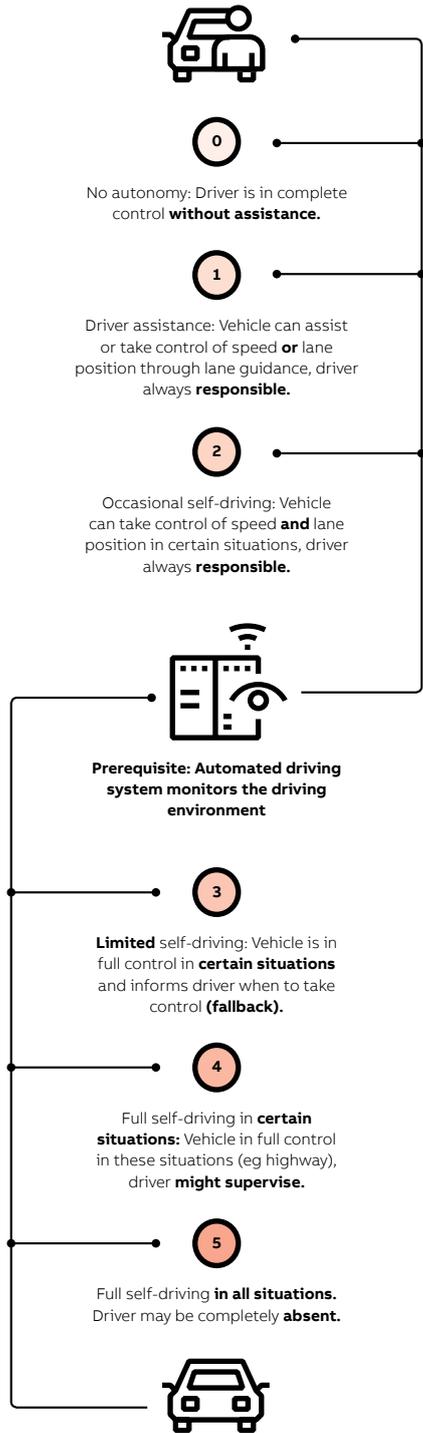
—
Many of the inputs required for autonomous operation are already available digitally.

Artificial intelligence (AI) is a valuable technology for processing this data. There can be a tendency to confuse AI with autonomous systems. AI is a technological means through which a specific level of autonomy can be achieved. Autonomy is the target that AI can help achieve.

An automation system typically performs precisely defined instructions within a limited scope of operation. A classical control loop can be broken down into the phases of sense, analyze and act. For example, a motor is running too fast (sense), the controller decides to reduce the speed (analyze) and reduces the current to the motor (act). An autonomous system feedback loop adds another shell, applying the same principle but on a more complex level, encompassing also with what



02



is not known or foreseen. A self-driving vehicle identifies an obstruction (perceive), recognizes that a potentially dangerous situation may arise (understand) and takes corrective action by modifying the speed and trajectory of the vehicle (solve) →1.

Artificial intelligence (AI) is a technological means through which a specific level of autonomy can be achieved.

Levels of autonomy

In order to define objectives in the transition to autonomous systems, it is important to establish a taxonomy so that automation providers and customers can define where they are and where they want to be in the short, medium and long-term. This article proposes a taxonomy of autonomy with six levels, inspired by definitions from the automotive industry →2,3. It is mainly based on two dimensions: scope of automated task and role of the human. The taxonomy begins with no autonomy (Level 0, extensive low-level automation may still be in place at this level) and rises to full autonomous operation (level 5), in which all decision making and actuation is done by the system.

On Level 1, systems provide operational assistance by decision support or remote assistance. Examples include software that helps localize underground mine vehicles, or provides situational awareness for ships by additional sensing such as LIDAR and radar →4.

Level 2 edges into occasional autonomy in certain situations. Here, the automation system takes control in certain situations when and as requested by a human operator, for limited periods of time. People are still heavily involved, monitoring the state of operation and specifying the targets for limited control situations. One example is an autopilot for ships that on request takes over speed and navigation control following a pre-defined route, but with an active captain still being fully responsible.

0	No autonomy, humans are in complete control without assistance.
1	Assistance with or control of subtasks. Humans always responsible, specifying set points.
2	Occasional autonomy in certain situations. Humans always responsible, specifying intent.
Prerequisite: Automation system monitors the environment	
3	Limited autonomy in certain situations. System alerts to issues. Humans confirm proposed solutions or act as fallback.
4	System in full control in certain situations. Humans might supervise.
5	Autonomous operation in all situations. Humans may be completely absent.

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02 Levels of autonomous systems as illustrated using example of self-driving car.

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03 Definition of levels of autonomous systems.

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04 ABB Ability™ Marine Pilot Vision.

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05 ABB Robot Charger for underground mine (image from EU project SIMS).

Reference

[1] David P. Watson, David H. Scheidt: Autonomous Systems, Johns Hopkins Applied Physics Laboratory, Technical Digest, vol. 26, no. 4, 2005.

On Level 3, automated systems take control in certain situations. This can also be called "limited autonomy". People "sign off," so to speak, confirming proposed solutions or acting as fallbacks. A prerequisite is a complete and automated monitoring of the environment. An example would be autonomous drilling followed by autonomous charging of explosives in an underground mine →5. In such a setup, the (remote) operator can still be alerted in exceptional situations, and can take over or confirm a suggested resolution strategy.

This article proposes a taxonomy of autonomy with six levels.

On Level 4, the system is in full control in certain situations and learns from its past actions, eg to be able to better predict and resolve issues by itself. An example for such a situation is the autonomous docking of a ship, with the captain at most having a supervisory role.

At the top level of this taxonomy is Level 5. Full autonomous operation occurs in all situations. No user interaction is required and humans may be completely absent. Today, this is aspirational, but for instance an electric self-driving mining vehicle for full autonomous loading of the ore would carry major advantages of safety and productivity.

There is an important demarcation between levels 0, 1 and 2 on the one hand and levels 3, 4 and 5 on the other hand. In the former group there is some capability for autonomous actions, but these are limited in scope and the human essentially

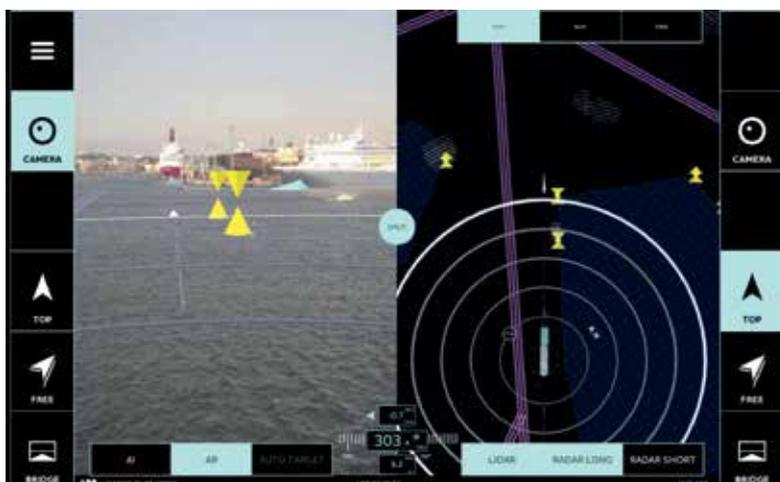
remains in active control at all times. The higher three levels are different because the human is in a passive role at most.

The legal issues raised when problems occur if a system is in control have not yet been fully addressed. There are parallels here when it comes to accidents involving self-driving cars. The legal and public acceptance situation is still developing.

Autonomy is initially attracting attention in applications similar to self-driving cars. In ABB terms this means ships, mobile robots, harbor cranes as well as mining vehicles and machines. ABB expects autonomy to enter also other traditional ABB domains such as process industries, power grids and buildings.

The legal issues raised when problems occur if a system is in control have not yet been fully addressed.

Work is in progress to define detailed autonomy levels for all of the above applications based on the presented taxonomy. Besides being a taxonomical tool, such detailed autonomy levels can help companies recognize at which level they presently are, at which one they want to be, and where the challenges of making the transition lie. The desired level will be influenced by individual acceptability of solutions, including aspects of risk, benefits, and liability, and the maturity of the relevant technology. ●



04



05

AUTONOMOUS COLLABORATION

Individualization of production

Beyond mass customization, "lot size one" production is the newest trend in discrete manufacturing. However, to be cost-efficient, such production systems must self-configure for any individual product design without human involvement and any individual product must be quality-perfect. How can this be achieved?



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From automotive to commodity goods, mass customization is the state-of-the-art in discrete manufacturing. In Industry 4.0 (the current trend of automation and data exchange in manufacturing technologies), one of the drivers is to cost-efficiently manufacture highly customized consumer goods in small batch sizes – literally down to "lot size one".

A good example of a product for which a lot size of one is desirable is the ABB-tacteo® KNX control element for smart buildings, where consumers can specify the functionality and look of each individual product [1]. To make such a perfectly individualized product, there are two main challenges: To be cost-efficient, the production system must self-configure for any individual product design without the need for human involvement; and, as essentially no spares are being produced, any individual product must be quality-perfect.

However, when designing the corresponding production line, it turned out that established integration concepts would not provide the flexibility or quality control needed. Achieving these goals turned out to be possible using concepts from Industry 4.0 such as the digital twin [2] and M2M (machine-to-machine) protocols such as OPC UA¹ →1. These concepts were successfully



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implemented by ABB-internal machine designers partnering with the system integrator, neogramm GmbH.

Made to order: ABB-tacteo KNX – the perfectly individualized product

The ABB-tacteo KNX sensor is a capacitive control element for intelligent building automation in high-end luxury hotels, offices and public and residential buildings →2.

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Mass customization is already the state-of-the-art in discrete manufacturing.

Constructed from glass, ABB-tacteo KNX meets all the requirements of modern design, the highest levels of quality and, above all, convenience for residents. From blinds, lighting and heating to media playback and room access, with ABB-tacteo KNX everything is easy to control.





01

— 01 Part of the production line for the ABB-tacteo KNX control element for smart buildings. Established production line concepts struggle with small lots sizes. However, Industry 4.0 concepts such as the digital twin and M2M protocols allow complete flexibility right down to a lot size of one.

— **Footnote**

1) The OPC Unified Architecture (UA) is a communication protocol for industrial automation developed by the OPC Foundation. What sets it apart from other M2M communication protocols is the versatility of communication patterns (from polling to event-based, from point-to-point sessions to publish/subscribe) and the extent to which the structure and semantics of data can be described.

The number of functions provided by the control element is variable and is determined by the customer's specific needs and wishes. Individually configured according to the customer's desire with an easy-to-use online configurator, each sensor is unique in design and function.

This means that the consumer is given direct control over the design of the end product, while the strengths of the traditional value network →3 – in which wholesalers take care of distribution and expert installers integrate building automation products according to the consumers' needs – are maintained.

A control element consists of high-quality glass, bearing the designed icons over an opaque background coating, behind which the KNX electronics reside. The manufacturing steps are as follows →4: After placing the panels on a tray, a near-infrared (NIR) laser removes the coating according to the shape of the designed icons.

— Consumers are given direct control over the design of their product, while the strengths of the traditional value network are maintained.

Then, the transparent areas are coated again by a digital printer to give them the level of translucency needed for each icon. Once the ink has dried, the electronics are attached and the finished product undergoes testing before it is shipped to the wholesaler. All physical, electro-mechanical and software features of the product are individualized according to customer design.



02

Quality – perfection in every step

Numerous innovations are possible in the context of Industry 4.0, such as autonomous machines that negotiate the production schedule with each

In individualized production, it is imperative to detect flaws in the product as early as possible; preferably, they are avoided altogether.

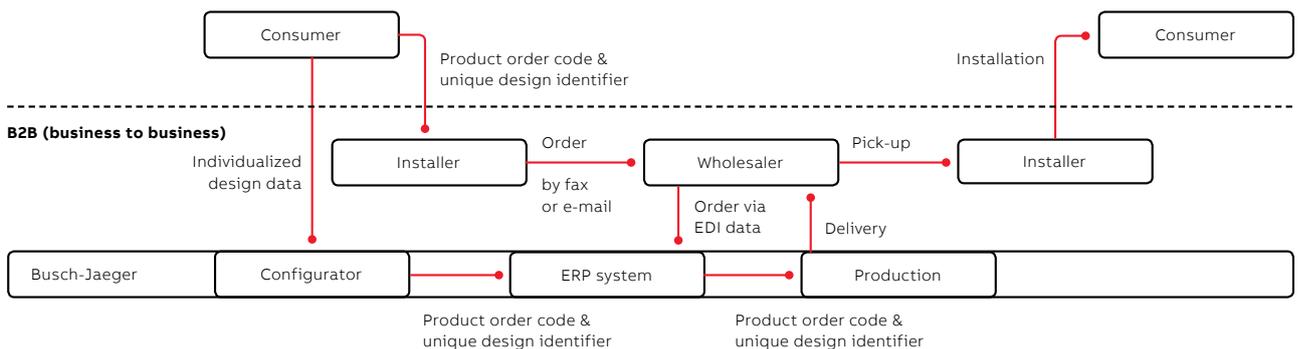
other, or smart products that steer themselves through the production process. The first challenge, then, is to decide which concepts are useful for a particular production environment.

Considering the design freedom the consumer has, every control element is potentially a unique product. Quality becomes both a top priority and a top challenge because a quality issue requires the complete element to be manufactured again and thus might delay the entire customer order.

Today, lack of digitalization is a main contributory factor to quality issues: Material is procured and transported manually, guided by order data on paper slips. Mix-ups happen easily but are hard to detect. While design data are available in digital form, they are manually transmitted to the machines on removable media. Quality-relevant data such as calibration settings for machines are not captured and cannot be audited should quality inspection of the finished product reveal any flaws.

In individualized production, it is imperative to detect flaws in the product as early as possible; preferably, they should be avoided altogether. Individualized production must not only be highly adaptive but also resilient, and human operators and machines need to collaborate seamlessly to close the quality loop.

B2C (business to consumer)



03

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02 ABB-tacteo
KNX sensor.

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03 Integrated value
network, tied together
by globally unique
product and order
identification.

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04 ABB-tacteo KNX
sensor production steps.
04a Glass panels in tray.
04b Laser processing.
04c Trays in drying rack.
04d Manual electronics
assembly.
04e Mounting the
electronics onto
the panel.
04f Glass with
electronics mounted.

Complete digitalization using digital twins

Individualized production has two key enablers: adaptive material transformation within, and digital interoperability between such machines. While material technologies like NIR lasers or digital printers already exist, machines still need to be taught how to work together naturally to achieve the needed efficiency and quality.

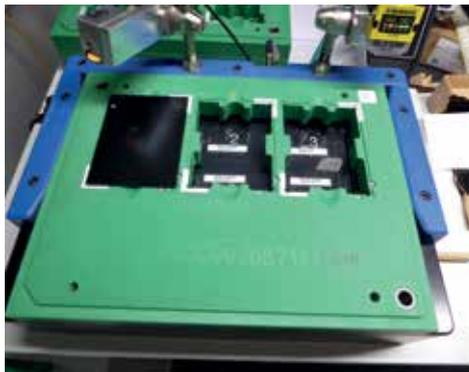
Today, machines are hardwired or coupled through PLC software. While this arrangement achieves a tight integration, it comes at significant effort and does not yield much flexibility for new product variants except that which is designed in from the start. For truly adaptive production, machine integration must be achieved with a much looser coupling, so the entire line can be flexibly reconfigured with minimal effort.

This is achieved by providing digital twins [2] that represent the specific skills of each machine in a common format on the network, independently

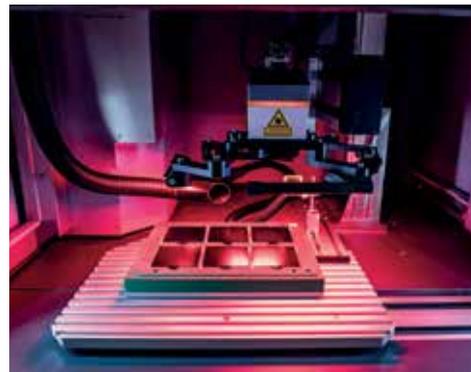
of any wired or programmed connection. To avoid “media breaks,” product design along with order and quality data are represented in the same manner. The idea is that by orchestrating the machine digital twins based on the ordered

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Any reconfiguration in software seamlessly translates to production steps in the physical world and quality information is mirrored back into the software domain.

product design, any reconfiguration in software seamlessly translates to production steps in the physical world and quality information is mirrored back into the software domain.



04a



04b



04c



04d



04e



04f

Using the digital twin concept, the ABB-tacteo KNX control element now passes each production station as follows: Upon arrival, the glass is scanned and its identity is used to get the approval, the design data and the process parameters for the next production step. To this end, the machine

To create these digital twins, the best practice was to first create a top-down OPC UA information model from the perspective of the overall production steps.

contacts an orchestration service provided by ABB Ability™ Operations Data Management zenon →5, which automatically replicates the product recipe from the ERP and holds the production history of the particular glass.

Once the glass has been processed, this is reported back to the orchestration service along with machine data used for quality tracking. The glass now departs for the next station as indicated by operations management and as shown on the HMI (human-machine interface) to direct the worker. For normal operating steps, station operators interact with the machine using a standardized ABB B&R² Automation Panel 900 →5. Manual steps, such as material transport, are electronically guided and supervised.

For example, if a glass is inserted into the printer before it has been lasered, it is rejected and the human operator is instructed to take it to the laser station instead. If glasses are transported from laser to printer out of order, the printer still is guaranteed to receive the correct raster data matching the lasered icons on the glass. Before leaving the printer, the current calibration data



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05 ABB products and solutions used for the ABB-tacteo Industry 4.0 production line.

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Footnote
2) B&R denotes Bernecker + Rainer Industry-Elektronik GmbH, the largest independent provider focused on product- and software-based, open-architecture solutions for machine and factory automation worldwide. ABB acquired B&R in July 2017. The strategic significance of the acquisition is that it made ABB the only industrial automation provider offering customers in process and discrete industries the entire spectrum of technology and software solutions around measurement, control, actuation, robotics, digitalization and electrification.

are captured for the particular glass. The same holds when calibrating the icon brightness on the product itself during automated testing. In this manner, a quality issue with the product can be traced to the potential root causes such

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Above all, quality issues are raised right when they occur, any flawed product is automatically removed and production of the corresponding design is restarted.

as problems with the machines or suboptimal process parameters. Above all, quality issues are raised right when they occur, any flawed product is automatically removed and production of the corresponding design is restarted.

To support the way machines, services and human operators work together as described, machines and their digital twins are derived from a common design template →6. Machines following this template are also easier to add or replace because they naturally plug into the existing production system.

In this production concept, the ABB-tacteo KNX control element qualifies as a smart product: The identity of each glass actively drives its own production and the outlined process steps allow the quality loop to be closed based on the global product memory.

ABB Ability™ Operations Data Management zenon securely delivers supervision, control, data acquisition, scheduling and performance reporting on production assets, scaling from single machines to complete production lines. In the ABB-tacteo project, zenon implements the production line control, leveraging its supervision and control functionality and built-in OPC UA connectivity.



The ABB AC500 PLC range provides a reliable and powerful platform to design and create scalable, cost-effective and flexible automation solutions. In the ABB-tacteo project, the PLC provides the machine digital twin and offers a low-cost way to wrap existing machines like the NIR laser behind an OPC UA gateway.

05b



The ABB B&R Automation Panel 900 is an industrial operator interface that fulfills the highest quality demands. In the ABB-tacteo project, the Panel 900 is the default interface for human-machine collaboration on all main production stations.

05c

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 06 Template building blocks for physical machine and its digital twin using OPC UA.

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 07 Material flow and service-based machine-to-machine communication using digital twins. The key message is that services and machines collaborate over an "Intranet of Things" using their digital twins, so everything interacts using the same techniques as the network equivalents.

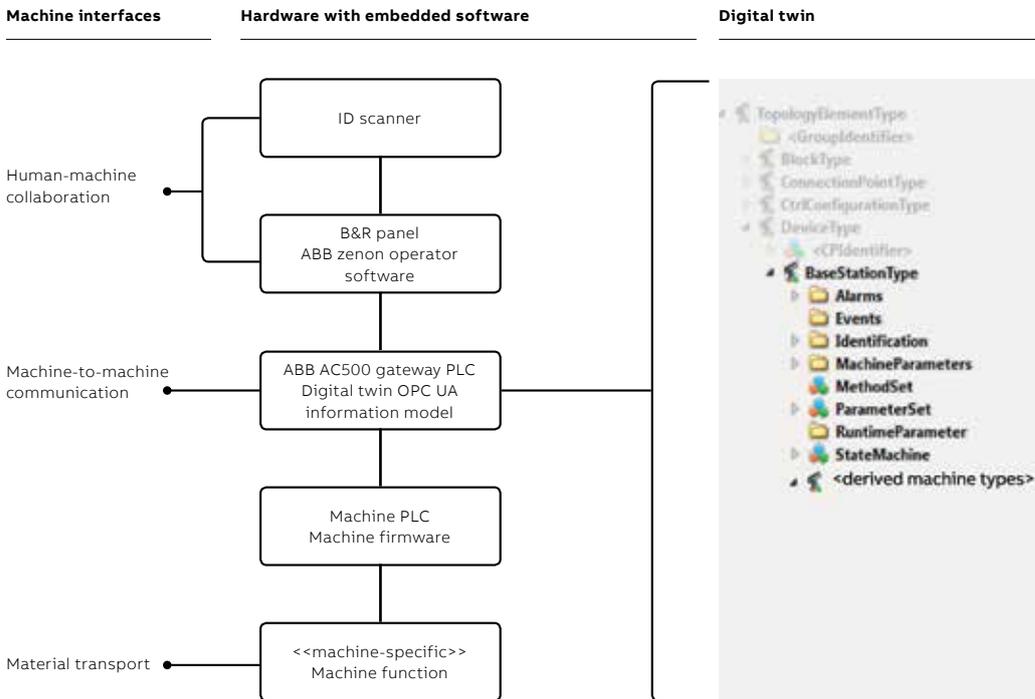
Designing the digital twins

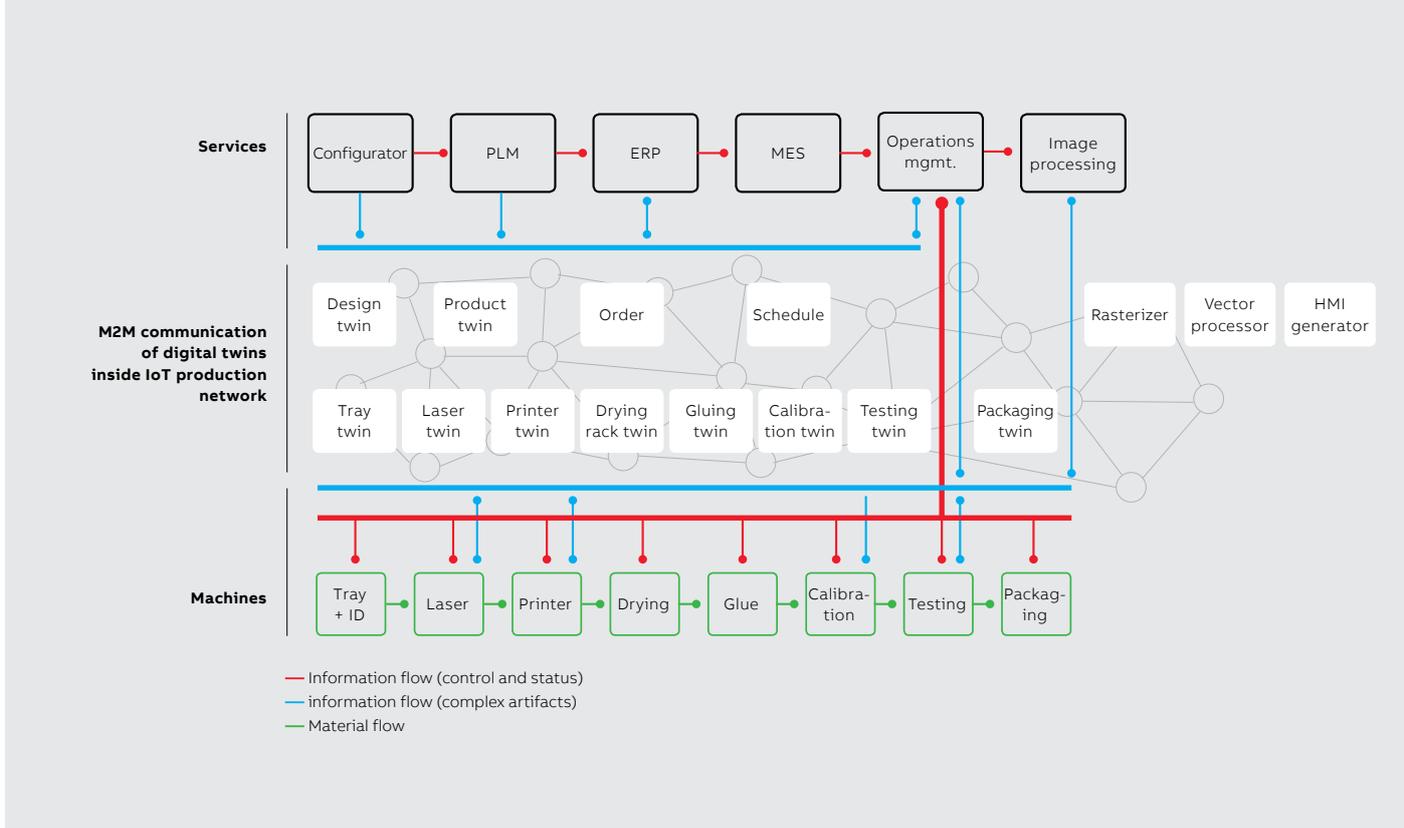
The production process described depends on a mix of very different data: some relate to the product design, some to the manufactured product, some to a specific machine and some describe information common to all products or machines.

—
Specialist machines need to be taught how to work together out of the box.

For example, for each product design, there are machine-independent characteristics such as the layout of the control icons; there are generic machine properties such as the current operating state; and there are properties like the printer calibration data, which are machine-specific but do not depend on the product. Product design is translated into machine-specific artifacts like rasterized icons and there are test results for each manufactured product.

To create these digital twins, the best practice was to first create a top-down OPC UA information model from the perspective of the overall production steps, as shown in the center of →7. Only in a next step was the model split and parts allocated to the individual machines and software services. To upgrade existing machines with this model, the best method was to wrap them using an ABB AC500 PLC →5 as an embedded OPC UA gateway. To this end, close collaboration between information designers, the integrator and the various machine builders was required to ensure the real machines could simply be plugged together in the factory to form the desired production system.





Reference

[1] "ABB-tacteo KNX sensor." Available: <https://new.abb.com/buildings/tacteo>

[2] "Digital twin – the software component of Industry 4.0", in this edition of ABB Review, pp 27-33.

Industry 4.0 for all

Designing the ABB-tacteo production line provided first-hand insight into the needs of machine-builders and production designers on the road to Industry 4.0. Particularly for individualized production, perfect quality control and automated reconfiguration are the key challenges to be addressed by an automation solution. These challenges can be met based on Industry 4.0 concepts such as digital twins, smart products and M2M technologies like OPC UA.

While today, individualized production requires significant up-front investment, future solutions must be covered by established annual investment budgets to be broadly competitive.

To this end, specialist machines need to be taught how to work together out of the box. This requires automation vendors to supply processes, tools and standards that make it easy for production designers, machine builders and integrators to build their digital twins independently and then run virtual integration testing before physical machines are actually built and commissioned in the factory.

Currently, premium products such as the ABB-tacteo

The vision is to offer Industry 4.0 not as a premium product but as an off-the-shelf solution that can be applied to any type of production – from large factories to small and medium-sized enterprises.

KNX control element are welcome catalysts to drive this type of innovation. The vision, however, is to offer Industry 4.0 not as a premium product but as an off-the-shelf solution that can be applied to any type of production, from large factories to small and medium-sized enterprises. ●

AUTONOMOUS COLLABORATION

An integrated building automation solution environment

Continuous digital workflows and unified information modeling are key enablers for efficient workflows, tools and solutions in modern building automation. How do new concepts and technical feasibility studies in the field assist in the transition to the digital era and building automation simplification?



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Building automation – or smart building technology – is a fast-growing market. ABB has a strong position in building automation with, for example, products based on KNX [1], the world's first open standard for the control of industrial, commercial or residential intelligent buildings. ABB is strong in building electrification, too, which allows the company to offer automation and power solutions in one, integrated package. In the future, other domains, such as grid interaction, local power generation and eMobility will become more tightly connected to the building and treat it as the central aggregator of digital information and solutions.

However, commercial buildings such as offices, hotels, or schools, which often have thousands of automation devices, typically do not display much commonality with respect to building automation functionality and electrification. This individuality entails complexity that makes the building costly to plan, engineer, construct, commission, operate and service. Multitechnology and multivendor integration, common in commercial buildings, further increases complexity →1,2.





Further, there are more roles involved over a building's lifetime than just the building owner or occupant – eg, engineering consultants, system integrators, mechanical and electrical installers, and facility managers. These players are often ABB customers and they too must adapt to the increasing complexity, as well as deal with time pressure, inefficient tooling, customer demands for open ecosystems, or new regulatory demands.

Commercial buildings often have thousands of automation devices and typically do not display much commonality with respect to building automation functionality and electrification.

These issues raise the question: What workflows, tools and technologies can be used in building automation to meet all these challenges and support more integrated, time-efficient solutions and open interfaces?

Pains and gains

To answer this question, ABB carried out a research project that focused on the early lifetime phases of the commercial building automation, ie, planning, engineering and commissioning →3. This scope addresses the abovementioned challenges and, therefore, many of ABB's customers' pains. Many aspects of the work are applicable to smart homes, too.

Key customer demands in this phase of the building automation lifetime are:

- Follow the trend of function-based specification
- Support multitechnology and multivendor projects
- Ensure continuity of workflows from design to operations without information loss or need for manual work
- Move toward open but functionally integrated ecosystems

Function-based specification means that during the planning phase, building automation functionality is specified independently of technology, vendors, devices, etc. Such specification is often based on, for example, the VDI 3813 standard [2] for room automation functions.

An open ecosystem allows continuity of workflows because it guarantees interoperability while being flexible and extensible enough for new technologies or technology alliances.

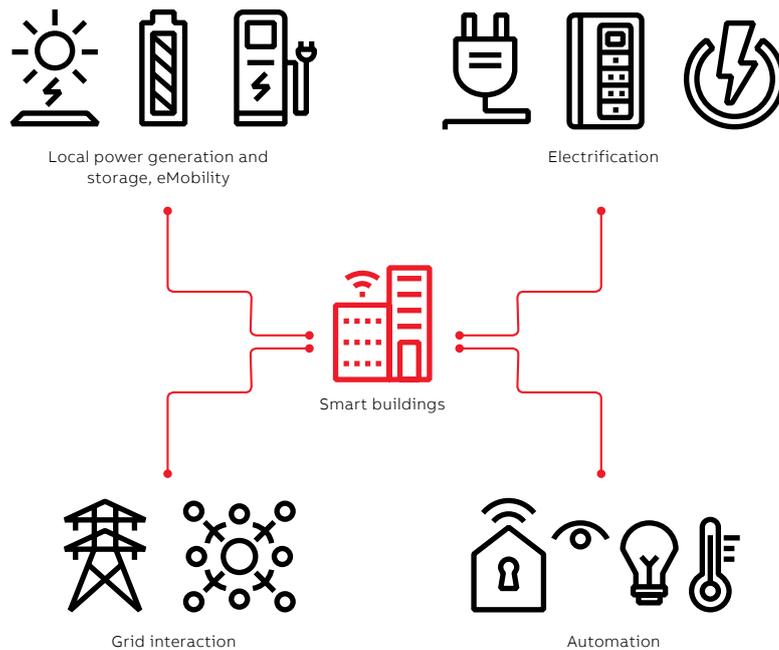
Most building owners, and, therefore, engineering consultants and integrators, want to combine best-in-class solutions to achieve their intended automation functionality. Therefore, different technologies might be chosen, eg, KNX for room automation, BACnet for central heating and ventilation, and ZigBee for retrofit or installation locations that might be costly to wire. On top of all this variation, different vendors might be chosen for different device types.

- The continuity of workflows has several aspects:
- Currently, multiple tools are used from planning through to operations. These tools often do not have well-defined interfaces.
- Handover between roles is often done via paper or pdf documents. Such a transfer cannot be processed automatically.
- Usability is sometimes an issue, especially if multiple technologies and devices from multiple vendors must be integrated – most often across multiple tools.

An open ecosystem allows continuity of workflows because it guarantees interoperability while being flexible and extensible enough for new technologies or technology alliances.

The customer benefits of the ABB proposed solution that emerged from the research project are:

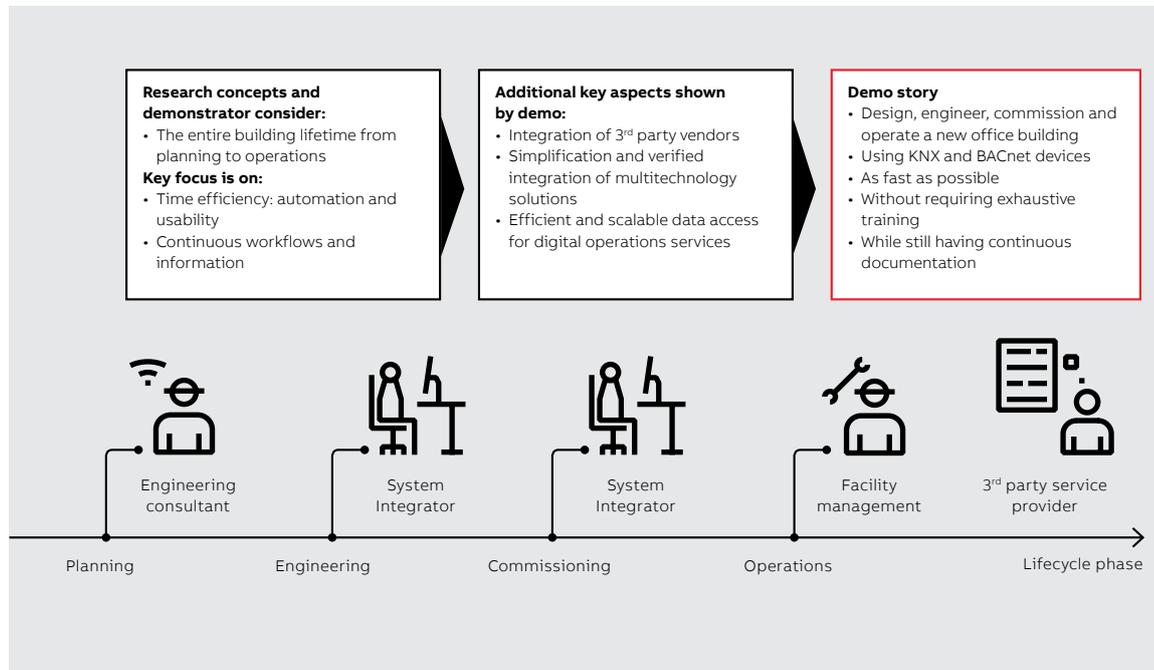
- Functional specifications based on standards
- Increased time-efficiency by automating as many steps as possible
- A continuous tool chain and unified information model to avoid error-prone manual work
- A device package concept offering a standardized way to integrate devices with different technologies and vendors
- A modular software platform with well-defined interfaces to integrate with existing tools, eg, ETS for KNX or cloud services



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01 Because commercial buildings are usually individual, planning their automation functionality can be a complex and expensive business. An ABB research project has explored ways to simplify commercial building automation by supporting more integrated, time-efficient solutions and open interfaces. (Photo: Anthony Byatt.)

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02 Future smart buildings as central aggregator of multiple domains.

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03 Overall storyline and key aspects of the proposed solution.



03

Overall picture of the proposed solution

The key element for all lifetime phases described below is ABB's unified information model (UIM). UIM is a domain model that describes and structures all information required for the lifetime of the building automation system. In addition, it provides various entry points and implementation methods. Entry points are, for instance, building structure, automation functions or installed devices. For the prototype, ABB decided to implement a single instance of the UIM for all lifetime phases with OPC UA (OPC Unified Architecture) [3], while providing additional interfaces.

—
UIM is a domain model that describes and structures all information required for the lifetime of the building automation system.

First, the actual workflow steps from building design to operations, which were common across domains and geographic regions, were clearly defined →4. During the planning phase, common tasks are to define the building structure, automation functionality and, finally, create a tender document. Planning is entirely technology- and vendor-agnostic, as actual devices are not yet considered.

During the engineering phase, the main tasks are to select actual building automation devices that fulfill the given specification and perform a first high-level configuration, eg, dimming levels for light switches or default temperature setpoints for heating actuators. Depending on region, project and customer, the system integrator can choose devices from his own catalog of preferred vendors or get a list of already installed devices from mechanical and electrical installers. This means that the proposed solution must cope with differing implementations of the overall workflow. As actual devices are involved in this step, multitechnology, multivendor integration concepts are required. The main element of the ABB solution in this step is the new device package concept, which enables the mapping from actual devices and their technological details to the functional abstraction of the planning phase in a standardized way.

-  VDI 3813
-  Device packages
-  Custom macros & templates



Planning and engineering tool prototype

Configure KNX



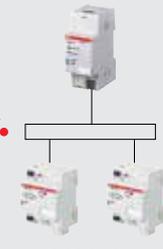
ETS importer app and ETS

Download engineering model and configure BACnet and ZigBee

Automation hub prototype

Download ZigBee and BACnet

Download KNX



Field devices



Engineering consultant



System integrator



System integrator



Facility management



3rd party service provider

Planning

Engineering

Commissioning

Operations

Lifecycle phase

During commissioning, a common task is to perform detailed configuration of the technology-specific parameters as well as the discovery of, and download to, the automation devices. Some technologies have mandatory commissioning tools, such as KNX with its ETS tool. In the ABB

Key elements of the solution are tool prototypes, software platforms, technological artifacts such as the UIM and device packages, as well as existing tools like ETS.

solution, existing tools are directly integrated into the workflow. With multitechnology systems, there is also the need for a device – the “automation hub” – that can understand the different technology segments, translate between them and potentially also execute advanced functionality. The automation hub is part of the operations phase but might also be used to commission technologies like ZigBee, which do not require a separate commissioning tool.

Key elements of the proposed solution

Key elements of the solution are tool prototypes, software platforms, technological artifacts such as the UIM and device packages, as well as existing tools like ETS.

Planning and engineering tool

This tool prototype →5 is based on HTML5 and can be packaged as a Web tool or standalone desktop version. The tool covers most aspects of planning, engineering and commissioning. It allows users to create a building structure and functional specification in a time-efficient way, eg, by offering a library of VDI 3813 function blocks, custom macros, search and filter functions, automatic validation and BIM (building information modeling) import of the building structure. A tender document can be created, or the project can be saved and sent to a system integrator. For the engineering phase, devices can be selected from a catalog by drag-and-drop. Basic channels and semantic parameters can be configured. Time-efficiency and usability are ensured by device search and filter (eg, for technology or vendor), preselection of valid devices for specific function blocks, custom device catalog import, tool tips or template definition. Finally, file export to ETS is offered as well as discovery of, and download into, ZigBee devices.

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04 Overall picture of key elements and interactions.

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05 Functional editor and sidebar of planning and engineering tool prototype.

Device package

To support or automate the selection of devices for a functional specification, this artifact describes a device's functionality and a mapping of technology-specific to semantic parameters. The ABB concept offers a standardized way,

The UIM uses standards like the OPC UA DI model as a basis and defines a small core model with extension points for semantics as well as technologies on top.

based on XML schemas, to create such device descriptions. Moreover, one can reuse and integrate existing information such as KNXprod files, which have simply to be extended with the semantic mapping information. The approach is applicable to various technologies.

Configuration generator

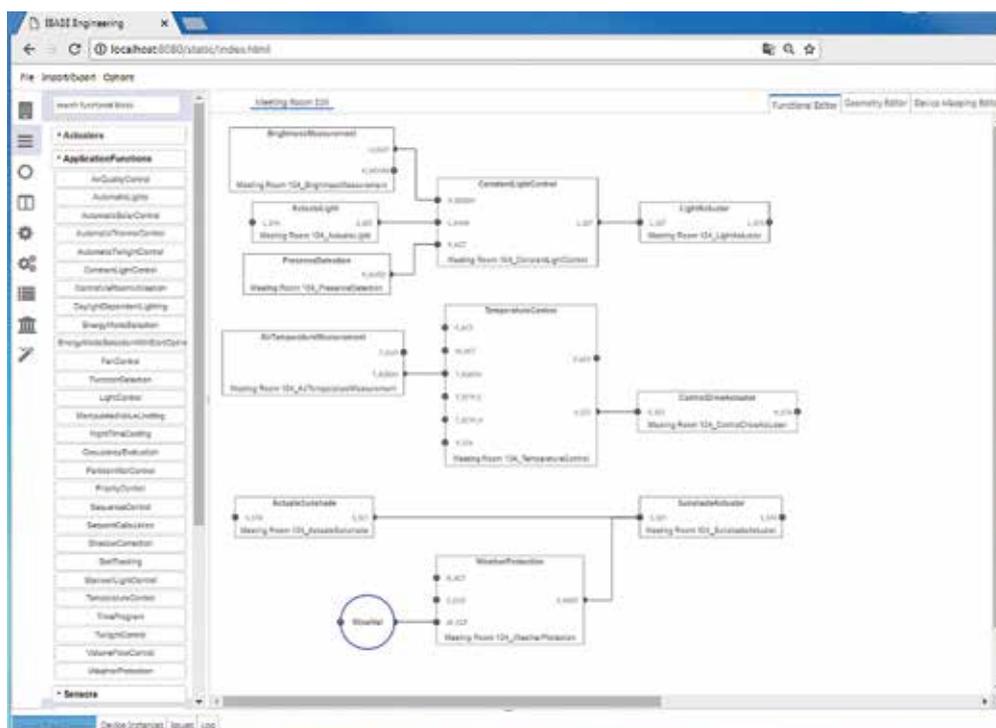
This artifact is part of the planning and engineering tool and fully automates the task of technology-specific configuration, ie, rules and heuristics are implemented to autogenerate a complete, valid and working configuration, eg, for the KNX part of a building automation system.

ETS importer app

This tool prototype takes the KNX-specific export of the planning and engineering tool created by the configuration generator and imports and translates all information into the data model of the ETS commissioning tool, which is mandatory for KNX devices. The design decision is to reuse available tools but also to allow a user to adapt the autogenerated configuration before download if needed.

UIM

This artifact provides a structural model of all required information and ensures understandability and portability of information by its well-defined structure, entry points and semantics. The UIM uses standards like the OPC UA DI (device integration) model [4] as a basis and defines a small core model with extension points for semantics as well as technologies on top →6. Thereby, it is modular and maintainable while still open and extensible; and it supports usage of multiple semantics and technologies in parallel. ABB implemented the UIM into an OPC UA server and is using it over the entire lifetime of a building.



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06 Unified information model architecture with extension points.

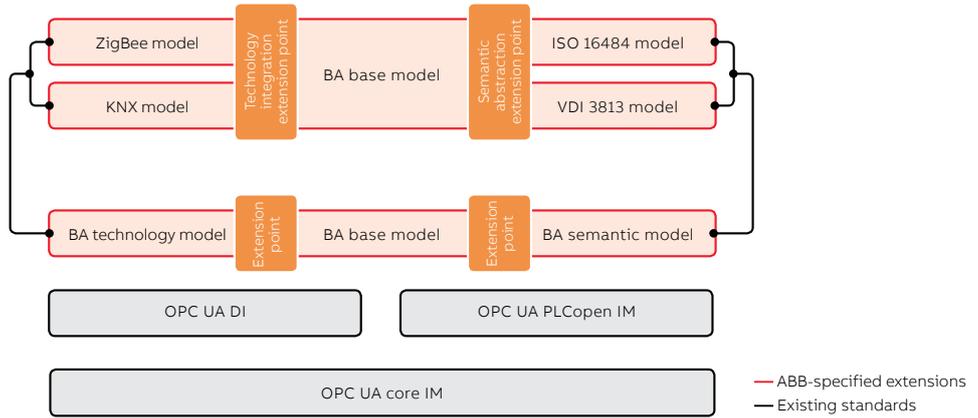
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06

Automation hub

This tool prototype is a modular and flexible software platform with the UIM as its core module. The automation hub wraps the OPC UA server with various interfaces such as REST or oBIX for easy integration, eg, into cloud services. It can be packaged with additional modules for advanced services as a full platform for the operations phase and can be executed, for example, on a Raspberry Pi Model B+. Alternatively, it can be packaged as a single module together with the planning and engineering tool and then transparently store and provide all required information without the user knowing it is there.

Feasibility study and demonstrator racks

All the concepts and key elements mentioned have been implemented and integrated into a demonstrator rack to validate feasibility and allow discussion with project stakeholders. The rack

The automation hub is a modular and flexible software platform with the UIM as its core module.

represents a meeting room in an office building that is equipped with advanced automation functionality such as constant light control, heating and ventilation, presence detection, and window sensors. The installed devices are from multiple vendors and use KNX (lighting, user interface, presence detection), BACnet (heating and ventilation control, user interface), and ZigBee (window sensor) as different technologies to ensure relevance and heterogeneity. The entire planning and engineering was performed with

the prototypes described above. For KNX, the automatic configuration was used. For BACnet and ZigBee, the discovery and download feature of ABB’s tool prototype was used, which means that only the standard profiles and objects of those technologies were used. It should be mentioned that the prototypes still apply some simplifications and are not fully-featured but focus on most challenging key features.

First customer demonstration and feedback sessions confirm that the proposed concepts and feasibility studies address actual customer challenges and that customers see valuable benefits in these concepts for their daily work as well for mastering the transition into the era of digitalization. Future research work will address topics not in the present project scope, such as integration with electrification, model life cycle management or addition of features required by specific technologies, market segments, or user roles.

Acknowledgments

This article would not have been possible without the ideas, work, and dedication of the entire project team and project stakeholders. Special thanks to Roland Braun, Florian Kantz, Somayeh Malakuti, Johannes Schmitt, Katharina Stark, Michael Vach, Retus Cathomen, Jens Czudai, Dirk John and Christian Lehnert. ●

AUTONOMOUS COLLABORATION

Digital twin – a key software component of Industry 4.0

A key enabler for Industry 4.0 is the “digital twin,” which allows the simple acquisition and exchange of data, access to a far greater variety of information than today and unprecedented interoperability out of the box. What are the latest developments in the rapidly evolving world of digital twins?

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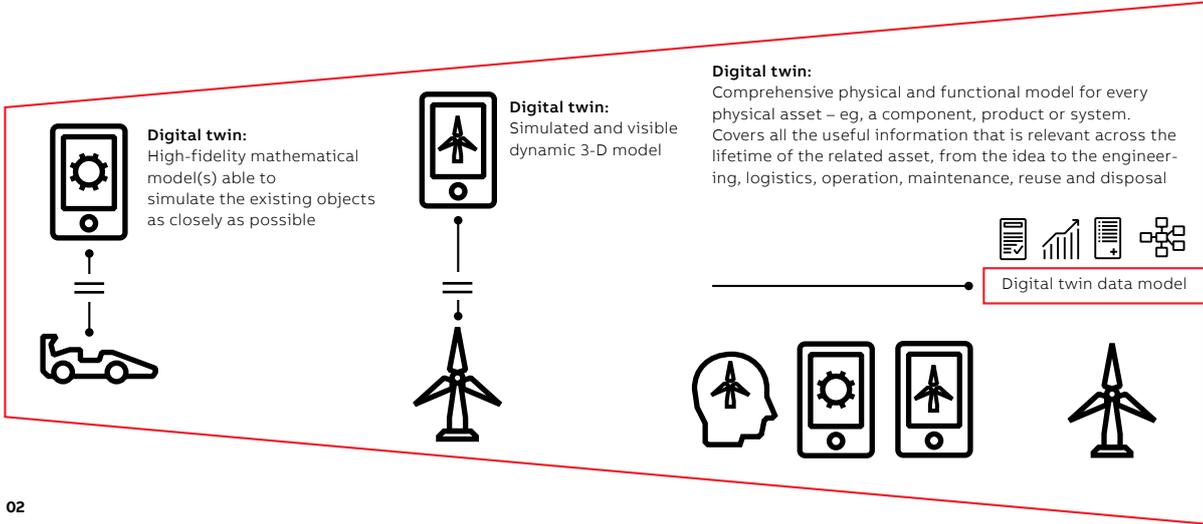
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02

Industrial Internet of Things (IIoT) systems enable the connectivity of numerous heterogeneous devices and other assets into one system to derive more intelligent actions from data. The application of the IIoT in industrial production systems is

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One key enabler for Industry 4.0 systems is the concept of a digital twin.

known as Industry 4.0. The German government, in particular, has recognized the importance of Industry 4.0 (“Industrie 4.0” in Germany; the two terms are often used interchangeably) and is continuously investing in academic research and industrial trials.

One key enabler for Industry 4.0 systems is the concept of a digital twin. A digital twin not only facilitates the acquisition and exchange of, and greater access to, a far wider variety of data than has heretofore been the case but also delivers previously unseen interoperability out of the box →1.

The definition of a digital twin is evolving [1]. It is, therefore, instructive to review the current state of research on the topic, explore the work of German “Plattform Industrie 4.0” and examine some use cases in which the digital twin is the key enabler.

The definition of the digital twin

As depicted on the left side of →2, the digital twin was initially considered to be a set of high-fidelity mathematical models that reflect the behavior of the real assets (eg, physical devices, plants and services) as closely as possible [2]. This perception evolved to include the simulated and visible dynamic 3-D models of real-world assets (center of →2). Currently, the digital twin is defined as “an evolving digital profile of the historical and current behavior of a physical object or process that helps optimize business performance. The digital twin is based on massive, cumulative, real-time, real-world data measurements across an array of dimensions” [3] →3. This information is completed by metadata, properties and documents such as reports, documentation, or operating procedures generated during all life cycle phases of the asset.

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01 The world of manufacturing is being fundamentally changed by the advent of the IIoT. A key component of this change is the digital twin.

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02 The evolution of digital twin definition (based on [1]).

—
03 Information dimensions that may be included in the digital twin of a device during its lifecycle phases (based on [4]).

The real value of the digital twin is unlocked when it interacts with other digital twins or software tools →4. While the digital twin on the manufacturer site contains various models for designing and manufacturing a product type, the digital twin on the customer sites contains various models to buy, install, operate, maintain and dispose of the product instances. Data exchange between digital twins completes the picture for both parties involved.

Digital twins in the lifecycle of Industry 4.0 plants

The digital twin is a key enabler of the benefits of Industry 4.0 because it ties information to the individual asset in the plant. With context-specific information available at the right time in the right place, it is possible to enable new use cases that are not possible with static, non-individualistic documentation and data. →5 shows ABB’s vision for design, construction and operation of Industry 4.0 plants and the role of the digital twin in each phase [5].

In Step 1, a complete digital model of all planning results must be developed (this is not the case in Industry 3.0). Implicit knowledge and assumptions of the planning engineers are explicitly modeled and stored in the digital twin of the plant. The devices required are selected by humans out of a digital role library and are linked to the plant’s digital twin. The roles are abstract and hardware-independent; in later phases, real devices will be fulfilling some specified roles.

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The digital twin ties information to the individual asset in the plant.

In Step 2, the manufacturers’ catalogs of available product types are accessible electronically and can be explored via standard interfaces. These catalogs maintain the digital twin of product types, which cover all life cycle aspects of the types and realize a standard interface for accessing the information.

In Step 3, the selected product types are instantiated and the information relating to them (identification, parameters etc.) is included in the digital twin of the product instances. The digital twins of product instances are included in the digital twin of the plant and are linked to the digital twin of product types. The digital twins of product instances can be used – eg, for simulation and testing, based on plant topology. The results of the simulation are, again, maintained in the digital twin of the product instances.

	Plan	Build	Operate	Maintain
Product lifecycle information	PLM	PLM	Operation instructions	Service records
3-D representation	Design drawings	Manufacturing instructions	Plant visualization	Service instructions, augmented reality
Model	Behavior prediction	Virtual commissioning	Control performance	Diagnostics
Simulation	Design simulation	Hardware-in-the-loop tests	What-if studies	Prediction
Data model	Engineering data	Manufacturing data	Operational data	Service data
Connected analytics			Operational KPIs	Asset health KPIs
Visualization	Design tool	Design tool	Operational state display	Health status display

—
04 Interaction between various digital twins.

In Step 4, utilizing the digital twin of product instances, the real products are ordered. Here, order-relevant parts of the digital twin are communicated to the product vendor. The product is, later on, integrated into the plant, configured, tested and put into operation. In this phase, the digital twins are enriched with installation and commissioning information, placement of devices, serial numbers, etc.

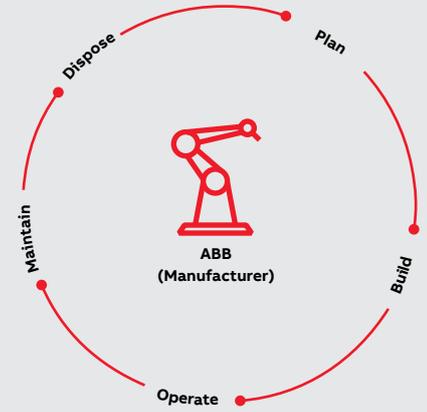
In effect, the digital twin of an asset matures during the life cycle of a plant, with every step adding information submodels.

In Step 5, the digital twin of individual product instances, as well as the plant, are supplemented with operational and maintenance information. For example, real-time parameters, health status and number of failures are added. In “Platform Industry 4.0,” the digital twin (known as the “administration shell” [6]) organizes information for a use case into submodels, which contain properties, files, method calls, external links or other data for that use case.

Each step described above enriches existing submodels or adds new submodels for that use case.

The digital twin as the enabler for Industry 4.0 use cases

A digital twin makes various use cases feasible in a more efficient way. In the following, some example use cases are discussed.



Plan

- Design ideation
- Design optimization
- Predictive design

Build

- Predictive engineering analytics
- Virtual commissioning

Operate

- Remote monitoring
- Remote operation

Maintain

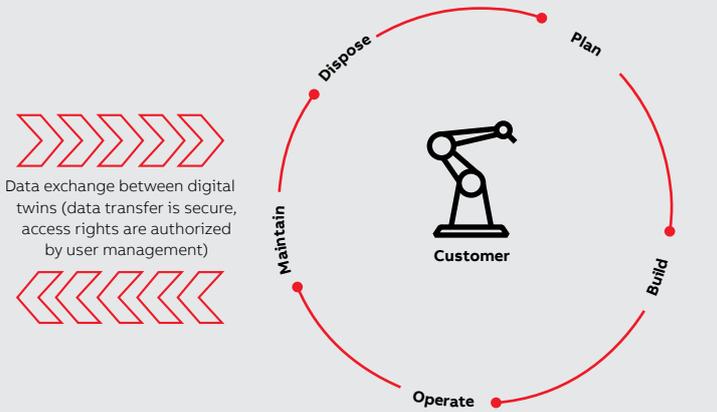
- Virtual inspection
- Data-based service
- Asset performance management
- Predictive maintenance
- Root-cause analysis

04

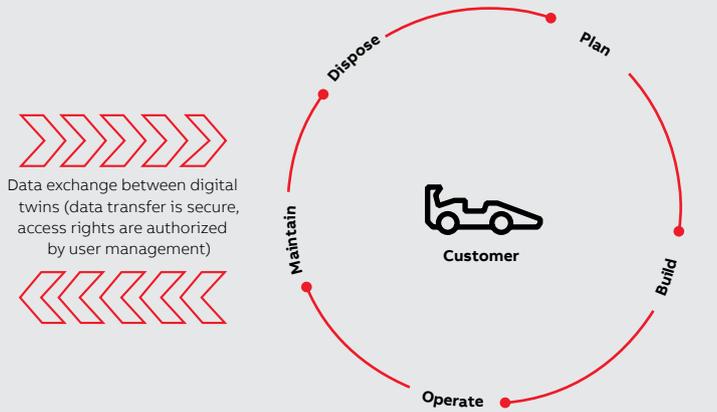
Use case: integrated engineering, integrated operation and integrated maintenance

During the lifecycle of a product, various information sources, models and tools become relevant →3. However, currently, the information flow within or across lifecycle phases is usually broken – eg, the maintenance information cannot easily be fed back to the engineering phase to better tune the parameters of a device. This broken information thread results in a scattering or even loss of information as well as difficulties in accessing the correct information.

A digital twin is the container for integrating information from various sources in different phases of the lifecycle. The information included may be in different formats from different tools and not necessarily be deployed in one central repository. A digital twin helps to reduce the effort required to access and manage information – eg, it can obviate the need for manual maintenance of engineering documents to reflect on-site changes during operation. The information contained in a digital twin can be used to learn from the current performance of assets and derive a rating for future systems.



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|--|---|
| <p>Dispose</p> <ul style="list-style-type: none"> • Replacement <p>Plan</p> <ul style="list-style-type: none"> • Acquisition • Production planning <p>Build</p> <ul style="list-style-type: none"> • Predictive engineering | <p>Operate</p> <ul style="list-style-type: none"> • Operator support <p>Maintain</p> <ul style="list-style-type: none"> • Asset performance management • Reliability management • Predictive maintenance • Root-cause analysis |
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| <p>Dispose</p> <ul style="list-style-type: none"> • Warranty <p>Plan</p> <ul style="list-style-type: none"> • Design ideation • Design optimization • Predictive design <p>Build</p> <ul style="list-style-type: none"> • Predictive engineering analytics • Virtual commissioning | <p>Operate</p> <ul style="list-style-type: none"> • Remote monitoring • Remote operation • Production planning and tracking <p>Maintain</p> <ul style="list-style-type: none"> • Maintenance planning • Fleet monitoring • Root-cause analysis |
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Use case: predictive product design, manufacturing and analytics

Currently, it is not feasible to exchange information across organizations in a seamless way. For example, information about the behavior of a product sold by ABB in the customer's environment is only visible for the type designer if the customer sends warranty claims or shares service reports created by service engineers, or the customer explicitly shares feedback to the vendor, eg, via a salesperson. However, all these sources are incomplete and possibly inaccurate, meaning that the product type designer has only limited and uncertain information available for the design of the next-generation product.

The digital twin is seen as the key enabler to exchange information across organizations – for example, selected operational and maintenance information about an asset can be managed within the digital twin and exchanged with external parties in an appropriate way. Particularly the process data and models provided in a digital twin, as well as the real-time simulation results, help to predict the requirements and improve the design for the next generations of asset types. Predictive analytics help manufacturers to confidently calculate future challenges. In this use case, the digital twin approach allows continuous improvement of the asset type designs, based on real data.

Use case: plug-and-produce for field devices

Today, deriving the correct configuration for field devices from an existing process design requires manual work. Standardized description formats are sometimes not used. Where they are used, they may still not be openly shared, or when shared the underlying standards in process and automation design may differ in how they express the same information. The flow of information can be cut at all points where data are forwarded.

Furthermore, using Fieldbus technology, the discovery, addressing, identification and online configuration of devices is a largely manual and error-prone task. In addition, measurement points, field devices, signals, etc. typically have different names or identifiers across the different tools. As a result, a manual mapping is typically required to achieve the correct associations. Above all, if a device should require replacement during plant operation, these commissioning steps need to be redone.

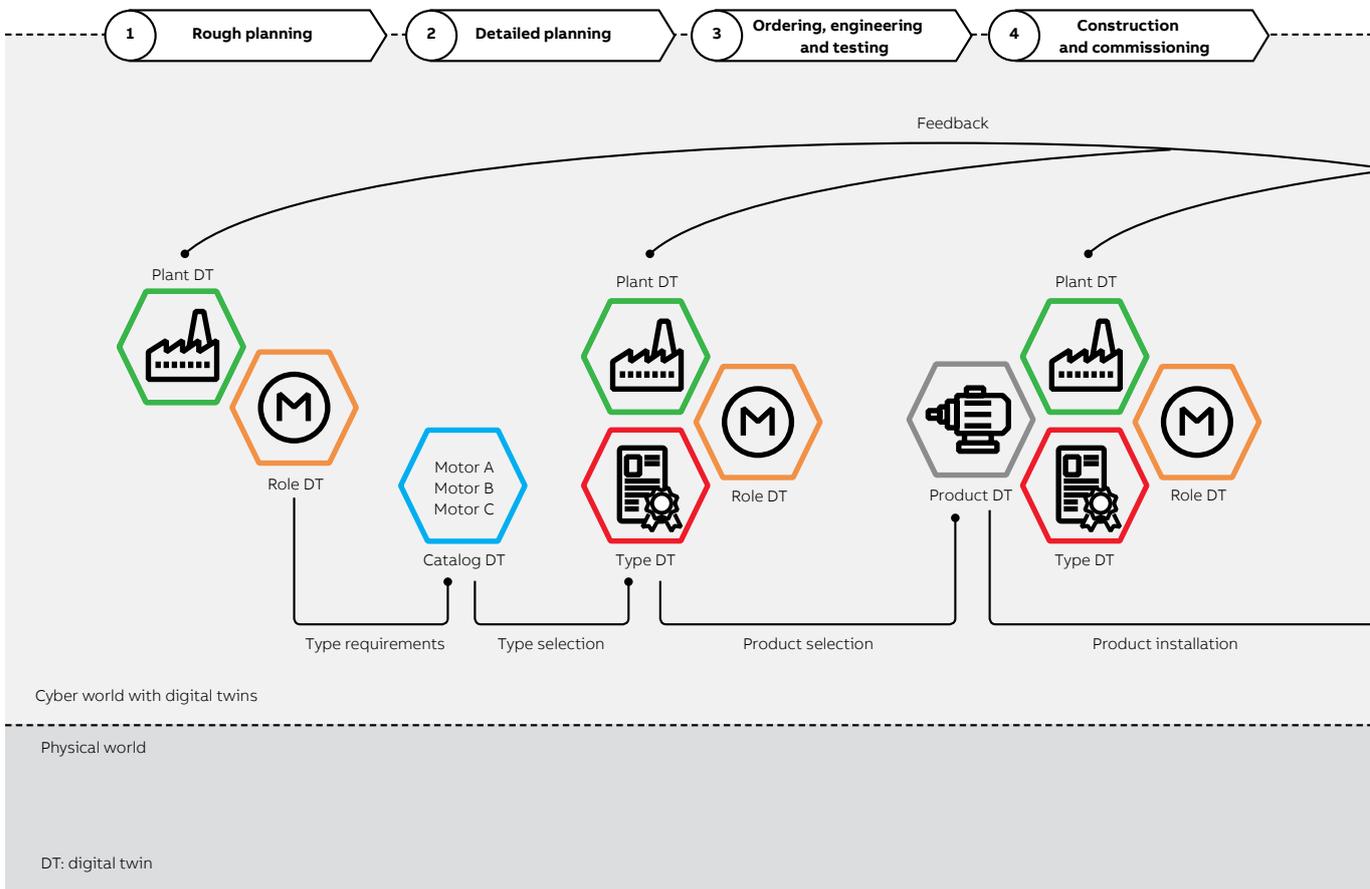
Technologies such as FDI (field device integration) and OPC UA (OPC unified architecture) already mitigate many of the issues of device commissioning. The digital twin for field devices

The digital twin reduces the time for the basic engineering and commissioning of a field device from some 10 minutes (provided no issues occur) down to fractions of a second.

builds upon these technologies and enables a plug-and-produce scenario for the field devices. By incorporating further standards from the ICT (information and communication technology) and automation domains – in particular by including recommendations from customer interest groups such as NAMUR – the digital twin consolidates all information needed for the engineering,

commissioning, use and replacement of field devices in a uniform manner. The link between the digital twin and its physical counterpart enables the operators to automatically download parameters to the field devices and bring them into operation. While the physical replacement still requires trained personnel, the digital twin allows instant reconfiguration without the need for a device or process expert.

Most obviously, the digital twin reduces the time for the basic engineering and commissioning of a field device from some 10 minutes (provided no issues occur) down to fractions of a second. For an average-sized plant with 10,000 I/O points, the work of a week is reduced to a few minutes.



05 The digital twin in Industry 4.0 plants.

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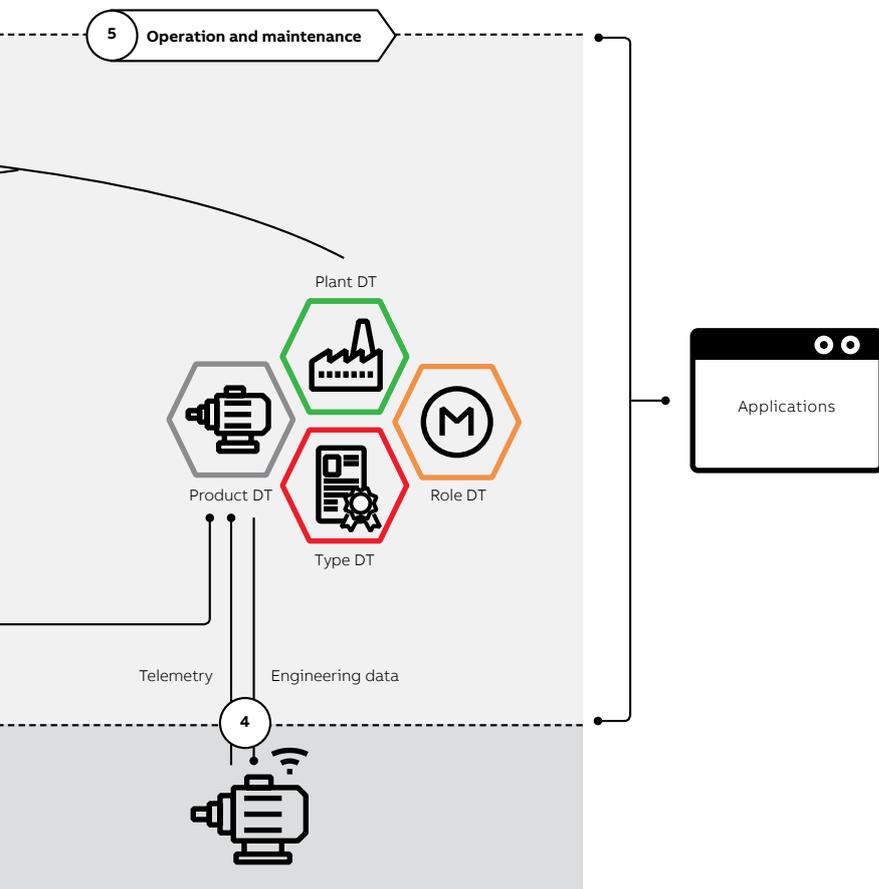
By maintaining the information flow across lifecycle phases, the systematic reuse of existing information from the original process design is potentially of even greater value. The configuration of a field device becomes a direct consequence of the intentions of the process engineer; the reason for any configuration can be objectively and automatically traced to a customer requirement. This situation increases the quality of engineering data because errors are confined to the original process design.

As the IIoT gains traction, digital twins will become a cornerstone of industrial automation.

The digital twin at ABB

Due to the significant role of the digital twin in Industry 4.0, its various aspects are being investigated by research projects in ABB. For example, the BaSys 4.0 [7] project, of which BMBF (German Ministry of Education and Research) are cofounders, unites 15 industrial and academic partners. The main goal of the project is to develop a reference open platform in which the digital twin is the key enabler to achieve flexibility in industrial manufacturing and process industries.

As the IIoT gains traction, digital twins will become a cornerstone of industrial automation. The ability to implement effective digital twins will be a critical skill in writing the digital future of the automation landscape. ●





Partnersh



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Successful partnerships go beyond collaboration to achieve true integration of purpose and processes. Innovation isn't just an outcome, but a tool for getting things done.

36 Digital innovation driven by university collaboration

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PARTNERSHIPS

Digital innovation driven by university collaboration

There is much value in combining the streams of data that flow from subsystems in a typical industrial process. ABB's university collaborations address the challenges involved in exploiting this data and equip researchers with the knowledge needed to continue to deliver digital innovations.

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Modern large-scale processes have become increasingly complicated over the decades and now often consist of many, complex process, mechanical and electrical subsystems. Automation

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ABB has been working closely with top universities over the last years to address the challenges involved in complex systems.

schemes treat these subsystems as an integrated whole, so the need arises to close information loops between them. However, because such subsystems now generate a vast amount of data, the efficient and sustainable operation of assets over their, typically, 30- to 50-year lifetime requires sophisticated and holistic concepts to manage information and resources. ABB has been working closely with top universities over the last years to address the challenges involved in creating such concepts.



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01 Imperial College London, aerial image of the South Kensington campus. Imperial is just one of the universities with which ABB is collaborating to address the digitalization challenges faced by process industries. Photograph © 2018 Imperial College London.

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Footnote
1) This project has received funding from the European Union's FP7-ITN research and innovation program under the Marie Curie grant agreement contract number PITN-GA-2010-264940.

ABB and Imperial College London

ABB's university collaborations address the digitalization challenges of the process industries at a fundamental level. For example, ABB and Imperial College London work together on a program of projects to manage industrial process information and resources so data insights can be converted into direct action in the physical world →1. The approach adopted by the program is characterized by its focus on improving efficiency in the huge installed base of process plants – chiefly by optimizing the operation of process equipment using techniques that include the prediction, detection, diagnosis and elimination of the root causes of process inefficiencies. The work has been undertaken by Imperial College researchers, ABB research engineers on secondment to the university and Ph.D. students sharing their time between Imperial College and industrial placements with ABB and other collaborating companies.

The fact that ABB has sponsored the Chair of Process Automation in the Department of Chemical Engineering at the university – where much of this work takes place – since 2007 shows how close the collaboration is.

—
ABB and Imperial College London work together to manage industrial process information and resources so data insights can be converted into direct action in the physical world.

ABB in European projects

The Energy-SmartOps ITN (Innovative Training Network)¹ ran from February 2011 to January 2015 and focused on integrated control and operation of processes, rotating machinery and electrical equipment →2.



02



The project was coordinated from Imperial College and involved ABB, end-user companies such as BASF and Equinor, and several universities (Imperial College, Cranfield, ETH Zurich, Politechnika Krakowska, and Carnegie Mellon). Energy-SmartOps generated and tested monitoring systems that integrate multiple measurements from the process, mechanical and electrical subsystems. Energy-SmartOps closed the loop with performance monitoring and control by capturing information from all three subsystems and devising new algorithms that explicitly manage the interfaces and interactions between them. An ITN is a doctoral training program and Energy-SmartOps has launched a cohort of well-qualified researchers with PhDs – as well as industrial training – into the areas mentioned above.

—

Energy-SmartOps generated and tested monitoring systems that integrate multiple measurements from the process, mechanical and electrical subsystems.

The REAL-SMART IAPP (Industry Academic Pathways and Partnerships)² scheme started in September 2010 and ran for four years. Its contribution to digital innovation was in measurement-based monitoring and management of electrical grids and the industrial loads they supply.

It also was coordinated from Imperial College and involved transmission system operators (Fingrid, National Grid and Statnett), companies that supply technologies (ABB and GE) and universities (Aalto University, Imperial College London, Graz University of Technology). The interdisciplinary consortium had experts in electrical power systems, modeling, instrumentation, signal analysis, condition monitoring and the automation of oil, gas and chemical processes.



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02 The EU Marie Skłodowska-Curie schemes supports Energy-SmartOps. (SmartOps banner © 2018 Imperial College London; Marie Curie banner © European Union).

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03 ABB control room.

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Footnote

2) This work was supported by the Marie Curie FP7-IAPP project, "Using real-time measurements for monitoring and management of power transmission dynamics for Smart Grid REAL-SMART," contract number PIAP-GA-2009-251304.

The IAPP scheme financed exchanges of researchers between industry and academia. REAL-SMART gave early-stage researchers from university partners a first taste of industrial research and development during their Ph.D.s and provided refreshers for experienced researchers with secondments in both directions between the industrial and academic partners.

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The ABB control room at Imperial College is housed in the Carbon Capture Pilot Plant in the Department of Chemical Engineering.

The European Union supported these joint activities through the Marie Skłodowska-Curie schemes.

ABB demonstrators

Of particular note is the ABB control room at Imperial College →3. This comprehensive facility is housed in the Carbon Capture Pilot Plant in the Department of Chemical Engineering →4. An agreement between ABB and Imperial gives the university access to advanced control and instrumentation technology, as well as services and support for the installation. In return, ABB has access to the pilot plant for customer demonstrations and training, and trials of new technology – all in the center of London. A second demonstrator unit is in the making. Last year, ABB signed a memorandum of understanding to explore opportunities for the creation of a unique digital power network demonstrator unit incorporating ABB Ability™, ABB's unified, cross-industry digital capability.

03



Next-level process network optimization – PRONTO

ABB participates in the PRONTO (PROcess NeTwork Optimization) project³. PRONTO is a European Industrial Doctorate program funded by the Marie Skłodowska-Curie Actions scheme under EU Horizon 2020 →5. The consortium partners include leading universities such as Imperial College London, TU Dortmund, the Norwegian University of Science and Technology, AGH University of Science and Technology, Cranfield University, the University of Valladolid and Carnegie Mellon University, as well as companies with good reputations for innovation such as BASF, Petronor, Equinor, Acciai Speciali Terni and INEOS.

PRONTO focuses on process network optimization for the efficient and sustainable operation of Europe's process industries, taking machinery condition and process performance into account.

The research topics in the project are:

- Data analytics for assessment of the condition and performance of networks of process industry production equipment.
- Optimization of resource use in process networks, taking account of real-time information about the condition and performance of the process equipment.
- New concepts for process operation identified as having high potential for impact by industrial partners.

The consortium offers early-stage researchers training under the European Industrial Doctorate scheme by involving the non-academic sector extensively in joint supervision of the doctoral training. There is a strong emphasis on industrially relevant Ph.D. projects that lead to practical demonstrations. Collaboration manifests itself in a wide range of forms: from knowledge transfer and shared case studies to joint publications and face-to-face brainstorming sessions during project meetings.

—

One solution brings together probabilistic approaches into an innovative analytics structure to provide a transparent, flexible, modular and scalable condition monitoring framework.

The PRONTO project continuously delivers innovations in process optimization and analytics technology. One such development aims to combine quantitative and qualitative data from diverse sources for process monitoring to enable more reliable and robust condition assessment →6. The motivation for this research is that industrial processes and machinery generate a variety of data from disparate sources, each of which may potentially be a valuable source for process monitoring. Different sources of information may be used to monitor the state of health of systems with each source or sensor typically being better suited to diagnosing different faults. Monitoring approaches that fuse data from multiple sources have the potential to diagnose a greater number of faults with greater accuracy and reliability.

04



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PRONTO 
 PROCESS NETWORK OPTIMIZATION

—
04 Carbon Capture Pilot Plant in the Chemical Engineering Department. Photograph © 2018 Imperial College London.

—
05 The PRONTO project focuses on process network optimization.

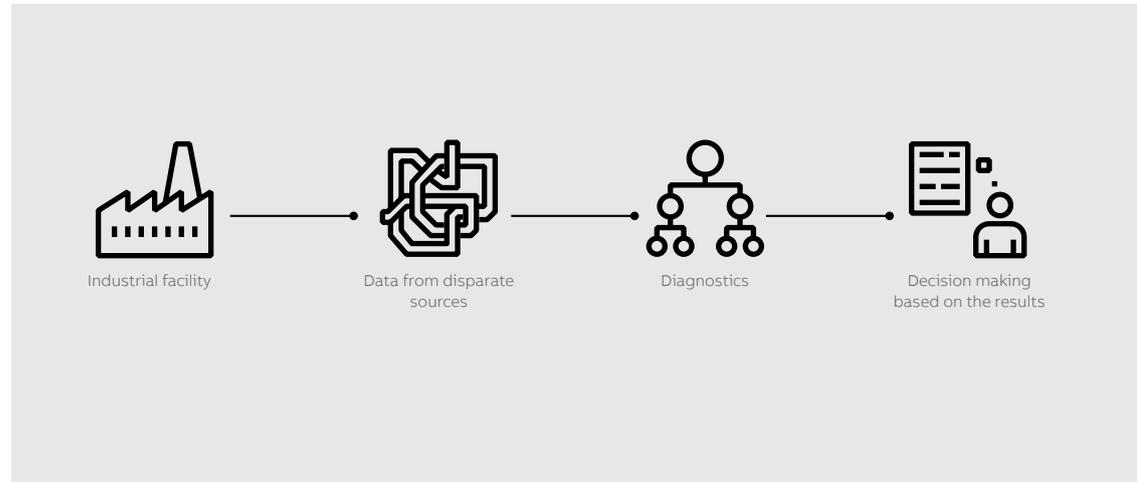
—
06 Disparate data can be combined to deliver more robust and accurate monitoring.

Reference

[1] A. Stief et al., "Two stage data fusion of acoustic, electric and vibration signals for diagnosing faults in induction motors," *Elektronika ir Elektrotechnika*, vol. 23, no. 6, pp. 19–24, 2017.

Footnote

3) This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement number 675215.



06

Another development recognizes that new condition monitoring techniques are needed to tackle the new challenges of big and heterogeneous data. One such solution brings together probabilistic approaches, such as Bayesian inference and multivariate statistical analyses, such as principal component analysis, into an innovative analytics structure to provide a transparent, flexible, modular and scalable condition monitoring framework. As well as fusing data from multiple data sources to achieve accurate fault diagnosis, the method allows the end user to trace the decision-making process back to the root cause and identify which signal types contributed to the decision [1]. This solution is just one of many currently being developed in the project.

Digitalization and collaboration

Digitalization will dictate the specifications of the next generation of products, systems and services. It also has the potential to revolutionize and reinvigorate already-existing and well-established applications. Next-level digital solutions will allow the performance of existing plants to be monitored more accurately, more reliably and holistically, allowing assets and resources to be managed in a more informed manner.

However, there are some challenges: Growing volumes of data from process subsystems demand better ways of combining information from disparate sources. Further, as more systems produce more data, the traditional boundaries between different process, mechanical and electrical subsystems are less meaningful, necessitating a multidisciplinary domain understanding of the interactions between different elements.

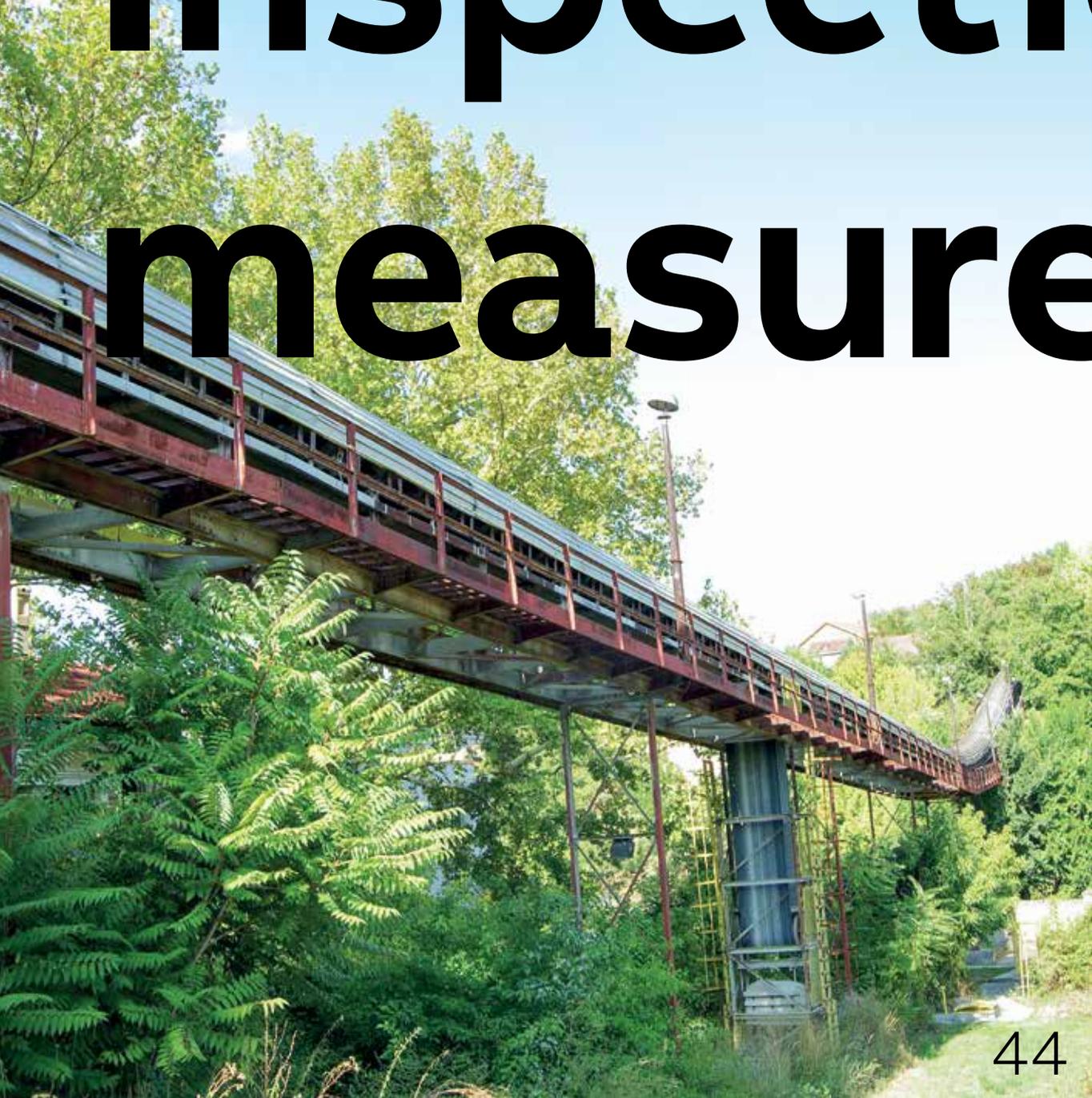
To address many of these challenges, ABB continues to engage in various collaborative projects with leading universities and innovative companies. The knowledge and experience shared during such collaborations allow industry-relevant

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Next-level digital solutions will allow plant performance to be monitored more accurately, more reliably and holistically, allowing assets and resources to be managed in a more informed manner.

challenges to be solved with cutting-edge digital technologies. Furthermore, and perhaps of even greater value, such academic-industrial collaborations are providing the next generation of talented researchers with the training and experience needed to continue to deliver such digital innovations in the longer-term future. ●



Inspection measurement



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n and ment

Detecting operational anomalies in distant physical locations, complex environments, and in ever-smaller gradients of change requires new ways of seeing and interpreting real-time performance data. ABB is implementing these solutions in industries like mining, oil & gas, and power transmission.

- 44 ABB Ability™ Conveyor roller inspection services
- 50 Cloud-based multiphase flow measurement
- 54 Opportunities for electrical sensors



54

INSPECTION AND MEASUREMENT

ABB Ability™ Conveyor roller inspection services

Unplanned downtime of the belt conveyors, widely used in mining, causes significant costs and production losses. Whereas ABB offers condition monitoring for conveyor motors, drives, belts, and transformers, the many thousand rollers that carry the belt and the load remained largely unmonitored – until now.

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—
01 Conveyors are widely used in the mining industry in all climate zones as well as underground. Monitoring the condition of the many thousands of idlers effectively and economically can bring great benefits.

Low market prices for many mined commodities are driving miners to maximize their efficiency. The reliability of key pieces of equipment is a critical factor in this effort. One strategy to achieve reliability is to introduce tools and services for intelligent process monitoring, analysis and optimization. The conveyor belt systems that are often so essential to mine operations are already usually equipped with monitoring tools and services for motors, drives, belts, and transformers. However, the many thousand rollers, or idlers, that carry the belt and the load have, until now, been largely excepted from this monitoring world.

—
Past attempts to measure idler degradation using vibration and temperature sensors at or inside the idlers were unreliable.

The problem with idlers

While noisy idlers can infringe noise emission regulations, failing idlers not only waste energy but also cause excessive belt wear and misalignment – or, in the worst case, belt rupture or fire. All these factors also present risks for personnel.

Belt conveyors are found in all climate zones, in low- and high-altitude locations and underground →1. Belts are usually several kilometers long, have a capacity of several thousand tons per hour and run at several meters per second. Such conveyors have tens of thousands of idlers →2,3. A basic problem of idler degradation detection is that degradation has various symptoms – such as ultrasound emissions and warm idler bearing faces – that call for multiple sensing technologies. Past attempts to measure idler degradation using vibration and temperature sensors at or inside the idlers were not shown to reliably detect wear and failure, or, indeed, to be any more reliable than the idlers themselves, given the harshness of mining environments.





02

A new idler service

ABB found that a combination of ultrasound and thermography snapshots, taken on a regular (eg daily) basis provides rich and sufficient information to catch idler degradation long before failure. This approach is similar to the current practice of inspection walks by conveyor operators but with much better consistency and data quality because operators often only use hearing or handheld thermal cameras and personal judgement. The current common practice of manual inspection is not only costly and inconsistent but is also hazardous.

ABB has now developed a system that will do the idler inspection job not only fully automatically and very consistently but also with higher sensitivity and better cost-effectiveness than manual inspection. This new service works with an automatic vehicle that carries the sensors, thus allowing repeatable, fast and safe inspections.

The service is called ABB Ability Conveyor Roller Inspection Services (CRIS). CRIS targets all global mining and metals companies and their conveyor installations. CRIS can be offered as a standalone item or as a complement to other ABB conveyor services. The service provides automated monitoring of all idlers and detects failed idlers or predicts failure ahead of time. This latter feature is achieved by rating the condition of individual

—
ABB has now developed a system to inspect idlers fully automatically, consistently and with higher sensitivity and better cost-effectiveness.

idlers on a performance curve →4 and finding idlers in the initial stages of degradation, early in the potential failure (P-F) interval. This allows the identification of idlers that need to be cleaned, greased or replaced during the next planned shutdown.

Vehicle and rail system

Besides supplying the correct sensor technologies, a major technical challenge is to position the sensors automatically, accurately and reliably. Since, as a minimum, thermography and ultrasonic recording are needed, a fixed installation is not an option, for cost reasons if nothing else. Instead, the sensors have to be brought to the scene regularly and remain there for the short duration of snapshot recordings.



03

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02 Belts can have lengths of several kilometers and several thousand idlers.

—
03 The idlers rotate at high speeds and are subject to rough conditions – vibration, shock, dust, heat, moisture etc.

—
04 CRIS monitors the performance of individual idlers and detects those not far into the P-F interval so maintenance can be planned in a timely fashion.

—
05 Technology prototype of the CRIS inspection vehicle.

05a The inspection vehicle is a train with one locomotive and one sensor car. The sensor head has a pan-tilt unit.

05b The vehicle has a compact cross-section.

5c The rail can be mounted at A or C with covered belts, or preferably at B for the best view of idlers.

As a sensor carrier, a ground or aerial vehicle, or the belt itself, were all considered. However, the best option was found to be a rail-guided vehicle because the carrier is required to collect data automatically – and for many weeks – without the need for manual intervention or maintenance →5.

The rail, the main cost item, is simply a standard L-stock, preferably steel, which can be sourced worldwide both in metric and imperial sizes. The brackets that mount the rail to the conveyor structure are also inexpensive and just need to be adapted for mounting to the particular conveyor design.

—
The sensor car controls the motion of the locomotive and the position of the sensor head on a pan-tilt unit.

The vehicle is a hanging (for stability) train with at least one locomotive and one sensor car. The locomotive provides traction and power supply. The sensor car controls the motion of the locomotive and the position of the sensor head on a pan-tilt unit. Inspection tours are preprogrammed and executed on a regular schedule, which eliminates the need for continuous radio connection to the vehicle and makes the behavior of the system predictable and consistent.

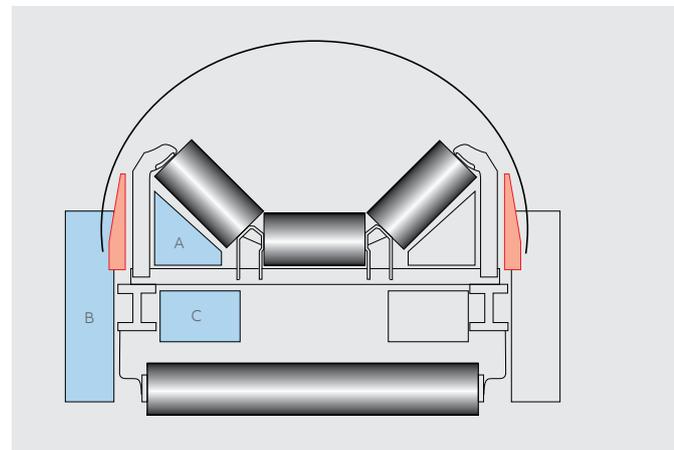
The total weight of the train is only about 6 kg. Derailing is prevented by mechanical guards, which ensures safe operation and practically eliminates any injury risks to personnel. The vehicle design includes a rubber shell and a tilted roof to prevent damage from falling rocks or rubble.



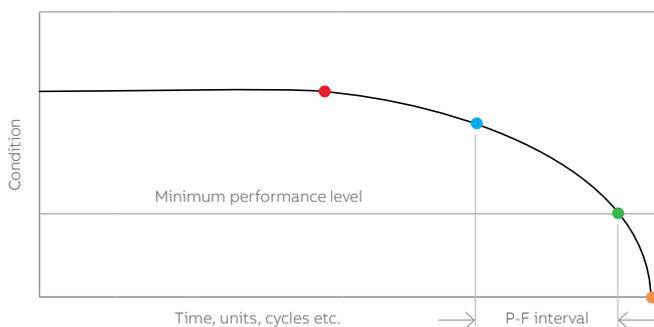
05a



05b



05c



- Point where failure starts to occur
- Point where user can find out idler is failing – potential failure
- Point where it has failed – functional failure
- Point where it has totally failed

04



06a



06b

Flexibility of installation

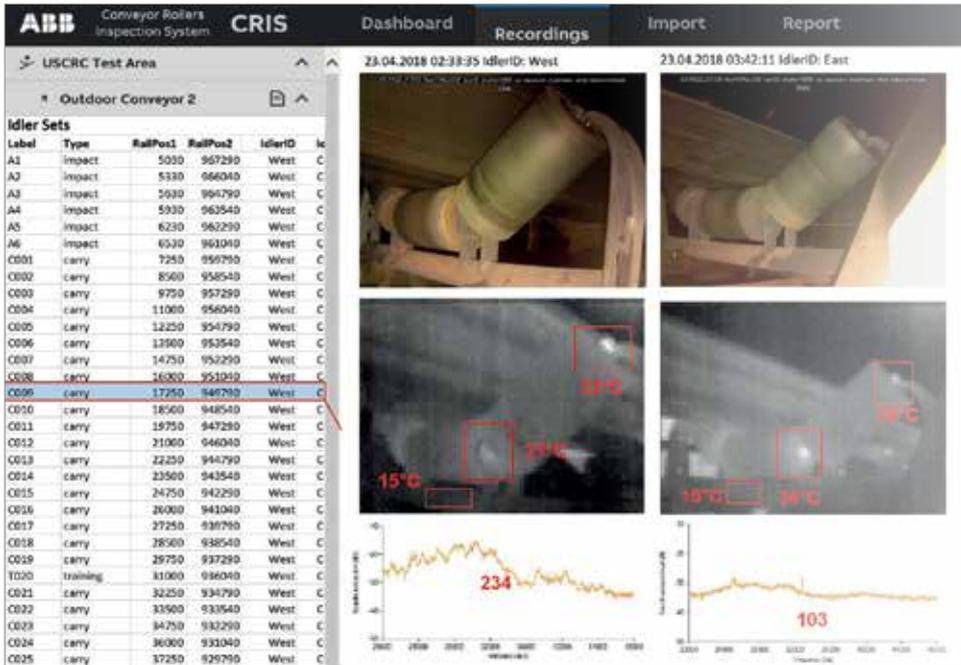
To adapt to the many different designs of conveyor structures and environments, a number of design variants are possible →6:

- The rail can be installed on either or on both sides of the conveyor. Installation on both sides improves detection results since the same idlers are sampled from different points of view.
- Curved rail sections allow obstacles to be bypassed or transition between locations A, B, and C in →5c. The minimum radius is currently 1 m. Horizontal and vertical curves are possible. Curves are prefabricated with a bending machine and shipped to the site.
- Slopes of up to 30° are possible in friction mode. A cogwheel mechanism can be added for even steeper sections.
- Depending on the mount points of the rail, there are different design variants for the mounting brackets. Welding is preferred for installation and joining rail segments, but there also is a bolting option, eg for coal conveyors and for underground.

- For additional protection of the rail and vehicle, the rail can be roofed.
- An additional locomotive can be added for long conveyors or slope conveyors where more traction power or battery capacity is needed. An additional sensor car can be added to speed up inspection or to improve detection results.
- The sensor head has a thermal camera, a visual camera with an LED light and an ultrasonic microphone. Other combinations are possible for certain conveyor types or environments – eg more microphones or a mix of microphone types for improved sonic mapping, or omission of the cameras in very dirty environments.

The screenshot shows the ABB CRIS software interface for a conveyor inspection system. The main window displays a list of 'Idler Sets' with columns for Label, Type, RailPos1, RailPos2, IdlerID, and Location. A table of idler data is visible on the left, and the main area shows a 3D visualization of the conveyor structure with various data points and charts overlaid.

Label	Type	RailPos1	RailPos2	IdlerID	Location
A1	Impact	5030	967290	West	C
A2	Impact	5330	966040	West	C
A3	Impact	5630	964790	West	C
A4	Impact	5930	963540	West	C
A5	Impact	6230	962290	West	C
A6	Impact	6530	961040	West	C
C001	carry	7250	959790	West	C
C002	carry	8500	958540	West	C
C003	carry	9750	957290	West	C
C004	carry	11000	956040	West	C
C005	carry	12250	954790	West	C
C006	carry	13500	953540	West	C
C007	carry	14750	952290	West	C
C008	carry	16000	951040	West	C
C009	carry	17250	949790	West	C
C010	carry	18500	948540	West	C
C011	carry	19750	947290	West	C
C012	carry	21000	946040	West	C
C013	carry	22250	944790	West	C
C014	carry	23500	943540	West	C
C015	carry	24750	942290	West	C
C016	carry	26000	941040	West	C
C017	carry	27250	939790	West	C
C018	carry	28500	938540	West	C
C019	carry	29750	937290	West	C
T030	trailing	31000	936040	West	C
C021	carry	32250	934790	West	C
C022	carry	33500	933540	West	C
C023	carry	34750	932290	West	C
C024	carry	36000	931040	West	C
C025	carry	37250	929790	West	C
C026	carry	38500	928540	West	C



08

06 Rail installation options.

06a The design of the rail mount bracket can be adjusted to the conveyor design.

06b Horizontal and vertical curves, and inclines are possible.

07 Screenshot of the CRIS control and data analysis station, showing the full list of idlers (left), their location on the satellite image (center) and results of past inspection data analysis (right).

08 Screenshot of the CRIS control and data analysis station, providing analysis results as well as access to raw inspection data. An inspection report is issued on a regular basis that is used to plan idler maintenance.

After each inspection tour, the vehicle docks at the battery-charging port of a base station and uploads all inspection data for analysis.

The CRIS control and analysis station is the graphical interface for the service expert to remotely schedule inspection tours and to display and analyze raw data →7,8.

By analyzing the history data of individual idlers, a detailed condition map of the entire conveyor belt is created.

Each inspection tour provides a detailed snapshot of the current status of each idler. By analyzing the history data of individual idlers, a detailed condition map of the entire conveyor belt is created. Furthermore, trend analysis can indicate imminent failure likelihood and allow replacements to be planned.

CRIS presents mining customers with a flexible inspection tool that is fully autonomous, easily installed, and simple to operate and maintain. CRIS travels alongside the conveyor belt and uses sensors matched to a variety of different physical parameters to identify impending idler failures. The data gathered allows the customer to reduce unplanned downtime, maintenance costs, production losses and the exposure of personnel to risk. ●



Inspection Report
 Belt Conveyor SP32C
 Inspection Period: 23.04.2018 22:32:00 – 24.04.2018 04:45:55

ABB

Acknowledgment

The authors would like to acknowledge the dedication, hard work and valuable contributions made to the CRIS project by its core team members: Otavio Rocha and Tiago Prata, ABB Process Industries, São Paulo, Brazil; Harshang Shah, Daniel Lasko and William Eakins ABB Corporate Research, Bloomfield, CT, United States; and Maria Rozou, ABB Process Industries, Baden-Dättwil, Switzerland.

INSPECTION AND MEASUREMENT

Cloud-based multiphase flow measurement

Oilfields produce flows as a mixture of oil, water and gas. Measuring these components has long been an expensive and tricky business. Now, ABB has collaborated with Arundo Analytics to create a cloud-based virtual multiphase flowmeter that derives measurements from existing data and devices.



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The popular image of an oil strike where a fountain of oil shoots into the sky is a rather outdated and misleading one. Such productive, easily accessible oil fields have, as far as is known, all been discovered and tapped long ago. Modern oil and gas production is more discreet and is often played out in remote or underwater locations. And to have a stream of oil as pure as the cascade shooting from the derrick in those old images is a rare occurrence. In reality, flows from an oil reservoir contain a forever-changing mix of oil, gas, water and sand →1.



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Oslo, Norway

—
Though smaller and less costly than separators, multiphase flowmeters are still expensive to buy, install and operate.

As an oilwell ages, the proportion of produced water (the so-called watercut) increases – some wells operate with watercuts of over 95 percent.

Though sandscreens near the production zone catch much of the sand, some can remain in the flow – an undesirable situation as flowing sand has a very heavy erosive effect on pipelines, valves etc.

If gas is present in small, noncommercial quantities it is flared off; higher gas content is put into a production stream.

Traditional multiphase flow measurement

Measurement of the various components of this multiphase flow is clearly of interest to oilfield operators. Indeed, multiphase flow measurement in the oil and gas industry has a long history and many different approaches have been tried over the decades, each with its advantages and disadvantages.

Gravity separators have been a popular approach. These allow the various components to separate out into individual layers and be piped away. However, separators have latency issues and have to be very bulky and heavy if high flows are involved – not an ideal situation when real estate on an offshore platform or other location is both expensive and hard to come by.

Partial separators cost less, are smaller and can be transported more easily but provide only a snapshot of the multiphase flow.



01

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Oil does not flow from an oil well as pure oil but rather as a mixture of oil, gas, water and sand. To run an oilfield effectively, operators must have an accurate measurement of each of these components.

Multiphase flowmeters have also proven popular in recent decades →2. These meters exploit a variety of principles and physical parameters – such as temperature, pressure, density, ultrasonics, electromagnetics – to calculate each component of the flow. This richness of sensing principles and associated hardware and software comes at

—
Digital technology is allowing operators of all sizes to profit from multiphase metering that is low-cost and scalable, and that requires no additional field hardware.

a cost: the meters are complex to produce and calibrate, and many experienced multiphase meter engineers are reaching retirement age. Though smaller and less costly than separators, multiphase flowmeters are still expensive to buy, install and operate. Also, as no two oil and gas applications are the same, off-the-shelf

flowmeters are not a viable option and meters have to be custom-built to specific requirements. Oilfield operators are, therefore, choosy about where these meters are used. Now, however, digital technology is completely changing the world of multiphase metering, allowing operators of all sizes to profit from multiphase metering that is low-cost and scalable, and that requires no additional field hardware.

From physical to virtual multiphase measurement

Arundo Analytics and ABB have collaborated to create the first cloud-based virtual multiphase flowmeters for the offshore oil and gas industry. The new solution will be part of the fully integrated ABB Ability™ portfolio.

The experience of Arundo Analytics complements that of ABB: Arundo Analytics provides cloud-based and edge-enabled software for the deployment and management of enterprise-scale industrial data science solutions. Their software exploits machine learning and other analytical methods to connect industrial data to advanced models, the insights from which allow better decision



02

making. ABB, on the other hand, has more than 50 years of experience with modeling and simulation – including modeling of individual phases and mixed fluids in multiphase streams – that provides analytical insights for the oil and gas industry.

The new cloud-to-cloud ABB Ability Virtual Multiphase flowmeter connects ABB Ability and

The analytics provided by the virtual flowmeter give operators real-time data on the constituent properties of any given stream of produced fluids.

Arundo’s Composer and Fabric software and makes multiphase metering much more affordable for oil and gas operators. The analytics provided by the virtual flowmeter give operators real-time data on the constituent properties of any given stream of produced fluids →3.

Nothing extra needed

A major feature of the new product is that it uses existing information about the field as well as data from the standard instrumentation already fitted on the well and pipeline system. From these data sources, real-time individual flow rates for oil,

gas and water are calculated. This means that the Virtual Multiphase flowmeter does not particularly need physical multiphase meters or any special hardware – it simply uses the devices, such as pressure, temperature and flow sensors, that are already there. Any qualified device from any manufacturer can be used.

A major feature of the new product is that it uses existing information about the field as well as data from the standard instrumentation.

The financial implications of this aspect are hard to overstate: By using what is already there, users can save hundreds of thousands of dollars that would otherwise be spent on the purchase, set-up and support of multiphase measurement equipment such as separators or flowmeters. Furthermore, the need to find specialists skilled in installation, commissioning and calibration of separators or flowmeters is eliminated.

Further savings are made by avoiding a well shutdown. The ABB Virtual Multiphase flowmeter is completely non-interventionary so wells do not have to be taken out of production to allow a physical flow measurement and the potential revenue loss from thousands of barrels of nonproduced oil is averted.

Cloud-to-cloud

The tool uses a three-phase flow model based on specific well data that includes:

- Information on well geometry and profile, eg length, inclination, diameter, etc.
- Pressure, volume and temperature data.
- Wellhead choke characteristics.
- Fluid compositions from lab tests.
- A minimum of three months’ operational data.

—
02 An ABB multiphase flowmeter.

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03 By displaying it in a clear and simple manner, the tool helps to maximize the utility of the gathered data, allowing operators to readily identify areas for potential improvements in well operation.

Real-time data collected from field instruments is used to update the model and continuously improve its interpretative power.

Both ABB Ability and the Arundo Analytics software are cloud-based. This makes it easy not only to share data between these two platforms but also to share data with any relevant and authorized parts of the client organization. A dashboard is provided to allow access to any of the Virtual Multiphase flowmeter data stored in a customer's data repository.

The scalable nature of the tool means that organizations that have previously been unable to continuously measure their multiphase flows can now do so at a fraction of the cost that would previously have been incurred to put the necessary infrastructure in place. If operations expand or more extensive monitoring is needed, the scalable pay-as-you-grow model makes it simple to add capability. And once an

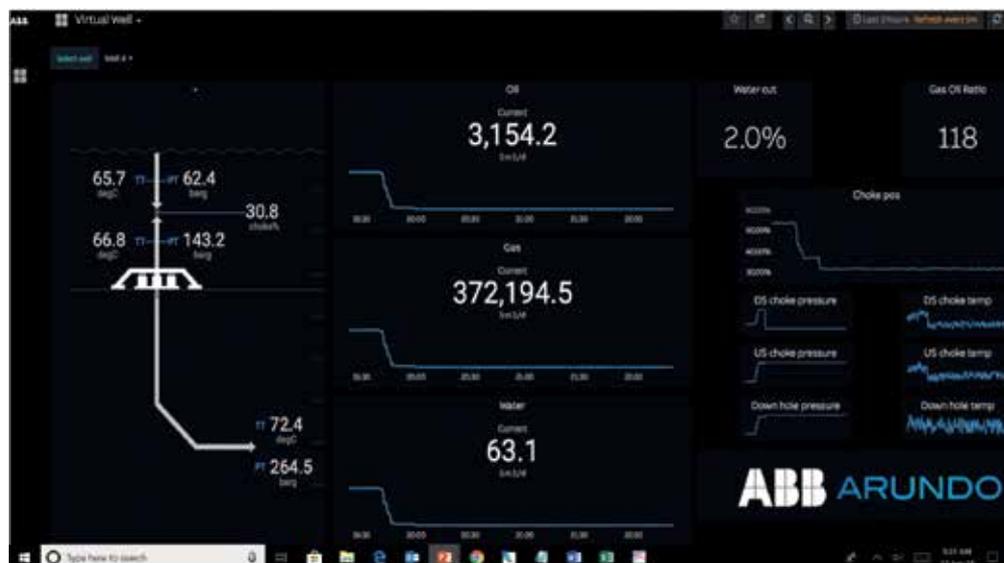
—
Both ABB Ability and the Arundo Analytics software are cloud-based, which makes it easy for them to share data.

organization has subscribed to the tool, it can be made universally available, enabling it to be used worldwide to monitor and compare the performance of multiple wells.

Multiphase and beyond

With viable, accessible oil and gas reserves becoming harder and more expensive to find and exploit, the need to optimize the efficiency and productivity of existing assets is paramount. By providing analytics as a service, the Virtual Multiphase flowmeter gives companies real-time data on the constituent properties of any given stream of produced fluids and, thus, more transparency into their operations so they can find cost-efficient, reliable solutions and minimize operational costs. Operators of all sizes can profit from this economic and scalable solution.

By using Arundo software to combine physical models with the latest in IT and machine learning, ABB can build on the experience gained from the Virtual Multiphase flowmeter development to deliver additional innovative cloud-based, data-driven applications to the oil and gas industry. ●



INSPECTION AND MEASUREMENT

Opportunities for electrical sensors

Demand for sensors that measure current, voltage and power at all voltage levels is rising. Technical and performance challenges faced by these sensors can be met by optimal utilization of new materials and technologies, enhanced simulation methods and innovative design approaches.



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In power transmission, distribution and control, the requirement to measure electric current, voltage, power and energy has always existed [1] →1. These measurements are now becoming even more significant with the increasing integration of distributed renewable energy sources, the need for more power converters and for flexible load management, upcoming

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There are also specific technical and cost requirements for which off-the-shelf solutions are not available.



Rolf Disselkötter
Former ABB employee

e-mobility →2, extensions of existing grids, and the changing structures of smart grids that need to control and optimize energy flow while still maintaining the necessary power quality. On top of this comes a high demand from the replacement of aging infrastructure: Refurbishment is often accompanied by the wish to upgrade functionality and reliability or for digital integration of the equipment.



—
01 Significant changes in the nature of power transmission, distribution and control require significant changes in the measurement of current, voltage, power and energy. New technologies and techniques can deliver these. (Photo: Anthony Byatt.)

01



All these factors require the precise measurement and control of electrical parameters at many points in the grid for protection, metering, monitoring and control applications. Apart from the need to merely increase the number of electrical sensors, there are also, in many cases, specific technical and cost requirements for which off-the-shelf solutions are not available. New designs and electronic solutions will offer new degrees of freedom and facilitate digital integration into protection and control systems. New standards (IEC 61869, IEC 61850, IEC 62052, IEC 62053 etc.) accommodate these developments.

—
It is usually challenging to design sensors that are more accurate than instrument transformers.

Demand across all voltage levels

ABB's application fields for electrical sensors range across all voltage levels: Starting from low-voltage (LV) applications in building automation or power distribution in industry →3, as well as in the control of converters and drives, through protection and monitoring of medium-voltage (MV) switchgear →4 or big MV machines [2] up to high-voltage (HV) gas-insulated switchgear (GIS) or HV air-insulated switchgear (AIS). In MV and HV there is also a need for sensing in the secondary equipment, for example, at the input of relays →5, which are on the LV level but involve additional specific requirements.

In many applications, it would also be beneficial if smaller, lighter and less costly current and voltage sensors could replace conventional, passive instrument transformers (ITs). Such sensors – also known as non-conventional instrument transformers (NCITs) – can be more easily integrated into existing structures, like GIS containers, bushings or post insulators →6 in MV switchgear. Such integration reduces device footprint. On the other hand, it is usually challenging to design sensors that are more accurate than ITs.

The case for employing sensors, however, is strengthened not only by the advantages mentioned above but also by the fact that auxiliary power for the electronics is available in more and more locations, making a supply from the ITs superfluous. Further, appearing on the market are increasing numbers of DC applications, which cannot be covered with passive ITs.

—
Electrical sensors should typically cover a large dynamic range in order to reduce the number of range versions required for a certain application.

While optical current or voltage sensors are, so far, used at very high current or voltage amplitudes [3], typical MV and LV applications are nearly exclusively covered by non-optical solutions such as voltage dividers, shunts, inductive current sensors and sensors that are based on magnetic field sensing elements. This restriction is due to the significantly lower budgets in LV and MV. Although there are already many such products on the market, it turns out that when breakthrough improvements are targeted for a specific application, the development of a customized sensor solution will almost always be required.

Challenges

As they are intrinsically self-compensated, well-designed passive ITs will work quite linearly and with a low phase shift. They suffer little impact from external fields or temperature and aging effects within their normal operating range. Further, they are self-supplied and not subject



—
02 ABB's Terra 53 rapid EV-charging station.

—
03 Emax 2 family of LV circuit breakers.

to any DC offset. Active sensors are different: They require an additional power supply and – depending on their operating principle – special provisions to achieve sufficiently high accuracy.

In addition to this, electrical sensors should typically cover a large dynamic range in order to reduce the number of range versions required for a certain application. Further, there are applications that need a large bandwidth, eg convertor control, or very low power consumption, such as autonomous devices. Other challenges can be to achieve high reliability of the electronics or low crosstalk at high integration densities in multiphase systems. For DC applications, low offset will be mandatory.



03

Meeting these goals can be quite challenging and often requires new design approaches. However, developing these new approaches is a price worth paying to harvest the advantages of sensors – eg small size and cost, increased functionality and easy mechanical and electrical integration. As application requirements are quite different, optimized sensor solutions need to be specific. Unfortunately, there is no one-size-fits-all approach.

—
A volume and weight reduction down to 35 percent and a cost reduction down to 25 percent could be achieved for the CT.

Details that make a difference

Successful electrical sensor developments have already been completed, for example, in a project to improve and cost-reduce existing current and voltage sensors based on Rogowski coils and resistive voltage dividers. Such sensors are implemented in different MV products such as block-type combisensors, bushings and post insulators →6.





04

In these projects, the focus was placed on enhanced amplitude and phase accuracy in extended dynamic ranges and on magnetic and electric cross-talk reduction, taking both aging and temperature drift into account. Designs, material selection and manufacturing processes were optimized in close cooperation with

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For a successful development, close cooperation between researchers, suppliers and academia is essential.

component suppliers in order to achieve improved winding homogeneity, temperature and aging stability, and voltage withstand of the sensors.

The fulfillment of these challenging requirements was verified in extensive tests. These tests were based both on the analog output of the separate sensor elements and with the sensors connected to a digital merging unit with signal processing, autocalibration and an IEC 61850-9-2LE interface with time synchronization.

Due to the innovative design of the voltage divider →6, which is protected by several ABB patents, the size and cost of the device could be approximately halved, while the accuracy and voltage withstand were significantly improved. The new technology has, meanwhile, been introduced into a wide range of ABB's MV sensors and ABB has entered into long-term collaborations with new suppliers.

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04 UniGear ZS1 MV
switchgear.

—
05 REC 650 protection
relay from the Relion
product range.

In a more recent technology development project, the goal was to improve the design of the matching transformers in power transmission protection relays →5 that form the interface between the relay electronics and the primary HV current transformers, which have a nominal 1 A or 5 A current output.

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Cost pressure and specific technical requirements often call for customized solutions and innovative sensing concepts.

Again, the focus was on size and cost reduction, while the dynamic range, as well as the tolerance with respect to superimposed DC pulses, was to be significantly improved in order to cope with short-circuit conditions and high overcurrents of up to 100 times the nominal current.

In this case, the choice was made for a low-power current transformer (LPCT) solution →7. As the relay has its own power supply, there is no need for a supply from the CT, which can, therefore, be combined with a very low load. This approach, together with a new design and an optimized material selection for the magnetic core, has made it possible to meet the requirements and to significantly improve accuracy. At the same time, a volume and weight reduction down to 35 percent and a cost reduction down to 25 percent could be achieved for the CT as compared to the solution implemented in the current products. Due to these significant benefits, it is likely that the new solution will not only be used in the originally targeted HV application but also in MV power distribution systems.

Alongside the matching transformer project, an alternative high-end solution was developed in parallel. The approach is based on an active current transformer and features an even better low-frequency response and a higher dynamic range at an even lower weight of the transformer (27 percent of the current solution). However, due to the need for additional electronics, the cost is about the same as the existing solution. This principle is currently being further developed for specific LV applications, where the cost could be lower.



05

Besides the AC applications discussed, ABB is also developing DC sensors. One example is the DC version of ABB's LV circuit breaker Emax 2 →3, where the target is to replace resistive shunts with arrays of magnetic field sensor elements. In this way, one could get rid of both the high cost and the power losses inextricably linked with high-current shunts. The focus in this project is on accuracy, stability and crosstalk reduction, which is very important in a multiphase application.

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 Another activity is related to DC metering in rapid-charging stations for electric vehicles.

Another activity is related to DC metering in rapid-charging stations for electric vehicles →2. By measuring the electric power at the output (DC) side of the converter with an accurate DIN rail meter, it is possible to determine the total energy transferred to the battery much more precisely than at the converter input, where converter and cable losses may impair the result. Suitable meters for this application are not yet on the market.

Cooperation

For the successful development of a technology that is ultimately to be implemented in a product, close cooperation between researchers, suppliers and academia is essential. For instance, new design ideas may affect suppliers' production processes – eg, coil or thick-film resistor manufacturers – in which case close collaboration will be required.

Universities can be strong partners when it comes to the evaluation and development of new technologies. In the area of electrical sensing, ABB has built up a successful strategic cooperation with the Polytechnical University of Milan, POLIMI. The focus of the POLIMI activities has been on the evaluation of special shunt designs, on magnetic sensor arrays for current sensing, and on the analysis of transformers and inductive components for sensing and other applications.



06a



06b

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06 Resistive divider voltage sensor.

06a Resistive divider voltage sensor integrated in an MV post insulator.

06b Comparison of the new (left) and the old divider technology.

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07 Printed circuit board (demonstrator) with four new matching transformers.

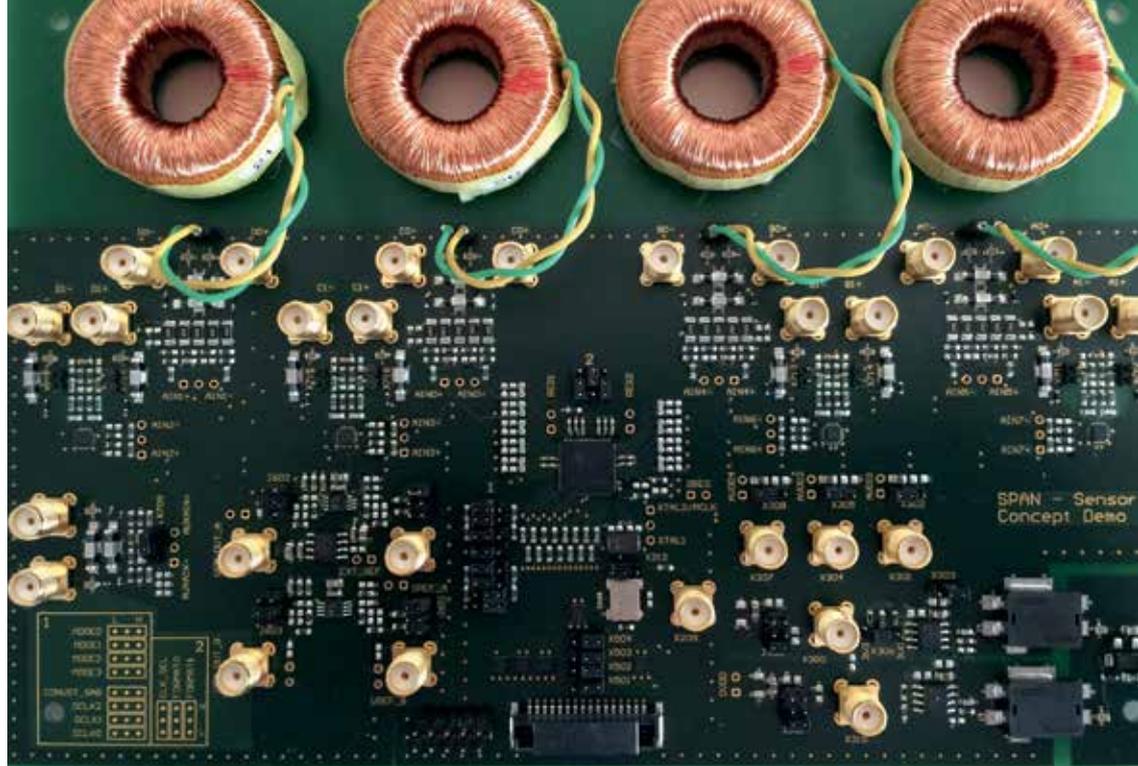
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07

For the latter purpose, the magnetic characteristics of soft magnetic materials play an important role as they will have an impact on the dynamic range, amplitude and phase accuracy, offset and bandwidth of sensors. Geometrical parameters may also affect these aspects and influence properties like crosstalk and DC tolerance. In some applications, the transient performance of a magnetic component may also be relevant, especially when it is integrated into an electric circuit.

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One of the goals was to accurately model the transient behavior of magnetic components in electrical circuits.

One of the goals was, therefore, to accurately model the transient behavior of magnetic components in electrical circuits. For more complex geometries, modeling is usually based on finite element (FE) methods [4]. Transient FE simulations, however, require long simulation times; for application in design tools, simulation times should be short. Therefore, ABB limited the new approach to devices with low geometrical complexity, which can be described with parametrized analytic models. These account for magnetic material properties like anisotropy, and static and dynamic hysteresis, as well as for the main geometrical elements, such as iron branches,

air gaps, coils and stray flux paths. The models are based on elementary building blocks that describe different types of magnetic components. ABB plans to implement libraries of calibrated magnetic material and component models, from which parts can be taken to model, analyze and optimize the design of magnetic devices in various development projects. This work is ongoing.

A wide range of interest

A recent ABB-internal survey has confirmed that there is a strong demand for electrical sensors in many applications. While a huge number of different products are already on the market, cost pressure and specific technical requirements often call for customized solutions and innovative sensing concepts. Demand for new development is seen across all voltage ranges and in applications such as overcurrent protection or arc detection, metering, control, and condition or load monitoring. Growth is also driven by renewable integration, extended grid control, building automation and digitalization. The development and design of new sensors will be supported by improved simulation methods and by the availability of new materials, technologies and products. ●



Power

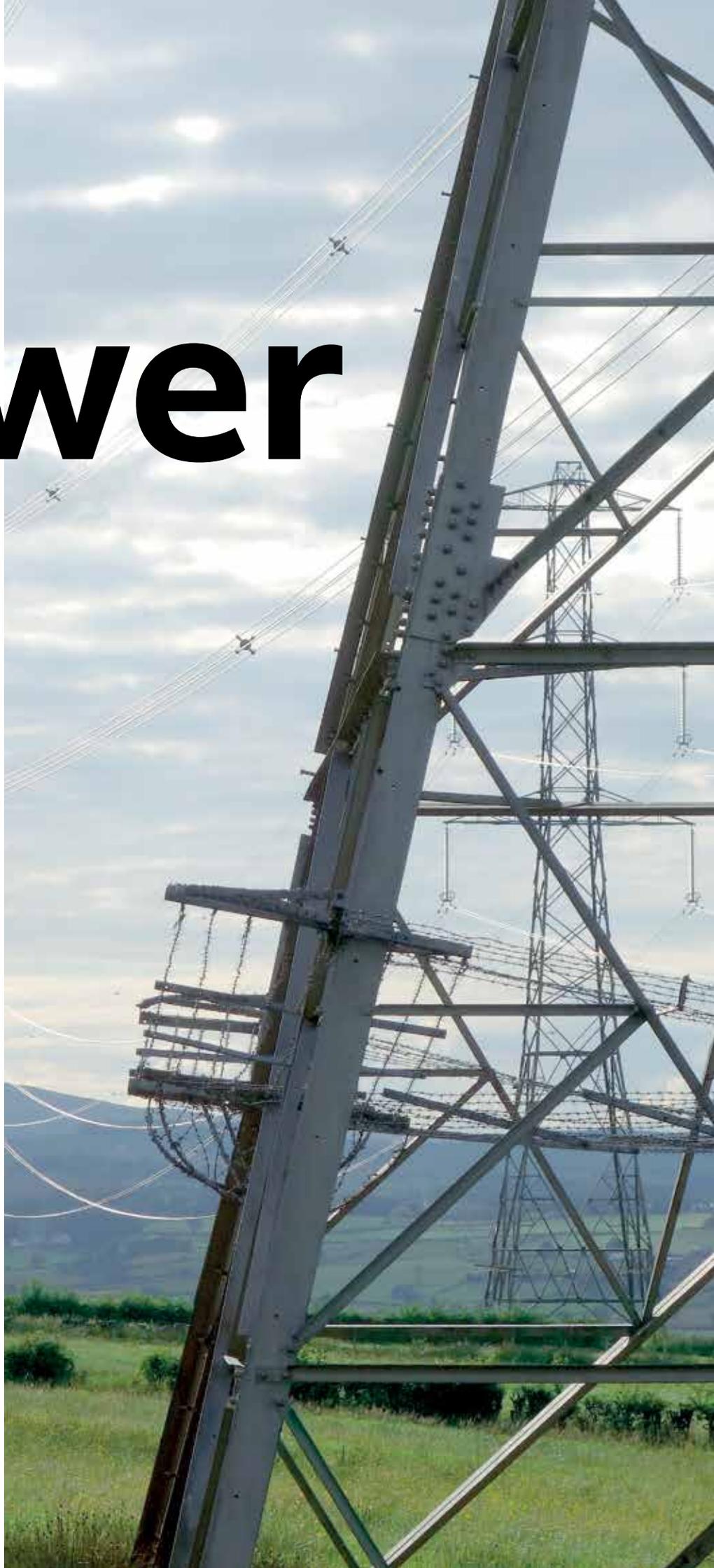


ABB led much of the electrical revolution that powered the 20th century, and is deeply engaged in innovating the transformation of energy production and distribution to meet demand not only for more energy, but for greater use of renewables in the 21st.

- 64 Convert from AC to HVDC for higher power transmission
- 70 Defining short-circuit values for circuit breakers



70

POWER

Convert from AC to HVDC for higher power transmission

Rising power demand and the integration of renewables are causing increasing congestion on AC transmission lines. Physically expanding AC capacity is not easy or cheap. By converting existing AC lines to DC, however, power levels can be boosted significantly without adding new lines.

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All around the world, and especially in developing countries, the demand for electrical power is rising. Along with climate change concerns, this increasing demand is fueling a rapid expansion in generation from renewable energy sources. In fact, wind and solar are the fastest-growing electrical energy sources in the world today. However, the additional electrical energy associated with these trends has to be transported to the consumer, which means existing AC transmission networks

Existing AC transmission networks are now struggling to cope with power transfer levels above those for which they were designed.

are now struggling to cope with power transfer levels above those for which they were designed. To complicate matters, renewable energy sources are intermittent, which makes economic planning of transmission capacity difficult.



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01 Traditionally, expanding transmission line capacity was no trivial matter. However, the conversion of existing AC lines to DC allows extra capacity to be added without adding significant and costly new infrastructure or having to deal with the complexities of opening up new rights of way. (Photo: Anthony Byatt.)

One obvious solution to transmission congestion is to construct additional AC lines. However, quite apart from the capital costs, new rights of way may require environmental impact and engineering assessments, and a long list of licenses,

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One alternative to AC is HVDC transmission, which has many advantages over AC.

agreements, authorizations and compulsory land purchases. Therefore, transmission system operators (TSOs) look for alternative technologies that can enhance power transmission and integrate renewables while maximizing the use of existing rights of way.

An alternative to AC

One alternative to AC is high-voltage direct current (HVDC) transmission. HVDC has many advantages over AC, such as enhanced power transmission capacity up to the thermal limit [1], low losses, ease of flexibility and controllability (both of which help counteract any disruption arising from the connection of renewables), less demanding right of way requirements, etc. In particular, HVDC technology based on voltage sourced converters (VSCs) is capable of independent control of real and reactive power, voltage support to the connected AC system and black-start capability. To understand the challenges and opportunities involved in the conversion of an existing AC transmission infrastructure into HVDC, some case studies will be examined and their major technical aspects discussed.

01



Environmental	Engineering	Economic
The pollution zone in which the AC system to be converted is located decides the creepage requirements of DC insulators.	The conversion can be a monopole, bipole or hybrid HVDC configuration.	In spite of converter station losses, operating expense is often lower for DC compared to AC owing to low line losses and enhanced transmission capacity.
Weather conditions determine the audible noise and radio interference level generated by the converted line.	DC voltage selection is based on the clearances in the transmission line towers. Current, based on the thermal limit of the conductor, decides the maximum power transmission capacity of the conversion.	Capital expenditure mainly depends upon the type of AC transmission tower, HVDC converter station and configuration planned, along with the transmission distance.
Corona and field effects depend on the voltage and current levels, and the configuration and positioning of the conductors.	To achieve the desired DC voltage and current, modifications to the insulator, and possibly the tower or conductor, may be required.	Time for conversion is shorter than the time taken to obtain permits and construct a new line, even if towers have to be modified or conductors or insulators replaced.

02

Factors that dominate AC to HVDC conversion

Before converting an AC line to HVDC, careful consideration must be given to a range of environmental, engineering and economic factors →2.

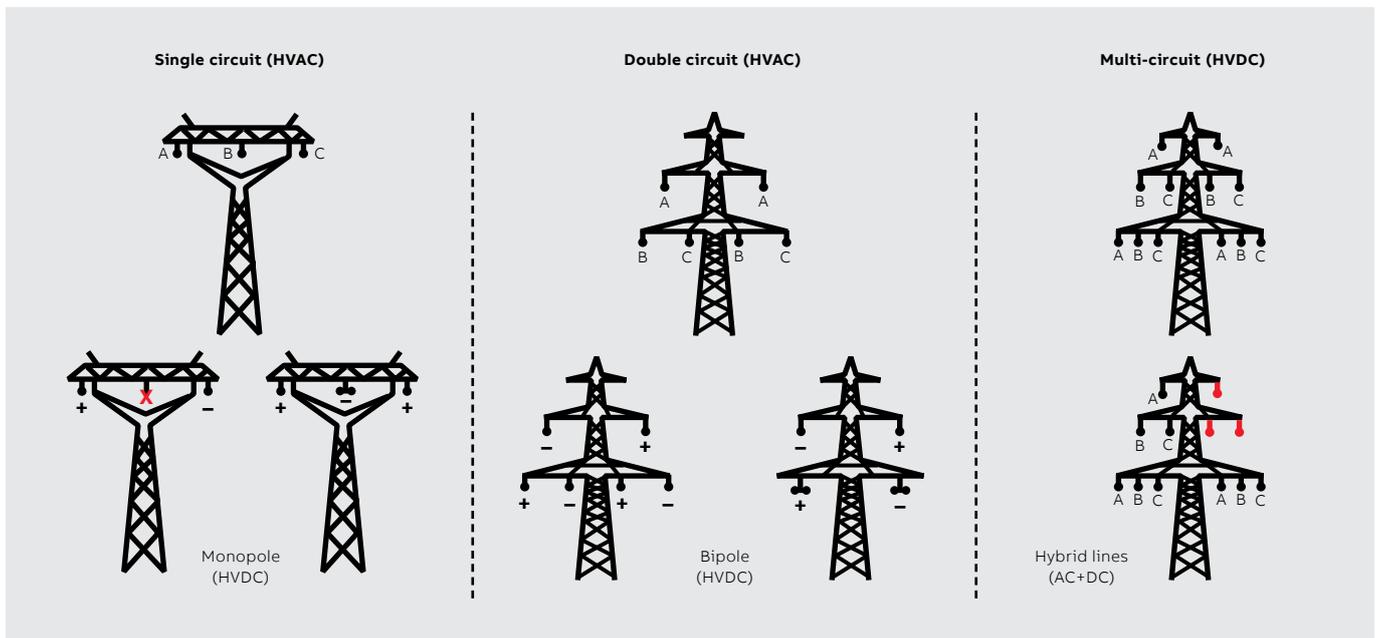
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Modifications may have to be made to the tower structure, insulators and conductors.

When a decision has been made to proceed with the conversion, the HVDC configuration must be decided: symmetric/asymmetric monopole or bipole or a hybrid that suits the tower configuration and the clearances available →3. For example, a horizontal single-circuit AC transmission line can be replaced with either one or two symmetrical monopole HVDC lines.

A bipole configuration is also an option. In the case of a double circuit or multi-circuit, either one or several AC systems can be converted to HVDC as shown in →3. However, replacement is not straightforward and modifications may have to be made to the tower structure, insulators and conductors [1]. The AC ceramic insulators are generally replaced with high resistivity toughened glass (HRTG) or composite insulators to meet the clearance requirements [2].

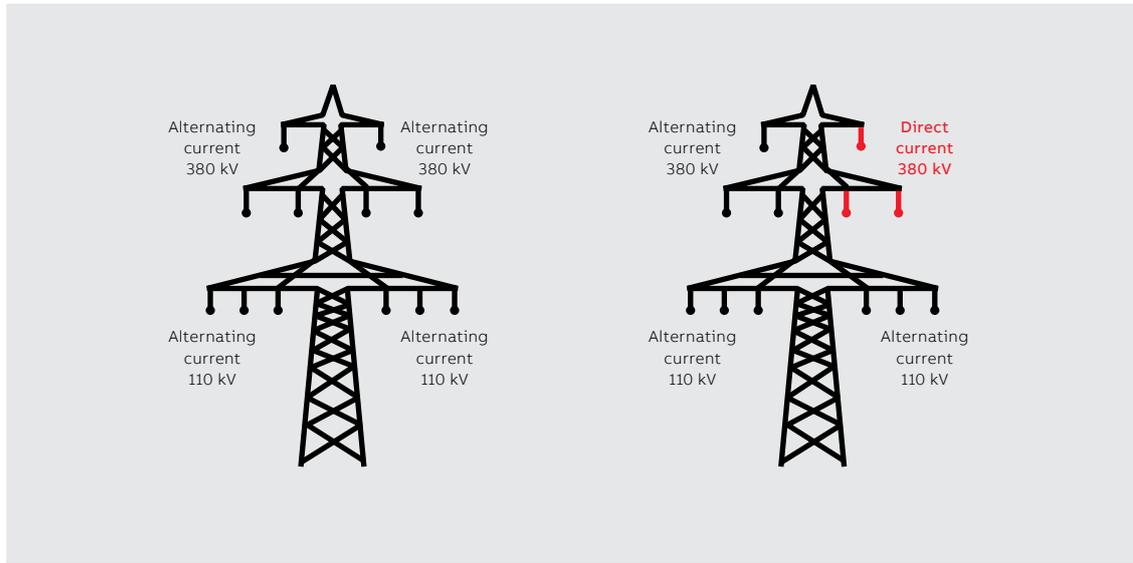
Existing conversions

AC to HVDC conversions to enhance the power transmission capacity of existing rights of way are ongoing. The first known example is the UltraNet project in Germany where a 400 kV AC line will be converted. Other lines have also been studied with a view to conversion.



03

- 02 Considerations in AC to DC conversion.
- 03 Some possible configurations of conversion from AC to DC.
- 04 AC to DC conversion in the UltraNet project in Germany [3]. © Amprion TransnetBW.
- 05 Power transmission capacity of existing right of way based on DC voltage selection and ambient temperature [2].



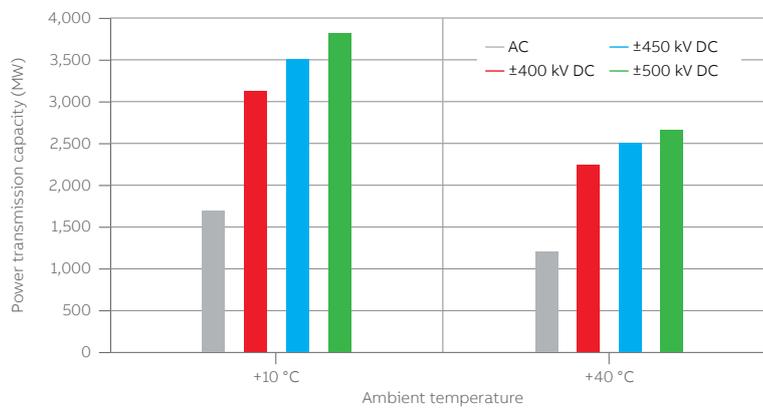
04

In the UltraNet project, two 380 kV AC and two 110 kV AC systems run between North Rhine-Westphalia and Baden-Württemberg over a

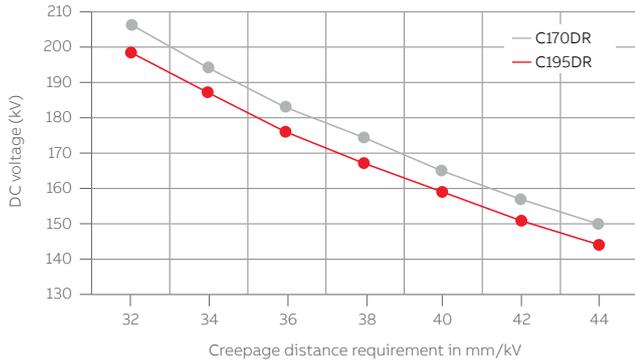
— One AC line has been converted to 380 kV DC, which will significantly increase power transmission capacity.

distance of 340 km [3]. One of the 380 kV AC systems has been converted to a 380 kV DC system, which will facilitate a power transmission

capacity of approximately 2,000 MW from wind farms in the North Sea to the industrial towns in the south of Germany →4. The conversion has significantly increased power capacity. Raising the DC voltage can increase capacity but care must be taken as ambient temperatures cause retained conductors to sag, endangering clearances – for example, an extra sag of around 1.3 m will occur in a conductor at 40 °C compared with its catenary at 0 °C [2] →5.



05



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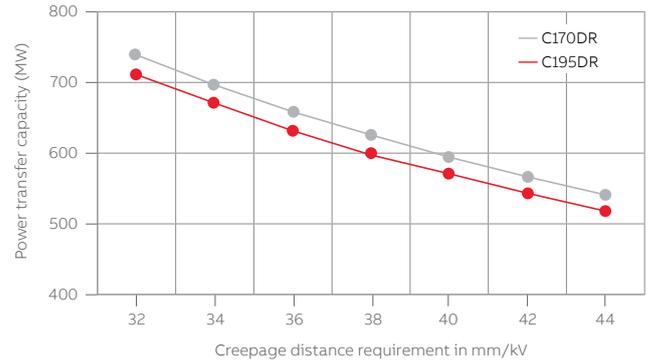
A further conversion example is found in the Angle-DC project [4]. Here, a 33 kV AC connection between North Wales and Anglesey in the UK has been converted to a 27 kV symmetric monopole HVDC line to achieve a 23 percent increase in power transmission capacity for an operating temperature of 50 °C. By allowing a cable operating temperature of 65 °C, capacity can be increased by 35 percent.

Selection of DC voltage

The string length determines the available clearance, which governs the maximum DC voltage that can be carried. The thermal rating of the conductor determines the current-carrying capacity of the transmission system. The DC voltage selected and the thermal current rating of the conductor together determine the maximum power transmission capacity of the line after conversion.

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 By allowing a cable operating temperature of 65 °C, a 35 percent improvement can be made.

The length of the insulator string depends on the creepage distance requirement. Creepage distances vary depending on local conditions, such as salt deposition from sea spray or atmospheric industrial pollution load. The creepage distance requirement for HVDC is higher than that of AC.



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For conversion of a typical 220 kV AC transmission system – assuming that the string length of 2,030 mm is retained to maintain allowable sag during operation – the DC voltage will be in the

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 The use of composite insulators can further improve power capacity as they are less affected by pollution and allow a higher DC voltage.

range of 146 to 206 kV for a symmetrical monopole HVDC configuration. The particular value will depend on the DC creepage requirement for the pollution zone in which the line finds itself. This is depicted in →6 for two different HRTG insulator arrangements from Sediver – C170DR and C195DR. Accordingly, the power transmission capacity

— 06 Range of DC voltage selection for different creepage distance requirements.

— 07 Power transfer capacity as a function of creepage distance requirement.

— 08 Conversion to higher DC voltage by suitable modification of the tower structure [5].

References

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ranges between 520 MW and 740 MW when the thermal current rating of the conductor is assumed to be 1,800 A with a symmetrical monopole HVDC configuration →7.

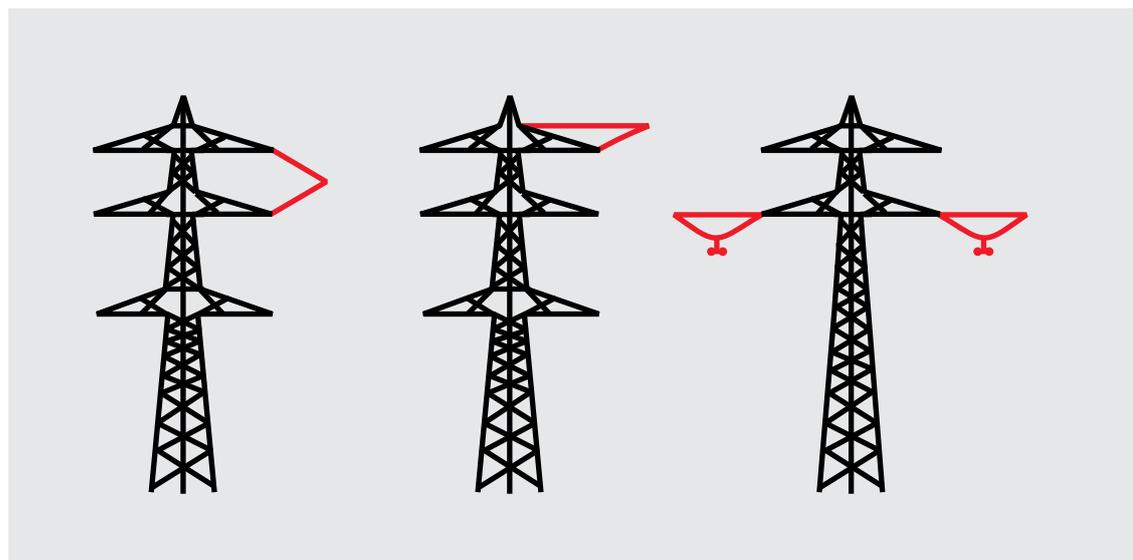
— **More AC lines will be converted to HVDC to take advantage of the higher powers that can then be carried without having to build a new line.**

The use of composite insulators can further improve the power transmission capacity as they are less affected by pollution and they also allow a higher DC voltage to be used. Suitable modification to the cross-arms arrangements can also improve clearance and allow higher DC voltages →8. The thermal current rating, and thus power transmission capacity, of the conductor can be increased either by adding more sub-conductors or replacing it with a new conductor.

AC to DC in the future

Given that certain basic economic, engineering and environmental conditions can be fulfilled, the conversion of an existing AC transmission line to HVDC can significantly increase the power capacity of an existing right of way. Higher DC voltages deliver higher capacities but account must be taken of conductor sagging and the effect of pollution levels on the creepage distance, which is one of the main determinants of the maximum DC voltage allowed. Tower modification or the use of composite insulators may enable an even higher DC voltage to be chosen. Conductor thermal ratings can be increased by adding more sub-conductors or by replacing the conductor, resulting in higher power transmission capacity.

As demand for capacity on transmission lines continues to increase, it is expected that more AC lines will be converted to HVDC to take advantage of the higher powers that can then be carried without having to build a new line. ●



POWER

Defining short-circuit values for circuit breakers

Circuit breakers protect electrical equipment from damage that may arise from short-circuit currents. However, the “short-circuit current” can vary depending on the application. How do IEC and EN standards help designers properly specify overcurrent protection in electrical equipment?



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In any modern society, the continuous availability of electrical power is vital. Without power, most residences, commercial businesses and industrial plants would be paralyzed. This electrical power must be delivered to the end user safely and reliably and it is here that distribution

—
Distribution equipment must protect the installation from faults by switching off the faulty circuit, while guaranteeing continued operation of nonaffected circuits.

switchgear plays a major role. Due to the obvious hazards involved, such switchgear, or the local distribution board, must be designed to protect the installation from faults by switching off the faulty circuit and, simultaneously, guaranteeing the continued operation of nonaffected circuits.



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01 A variety of circuit breakers are used to protect electrical equipment when short-circuit current conditions arise. ABB's comprehensive range of breakers covers virtually all voltage and current values. Shown is an ABB S753DR-E63 main circuit breaker.

Breaker types

A short circuit places equipment under great stress. Therefore, when designing the switchgear assembly or distribution board, the thermal and dynamic stresses caused by the maximum short-circuit current at the connection point on-site must be considered. To prevent damage to the installation (or personnel) short-circuit protection devices are used to switch off the short-circuit current at the connection point →1.

—
When designing the switchgear assembly or distribution board, the thermal and dynamic stresses caused by the maximum short-circuit current at the connection point on-site must be considered.

Most often used for this switching task are molded-case circuit breakers (MCCBs) →2, miniature circuit breakers (MCBs), residual current operated circuit breakers (RCCBs) and residual current operated circuit breakers with overcurrent protection (RCBOs). These devices are marked with their maximum short-circuit capacity to allow the panel builder to select the correct product for the application. Such breakers are suitable for isolation, but switch-disconnectors are usually also installed so that the equipment can be completely de-energized for service or maintenance.

The uninterrupted short-circuit current

Low-voltage installations are typically supplied by transformers. In such a low-voltage network, the uninterrupted short-circuit current (I_k) is calculated from the rated voltage and the AC resistance (impedance) of the short circuit. A superimposed DC component, which slowly decays to zero, also exists →3. The peak value of I_k is an important value for the short-circuit definitions in the standards.

Standards relating to circuit breakers

Depending on the particular application, different standards may be referred to when a designer is specifying circuit breakers or associated equipment for power network protection:

- The IEC/EN 60898-1 standard applies to circuit breakers for overcurrent protection in households and similar installations – for example, shops, offices, schools and small commercial buildings. These breakers are designed to be operated by uninstructed people and without the need for maintenance.
- The IEC/EN 60947-2 standard applies to circuit breakers used mainly in industrial applications where only instructed people have access.
- Switch-disconnectors are tested against the IEC/EN 60947-3 standard.
- Switchgear assembly or distribution boards are tested against the IEC/EN 61439 standard.

Due to the different scope of the standards, in some cases, different definitions are used for the same electrical process. The engineer must, therefore, ensure that he fully understands which particular definition, for, say, short-circuit capacity, applies to the design he is working on.

Circuit breakers and IEC/EN 60898-1

IEC/EN 60898-1 defines the rated short-circuit capacity (I_{cn}) as the breaking capacity according to a specified test sequence. This test sequence does not include the ability of the circuit breaker to carry 85 percent of its nontripping current for a specified conventional time. The service short-circuit breaking capacity (I_{cs}) is the breaking capacity according to a specified test sequence that does include the capability of the circuit breaker to carry 85 percent of its nontripping current for a specified time.

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IEC/EN 60898-1 defines fixed values of the ratio of I_{cs} to I_{cn} . The I_{cs} and I_{cn} values are expressed as the root-mean-square values of the prospective short-circuit currents.

To comply with the requirements of the standard for both these short-circuit capacities, the open/close operations of each of three circuit breakers have to be tested. For the open operation, the short-circuit current is initiated at a specified phase angle with respect to the voltage waveform. The three circuit breakers are tested at different angles. The test sequence for I_{cn} is "O - t - CO" where "O" is an open operation and "CO" is a close-open operation, which means that the circuit breaker under test is switched on and experiences the short-circuit current for a certain duration. The time "t" between the operations is 3 min. For I_{cs} , the test sequence is "O - t - O - t - CO" for single-pole and two-pole circuit breakers, and "O - t - CO - t - CO" for three-pole and four-pole circuit breakers. The way the initiation of the short-circuit current is specified in the standard means at least one circuit breaker under test has to switch off at the most severe voltage phase angle.

Circuit breakers and IEC/EN 60947-2

IEC/EN 60947-2 defines the ultimate short-circuit breaking capacity (I_{cu}), also known as the breaking capacity, according to a specified test sequence. This test sequence includes the verification of the overload release of the circuit breaker. In IEC/EN 60947-2, I_{cs} is the breaking capacity according to a specified test sequence that includes the verification of the breaker's operational capability at the rated current, a temperature rise test and verification of overload release. IEC/EN 60947-2 defines values between 25 and 100 percent for the ratio of I_{cs} to I_{cn} . Again, the I_{cs} and I_{cn} values are expressed as the root-mean-square values of the prospective short-circuit currents. To comply with the requirements of the standard, for both short-circuit capacities each of two circuit

At least one circuit breaker under test has to switch off at the most severe voltage phase angle.

breakers have to be tested. In a similar manner to IEC/EN 60898-1, the short-circuit current is initiated at a specified phase angle with respect to the voltage waveform for the open operation, but here the two circuit breakers are tested at the same angle. The test sequence for I_{cu} is "O - t - CO" and "O - t - CO - t - CO" for I_{cs} . The time "t" between the operations is again 3 min and, for opening, the short-circuit current is initiated at a specific voltage phase angle – defined as the angle at which peak current is reached. This peak current is simultaneously the rated short-circuit making capacity (I_{cm}) and is expressed as the rated ultimate short-circuit breaking capacity, multiplied by a factor defined by IEC 60947-2.

02 ABB A1 frame low-voltage molded-case circuit breaker (conforms to IEC/EN 60947-2).

03 Short-circuit current characteristics.

Switch-disconnectors and IEC/EN 60947-3

When switches, disconnectors, switch-disconnectors or fuse-combination units are included in a design, the IEC/EN 60947-3 standard is used. A switch-disconnector is capable of switching on and off a current under specified conditions. In the open position, the switch-disconnector provides an isolation function.

The switch-disconnector must be able to withstand the current limited by the SCPD.

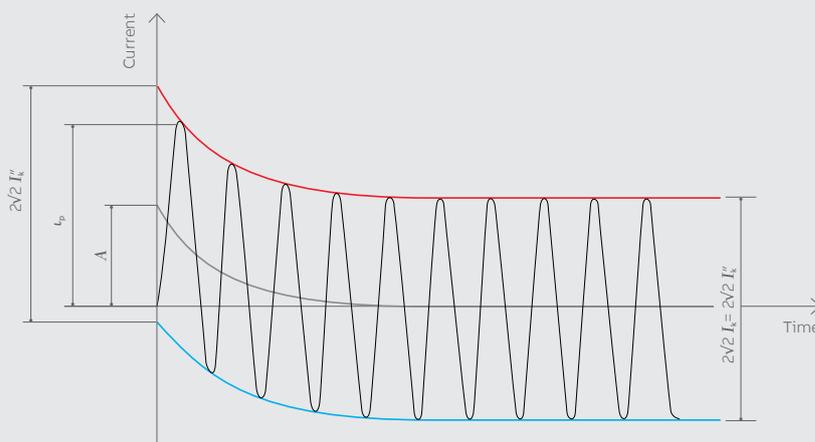
As the switch-disconnector is not equipped with an overcurrent release, it must be protected by an MCB, MCCB or fuse. The short-circuit capacity of the combination of switch and circuit breaker is defined as the rated conditional short-circuit current. It is expressed as the value of the prospective short-circuit current the switch-disconnector, protected by a short-circuit protective device (SCPD), can withstand. It is important to keep in mind that the switch-disconnector must be able to withstand the current limited by the SCPD.

This approach is also valid for RCCBs – ie, the short-circuit current stated on the device is the rated conditional short-circuit current of the combination of the RCCB with an SCPD.

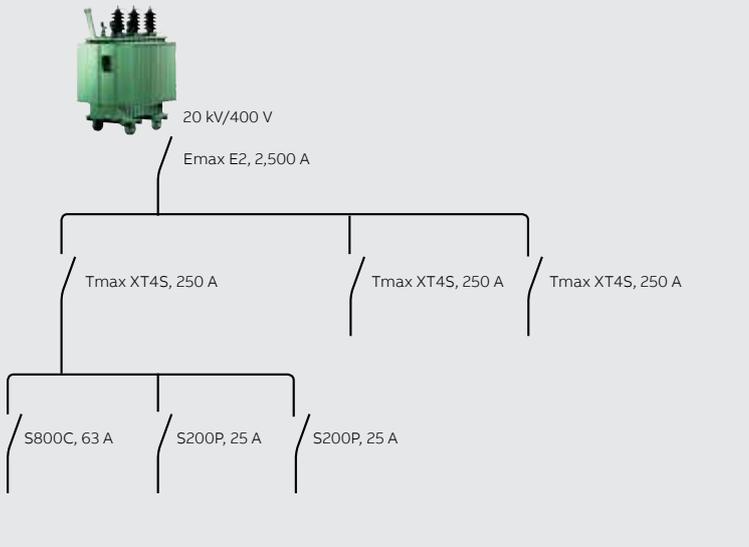
A further short-circuit value defined in both IEC/EN 60947-3 and IEC/EN 60947-2 is the rated short-time withstand current (I_{cw}). This value may apply to switches (eg, a switch-disconnector), circuit breakers such as an MCCB or air circuit breaker (ACB), and busbars. I_{cw} is the value of the current the equipment can withstand for a specified time without damage occurring. IEC/EN 60947-2 defines preferred values of this time of 0.05, 0.1, 0.25, 0.5 and 1 s; IEC/EN 60947-3 defines 1 s. For AC, I_{cw} is the root-mean-square value of the current.

The I_{cw} value is important for switchgear with equipment connected in series where the selectivity between the protective devices is realized by a time delay. For example, if a feeder circuit is equipped with an ACB and the downstream branch circuits are protected by MCCBs then to achieve selectivity a time delay is set for the release of the ACB. The installation between ACB and MCCB must withstand the specified short-circuit current for the duration of the ACB time delay.

03



- I_k'' Initial symmetrical short-circuit current
- t_p Short-circuit surge current
- I_k Uninterrupted short-circuit current
- t_{dc} Decaying DC component of short-circuit current
- A Initial value of DC component
- Upper part of envelope
- Decaying DC component
- Lower part of envelope



04

Low-voltage switchgear and IEC/EN 61439-1

IEC/EN 61439-1 applies to low-voltage switchgear and controlgear assemblies. For assemblies with an SCPD in the incoming unit, the manufacturer must indicate the maximum prospective short-circuit current at the input terminal of the assembly. To protect the assembly, the I_{cu} or I_{cn} of the SCPD must be equal to or higher than the prospective short-circuit current. If a circuit breaker with a time delay is used as an SCPD, or no SCPD is incorporated in the assembly, the I_{cw} with the maximum time delay must be stated.

IEC/EN 61439-1 applies to low-voltage switchgear and controlgear assemblies.

Application example: copper and copper alloy factory

Suppose a copper factory is supplied from the 20 kV medium-voltage power grid by a 20 kV/400 V stepdown transformer. The rated output of the transformer, S_r , is 1,600 kVA and the rated impedance voltage, u_{kr} , is 6 percent.

For distribution transformers with ratings up to 3,150 kVA, the network impedance can usually be disregarded. The short-circuit impedance of the transformer limits the short-circuit current, which is expressed as:

$$I_k = \frac{S_r}{\sqrt{3} \times U_n \times u_{kr}} = \frac{1.600 \text{ kVA}}{\sqrt{3} \times 400 \text{ V} \times 0.06} = 38.5 \text{ kA}$$

→4 shows the circuit diagram of the power supply.

For the incoming supply, an ABB Emax E2 breaker with a current rating of 2,500 A is used. The distribution level is protected by an ABB 250 A Tmax XT4S breaker. The final circuits are equipped with ABB S800C and S200P MCBs.

To achieve the correct cascading, the following calculation is made: The I_{cw} of the Emax E2 (version B) is 42 kA. The time delay is set to 0.1 s. Consequently, the Emax can withstand the short-circuit current. On the distribution level, the I_{cu} of the Tmax XT4S is 50 kA. The cable between the Tmax and the busbar for the sub-distribution has a cross-section of 95 mm² and a length of 15 m. The resistance of the cable can be found in technical handbooks to be 0.246 ohm/km.

The resistance of the transformer is 0.00597 ohm. The short-circuit current at the sub-distribution is then:

$$I_k = \frac{U_n}{\sqrt{3} \times (Z_r + Z_l)} = \frac{400 \text{ V}}{\sqrt{3} \times (0.00597 + 0.00369) \text{ ohm}} = 23.9 \text{ kA}$$

By using S800C and S200P MCBs, no backup protection is needed as the ultimate short-circuit capacity of these devices is 25 kA. Total selectivity between the Tmax XT4S and S800C, S200P is given.

—
04 Example protection device configuration for an application such as a copper factory.

—
05 Example protection scheme for a large office building.

Application example: power distribution in a large office building

If an office building is supplied from the 20 kV/400 V transformer, with an S_r of 630 kVA and a u_{kr} of 4 percent, the short-circuit impedance of the transformer once again limits the short-circuit current, which is:

$$I_k = \frac{S_r}{\sqrt{3} \times U_n \times u_{kr}} = \frac{630 \text{ kVA}}{\sqrt{3} \times 400 \text{ V} \times 0.04} = 22.7 \text{ kA}$$

→5 shows the circuit diagram of the power supply.

The I_{cu} of the Tmax XT4 (version N) breaker is 36 kA. The I_{cu} of the ABB S750DR selective main circuit breaker is 25 kA. Consequently, the Tmax and the S750DR are able to break the short-circuit current. The cable between the S750DR and the sub-distribution network has a cross-section of 16 mm² and a length of 10 m. The resistance of the cable can be found from technical handbooks to be 1.32 ohm/km. The resistance of the transformer is 0.01012 ohm.

The short-circuit current at the sub-distribution level can then be calculated as:

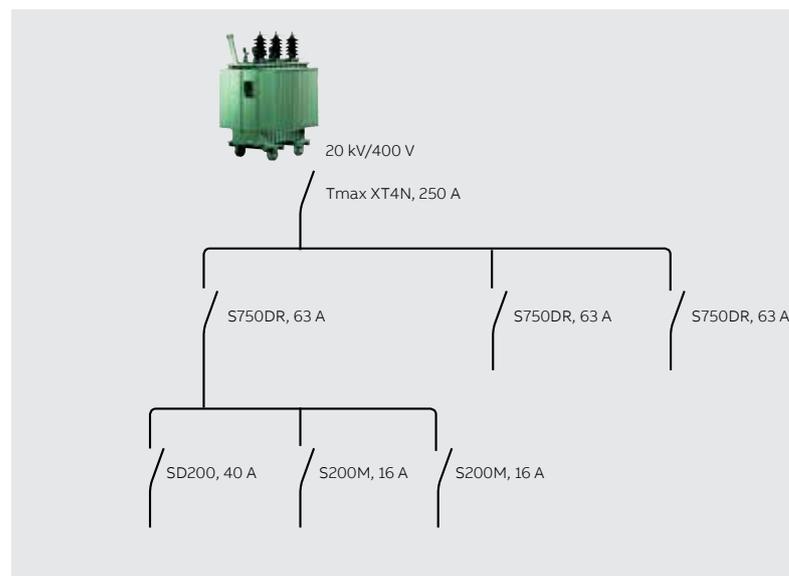
$$I_k = \frac{U_n}{\sqrt{3} \times (Z_r + Z_l)} = \frac{400 \text{ V}}{\sqrt{3} \times (0.01012 + 0.0132) \text{ ohm}} = 9.9 \text{ kA}$$

By using an S200M MCB, no backup protection is needed as the ultimate short-circuit capacity is 15 kA. Total selectivity between S750DR and S200M is given.

For the SD200 MCB, shown in →5, the rated conditional short-circuit current is important. The value for the combination SD200/S750DR is 10 kA. Consequently, the SD200 is protected by the S750DR as the maximum short-circuit current at this point is 9.9 kA.

—
The correct configuration of protective devices can allow distribution switchgear to operate in a safe and reliable way under short-circuit conditions.

The examples above show that the correct configuration of protective devices can allow distribution switchgear to operate in a safe and reliable way under short-circuit conditions. The various IEC/EN standards mentioned assist designers in choosing the correct ratings for the products they employ and thus ensure that electrical power continues to flow to the application no matter what electrical fault conditions arise. ●



BUZZWORD DEMYSTIFIER

Text mining

Information often lies, unstructured and inaccessible, in disparate document formats. Data mining can open up this valuable seam of data and deliver valuable business intelligence from it.



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It is estimated that up to 80 percent of all information in organizations is stored in an unstructured text format. This information includes customer requirements, sales dossiers, technical specifications, maintenance reports and stakeholder feedback. It is difficult to extract business intelligence from such disparate data using traditional data analysis methods so, instead, text-based data mining, or text mining, is used →1.

Simply put, text mining is the set of processes required to transform unstructured text documents or resources into meaningful, structured information. The structured information can then be used to automatically discover hidden patterns and predict future outcomes using a combination of statistical, linguistic and pattern-recognition techniques.

01 Large amounts of valuable data can be hidden in company documentation. Data mining can bring it to light.

02 Data mining can deliver important, hitherto unavailable, insights for sales and marketing, business decision making, investment or purchase decisions, customer relationships, etc.

02



01

Text mining is an interdisciplinary field that draws on information retrieval, data mining, machine learning, statistics and computational linguistics. These techniques are used to discover and present knowledge – facts, business rules and relationships – that is otherwise locked in textual form, impenetrable to automated processing.





searching through the tokenized text and storing the results in a more structured, organized manner that is amenable to further analyses.

- Select important features to build concept and category models. The number of concepts present in unstructured data is typically very large. The key to this step is to identify the most relevant features and use these to build meaningful models based on data categories and relationships.
- Analyze the structured data to discover relationships between the concepts. At this point, the text mining process merges with the traditional data mining process. Classic data mining techniques, such as clustering, prediction and classification can be used on the structured data resulting from the previous steps.

Text mining is the set of processes required to transform unstructured text documents or resources into meaningful, structured information.

Common applications resulting from these analyses include recognition of named entities, automatic summarization, categorization based on relevant features, and mining for customer sentiments and opinions expressed within the text →2. ●

A typical text mining process includes the following steps:

- Identify and preprocess the text to be mined. This step involves text clean-up to remove unnecessary information from the text, splitting the text into individual tokens (ie, smaller components) and identifying parts-of-speech based on the grammar of the language used.
- Extract relevant information and transform it into structured data. Information is retrieved by

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Innovation

Addressing the world's most pressing challenges requires innovation in how and where things are made, the ways people are empowered and processes are enabled to do more, and the sustainable creation and distribution of the necessary energy. The next issue of ABB Review is a collection of the latest thinking and tools that meet those challenges.